Water Quality Monitoring in Ozaukee County

Wisconsin Department of Natural Resources
River Protection Planning Grant
RP31018 Final Report

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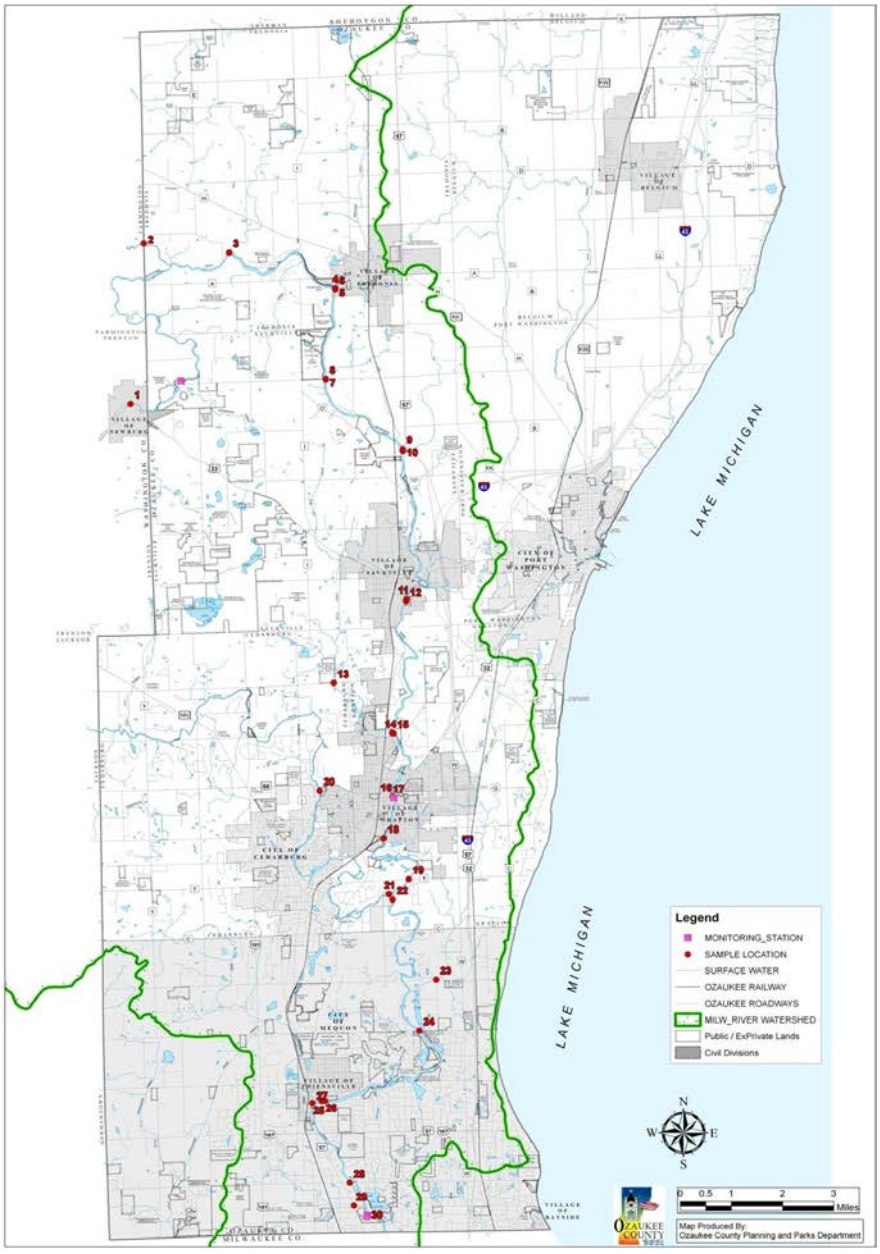
Introduction

Between 2011-2013, through a USEPA Great Lakes Restoration Initiative (GLRI) funded grant, the Ozaukee County Planning and Parks Department (Department) collected water quality data through discrete water quality sampling and continuous instream monitoring on portions of the Milwaukee River Watershed, primarily on the Milwaukee River, located in Ozaukee County (Figure 1). The data collected provided baseline water quality information and preliminary trends throughout the watershed in Ozaukee County. Two major tributary streams to the Milwaukee River, Mole and Ulao Creeks, were included in the study and were found to have high levels of pollutants including fecal coliform, *E. coli*, phosphorus, chlorides, and total suspended solids. Similar results have been detected during recent water quality monitoring completed by the Wisconsin Department of Natural Resources (WDNR), Milwaukee Metropolitan Sewerage District (MMSD), and Milwaukee Riverkeeper.

Figure 1. Water quality monitoring locations sampled 2011-2013 in Ozaukee County, Wisconsin.



Since the initial monitoring effort, the Department engineered, designed and implemented two-large scale restoration projects on Mole and Ulao Creeks in conjunction with continued water quality monitoring. In 2016, the Department began engineering and design of a similar restoration project on the Little Menomonee River (LMR), a major tributary to the Menomonee River (Milwaukee River Basin) that drains into Lake Michigan. Project elements of all three large scale holistic restoration projects include restoring multiple stream reaches through channel remeandering, floodplain reconnection, wetland restoration and enhancement, invasive vegetation management, native vegetation restoration (e.g. tree and shrub planting, native prairie and wetland seeding), installation of avian, fish, and wildlife habitat structures, and monitoring of fish, wildlife, and avian communities as well as water quality. These habitat restoration projects provide direct, tangible improvements to the populations of local and migrant species of birds, native and stocked fish, and wildlife in the Milwaukee River Watershed and Lake Michigan Basin in addition to potential improvements to the water quality (the subject of this monitoring grant).

Through WDNR River Protection Planning (RPP) grants awarded in 2016 (RP29016; Ulao and Mole Creek water quality monitoring, 2/15/16-12/31/17), 2017 (RP30017; LMR and Mole Creek water quality monitoring, 2/15/17-12/31/18), 2018 (RP31018; LMR and Mole Creek water quality monitoring, 2/15/18-12/31/19), and 2019 (RP32719; LMR and Ulao Creek water quality monitoring, 2/15/19-12/31/20) in conjunction with a NOAA GLRI grant (NA14NMF4630286; LMR water quality monitoring), National Fish and Wildlife SOGL grant (0501.16.052818; Mole Creek water quality monitoring), and the Fund for Lake Michigan grants (20160579, 20175784; Ulao and Kaul Creek monitoring) the Department has established a robust water quality sampling and monitoring program on the LMR, Mole Creek, and Ulao/Kaul Creek. This report is an update to previously submitted reports for awarded WDNR RPP grants. A series of discrete water quality sampling events and continuous water quality monitoring using stationed units has provided data necessary to establish a baseline and provides insight into water quality trends associated with stream and habitat restoration pre- and post-construction, potentially validating the numerous benefits of the Department's restoration projects. Furthermore, the additional water quality information is useful in watershed planning and implementation of efforts aimed at reducing pollutants (e.g., TMDLs, priority BMP locations) entering these streams and subsequently the Milwaukee River and Lake Michigan.

The LMR is approximately 10 miles long and described as a cool-warm headwater natural community in "poor" condition. The LMR originates in southwestern Ozaukee County and flows in a mostly southerly direction to its confluence with the Menomonee River in the City of Milwaukee. The land use surrounding the LMR is primarily agricultural (60%), openlands - including forest and wetland (20%), and suburban/urban residential (20%) (Figures 2 and 3). This subwatershed is approximately 21.8 square miles and comprises 16% of the Menomonee River Watershed (136 square miles) that spans across Milwaukee, Ozaukee, and Washington Counties (WDNR 2001). Currently, all Ozaukee County water quality monitoring efforts on the LMR are concentrated in Ozaukee County and referred to as the "Upper Little Menomonee." The LMR has several impairments, identified by the WDNR, MMSD, and the Department, with the support of several funding partners such as USEPA, WDNR and FFLM, including chronic/acute aquatic toxicity (e.g. chlorides), degraded biological community, and recreational restrictions (due to pathogens). Past monitoring has detected high levels of creosote, fecal coliform, and total phosphorus. As a tributary to the Menomonee River (and within the Milwaukee River Basin), the LMR watershed is part of the Milwaukee Estuary AOC and is a high priority for restoration projects (WDNR 2017, WDNR 2020).

Mole Creek is an 8.9 mile stream described as a cool-cold headwater stream in the Milwaukee South Watershed. Although not officially categorized as a cold water stream, it contains a diverse population of

cold and cool water fishes and is considered in “good” condition based upon the instream fish habitat (e.g., spawning regions for salmonids) and fisheries (WDNR 2001a). The Mole Creek headwaters are located in the Town of Saukville and the creek enters the Milwaukee River in the Town of Grafton, north of the Village of Grafton. The 5,682 acre watershed is composed of nearly 50% agricultural land, 30% open lands, including forest and wetland, 15% residential land, and 6% transportation or industrial land (Figures 2 and 3).

Ulao Creek, in the Milwaukee River South Watershed, is an 8.6 mile creek described as a cool-warm headwater natural community in "poor" condition. It is designated as an Area of Special Natural Resource Interest. The Ulao Creek headwaters are in the Town of Grafton at the 342 acre Ulao Swamp and the creek enters the Milwaukee River in the City of Mequon. Land use in Ulao Creek’s 8,246 acre watershed is primarily agricultural land (44%) and openlands (26%), with 13% residential and 17% industrial and transportation (Figures 2 and 3). Ulao Creek is identified as impaired due to chronic aquatic toxicity, degraded biological communities, and acute aquatic toxicity. Pollutants identified as contributing to the impairments include total phosphorus and chloride. Although impaired, Ulao Creek connects to important wetland habitat, namely the 342 acre Ulao Swamp Natural Area (Ozaukee County Park and Open Space Plan, June 2011) containing 28% of the known northern pike spawning habitat in the Milwaukee River watershed.

This report is a detailed summation of previous and current water quality monitoring efforts completed on the Little Menomonee River, Mole Creek, and Ulao Creek. Specifically, it is the final report for the completion of WDNR RPP Grant #RP31018 awarded to Ozaukee County for the project “TMDL and BMP Water Quality Monitoring on Mole Creek and LMR.” Data through the 2019 sampling season is presented as well as the most up-to-date data on Ulao Creek in essence of clarity and the continuation of water quality monitoring on the 3 streams of interest.

Successful stream channel and adjacent floodplain restoration occurring along Ulao Creek as well as ongoing rehabilitation projects on the Little Menomonee River and Mole Creek have been previously coordinated organized and completed by the Department and funded through multiple grants awarded through the Fund for Lake Michigan, NOAA, USEPA, USFS, Wisconsin Costal Management Program, and WDNR. The overarching goal of these projects is to restore ecological function and structure to these Milwaukee River tributaries and adjacent wetlands. Through a series of wetland and floodplain enhancement/recreation and stream channel restoration, the lotic systems are hydrologically connected to critical habitats for northern pike and other phytophilic spawners. Additionally, the habitat enhancement projects occurring within the northern region of the Milwaukee River Basin provide essential habitat and resources for local and migrant bird and waterfowl species as well as reptiles, amphibians, and mammal populations that are dependent upon small streams, wetlands, and wet mesic prairie and forested (e.g. swamp) ecosystems.

Figure 2. Water quality monitoring stations and land use within the Little Menomonee River Watershed, Ozaukee County.

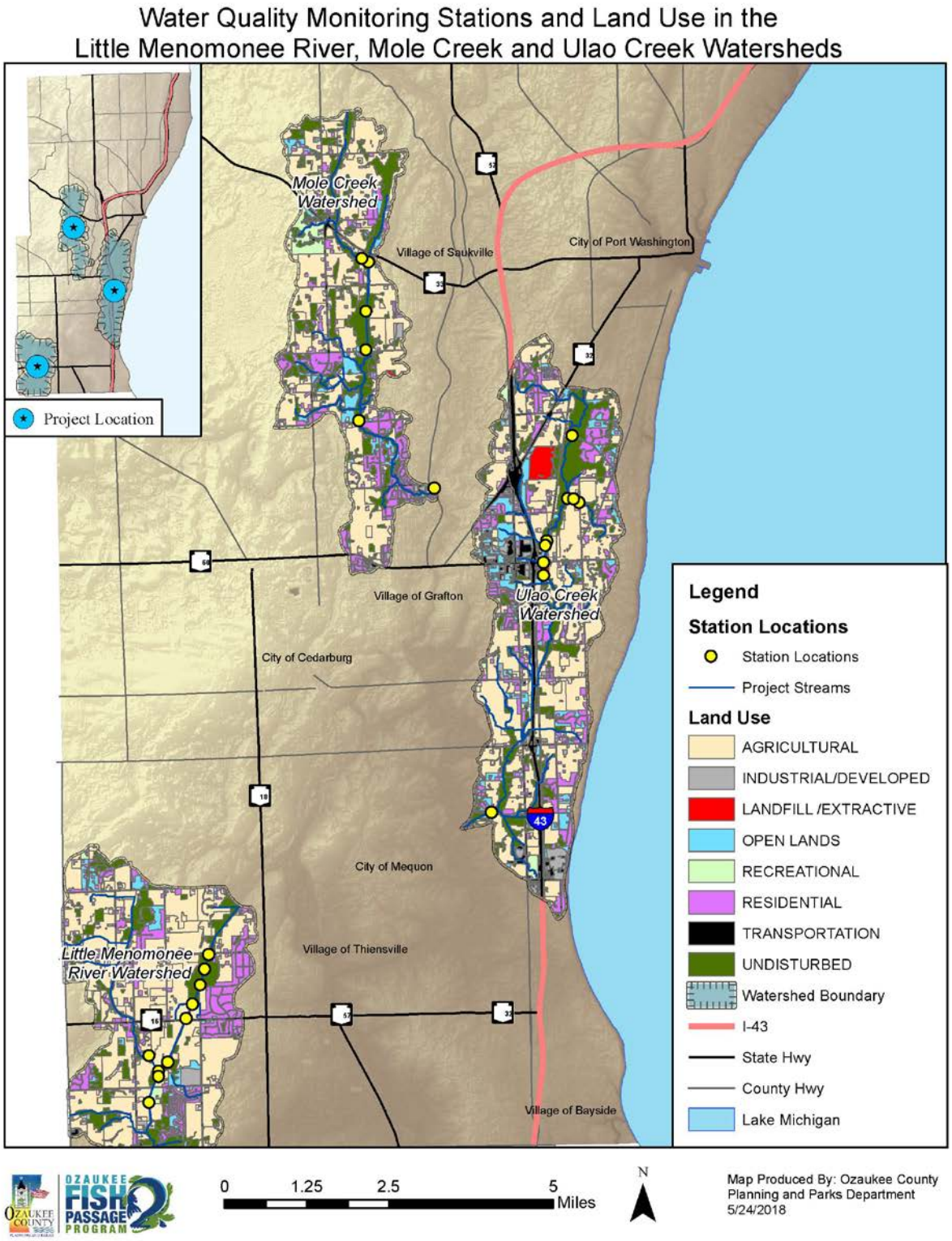
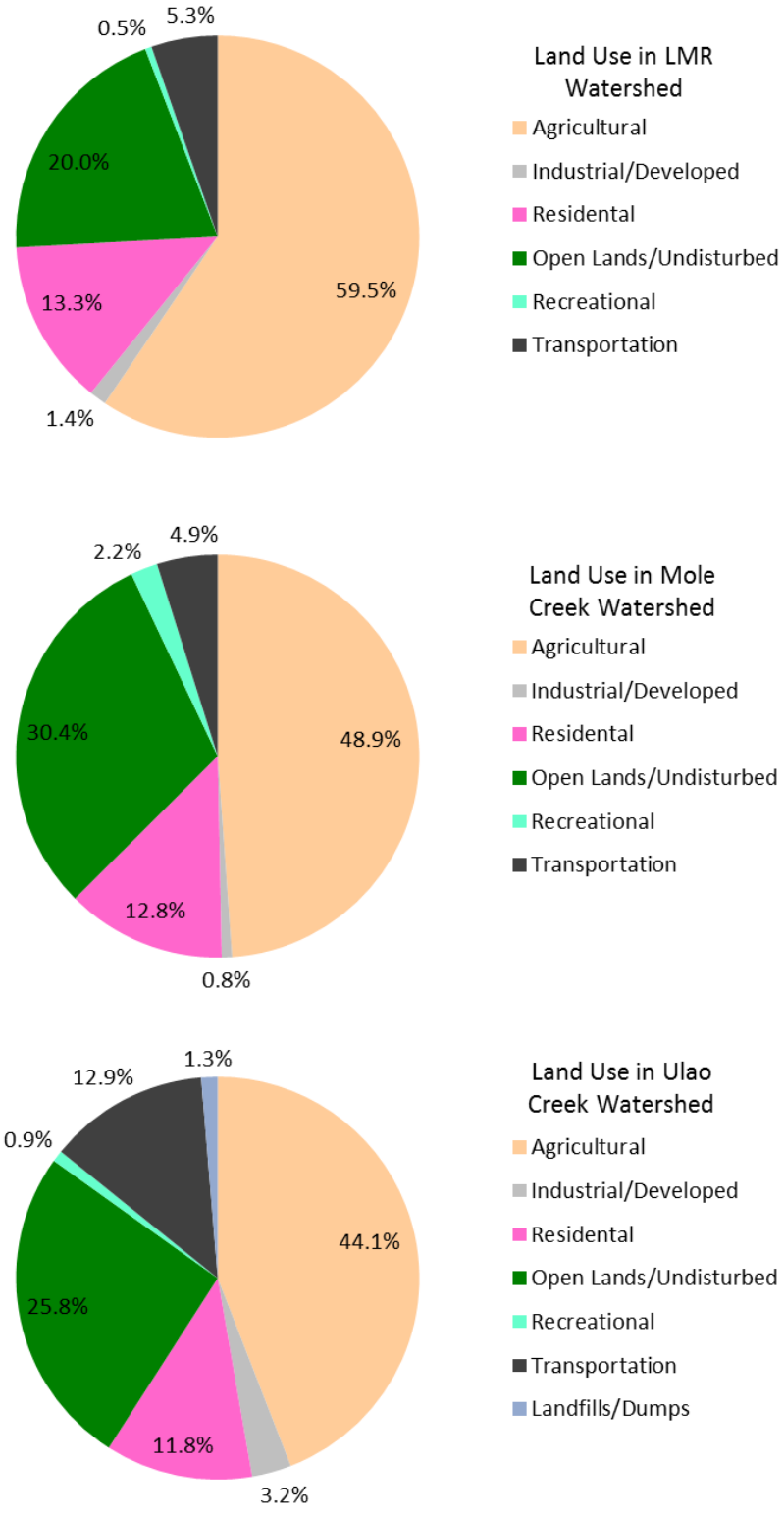


Figure 3. Land use comparisons within the Little Menomonee, Mole Creek, and Ulao Creek Watersheds.



Project Objectives

Through WDNR RPP, FFLM, NFWF-SOGL and NOAA grant funding, the Department conducted targeted water quality sampling from 26 strategically chosen locations on the LMR, Mole Creek, and Ulao Creek to establish a baseline and gain insight into water quality trends on tributary streams of the Menomonee and Milwaukee Rivers, which flow to the Lake Michigan estuary. In addition, continuous water quality monitoring units were deployed at three rotating locations on each stream. The Department will use the data for the following purposes:

1. To provide baseline data and better understand trends associated with pre- and post- stream remeandering, floodplain reconnection and wetland restoration to demonstrate the potential for implementing stream restoration as a management practice (BMP) for pollutant load reduction;

2. To better understand types of pollution entering the waterways and location of where pollution may be originating;

3. To provide information and data that supports Total Maximum Daily Load (TMDL) development and implementation;

4. To determine what correlations exist between various water quality parameters and biological (e.g., fisheries, wildlife, avian, herptiles) communities through paired sampling efforts; and,

5. To relate water quality parameters to biological (e.g. fisheries, wildlife, avian, herptiles) monitoring data across three similarly sized subwatersheds with similar land uses but different biological communities (e.g. cool-cold water to warm-water biological communities).

The data collected through this project allows the Department to evaluate the effects of restoration on the physical, biological, and chemical stream function using traditional water quality parameters. It also assists in the prioritization of the location and type of future restoration projects such as additional channel remeandering, bank stabilization, floodplain reconnection, wetland restoration and enhancement, and other best management practices. This information is useful to partnering organizations and agencies working on regional water quality improvement plans (e.g., 9 key element plans) and seeking additional data for the planning and design of local water quality improvement projects.

Monitoring Design

This project consisted of developing and implementing a monitoring design, not an experimental design, for collecting preliminary baseline water quality data and establishing temporal and spatial trends for nutrient and pathogen loading within the system during baseflow conditions and/or immediately after rain (surface runoff) events. As such, the measurement and data quality objectives were largely based on the precision and accuracy limits specified in the Standard Operating Procedures (SOPs) of the lab chosen for the project, the Wisconsin State Lab of Hygiene (SLOH). Applying robust statistical inferences to the entire project area was not a project objective. Thus, the data quality objectives were that data collected in the field or generated in a laboratory conforms to the items below to ensure it provided accurate representation of water quality at the time of sampling/measurement.

Results from water quality samples were considered data of acceptable quality if the samples were:

- Collected in accordance with federally-approved Quality Assurance Project Plans (QAPPs) developed for our monitoring program;
- Preserved (if required) in accordance with certified laboratory SOPs;

- Documented in accordance with certified laboratory SOPs; and
- Analyzed in accordance with certified laboratory SOPs.

Discrete water quality samples were collected and analyzed for:

- Chloride
- *E. coli*
- Orthophosphate (Dissolved Reactive Phosphorus)
- Total Phosphorus
- Total Suspended Solids (TSS)

Continuous water quality monitoring was performed using deployable systems (Eureka Water Probe Manta 2) designed to measure:

- Water temperature
- Water depth
- Dissolved Oxygen (DO) Concentration
- Hydrogen Ion Concentration (pH)
- Nitrate
- Conductivity

During installation and maintenance (e.g. calibration, battery replacement) of continuous monitoring units and pressure transducers and during discrete water quality monitoring events, Department staff collected additional measurements and observations using handheld instruments including:

- Water temperature
- Water depth (at one foot increments across the stream)
- Hydrogen Ion Concentration (pH)
- Conductivity
- Velocity (at one foot increments across the stream)
- Wet width of the stream
- Bankfull width of the stream
- Total dissolved solids (TDS)
- Resistivity
- Atmospheric pressure
- Air temperature
- Water clarity
- General observations about the stream and adjacent riparian areas
- Dissolved oxygen (DO) concentration and percent saturation
- Turbidity
- Salinity

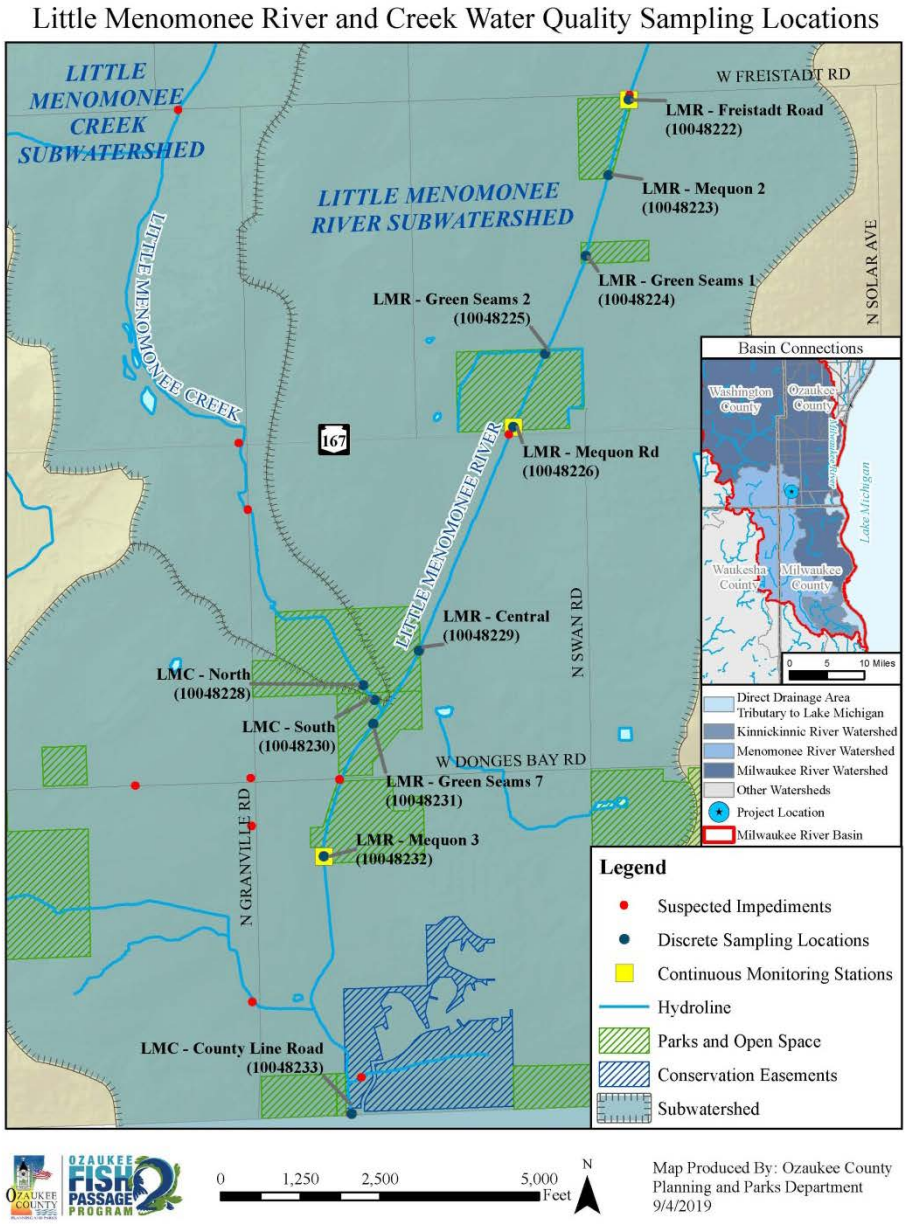
Monitoring Locations

The collection of baseline and trend data for nutrients and pathogens throughout Ozaukee County was designed to incorporate the headwaters, above and below confluences with other tributaries, above the

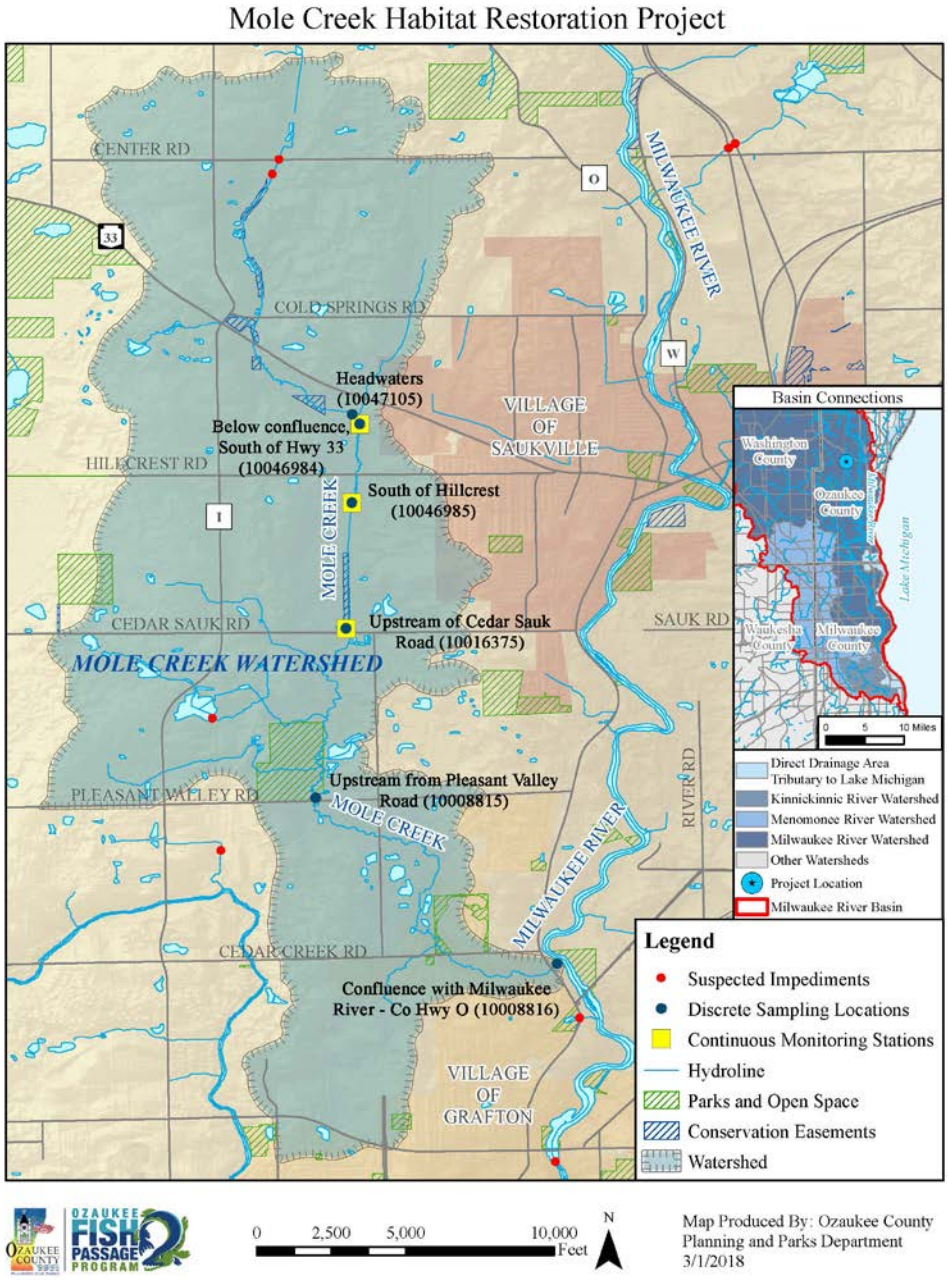
confluence of Mole Creek and Ulao Creek with the Milwaukee River, and above, within, and below project restoration sites (Figure 4, Table 1).

Figure 4. Discrete and continuous water quality monitoring locations in Ozaukee County.

a. Little Menomonee River



b. Mole Creek


Mole Creek Habitat Restoration Project
CENTER RD
COLD SPRINGS RD
HILLCREST RD
CEDAR SAUK RD
SAUK RD
PLEASANT VALLEY RD
CEDAR CREEK RD
RIVER RD
MILWAUKEE RIVER
MOLE CREEK
MOLE CREEK WATERSHED
VILLAGE OF SAUKVILLE
VILLAGE OF GRAFTON
Headwaters (10047105)
Below confluence South of Hwy 33 (10046984)
South of Hillcrest (10046985)
Upstream of Cedar Sauk Road (10016375)
Upstream from Pleasant Valley Road (10008815)
Confluence with Milwaukee River - Co Hwy O (10008816)
Basin Connections
Washington County
Ozaukee County
Waukesha County
Milwaukee County
Lake Michigan
0 5 10 Miles
Direct Drainage Area Tributary to Lake Michigan
Kinnickinnic River Watershed
Menomonee River Watershed
Milwaukee River Watershed
Other Watersheds
Project Location
Milwaukee River Basin
Legend
Suspected Impediments
Discrete Sampling Locations
Continuous Monitoring Stations
Hydroline
Parks and Open Space
Conservation Easements
Watershed
OZAUKEE FISH PASSAGE PROGRAM
0 2,500 5,000 10,000 Feet
N
Map Produced By: Ozaukee County Planning and Parks Department 3/1/2018

c. Ulao Creek

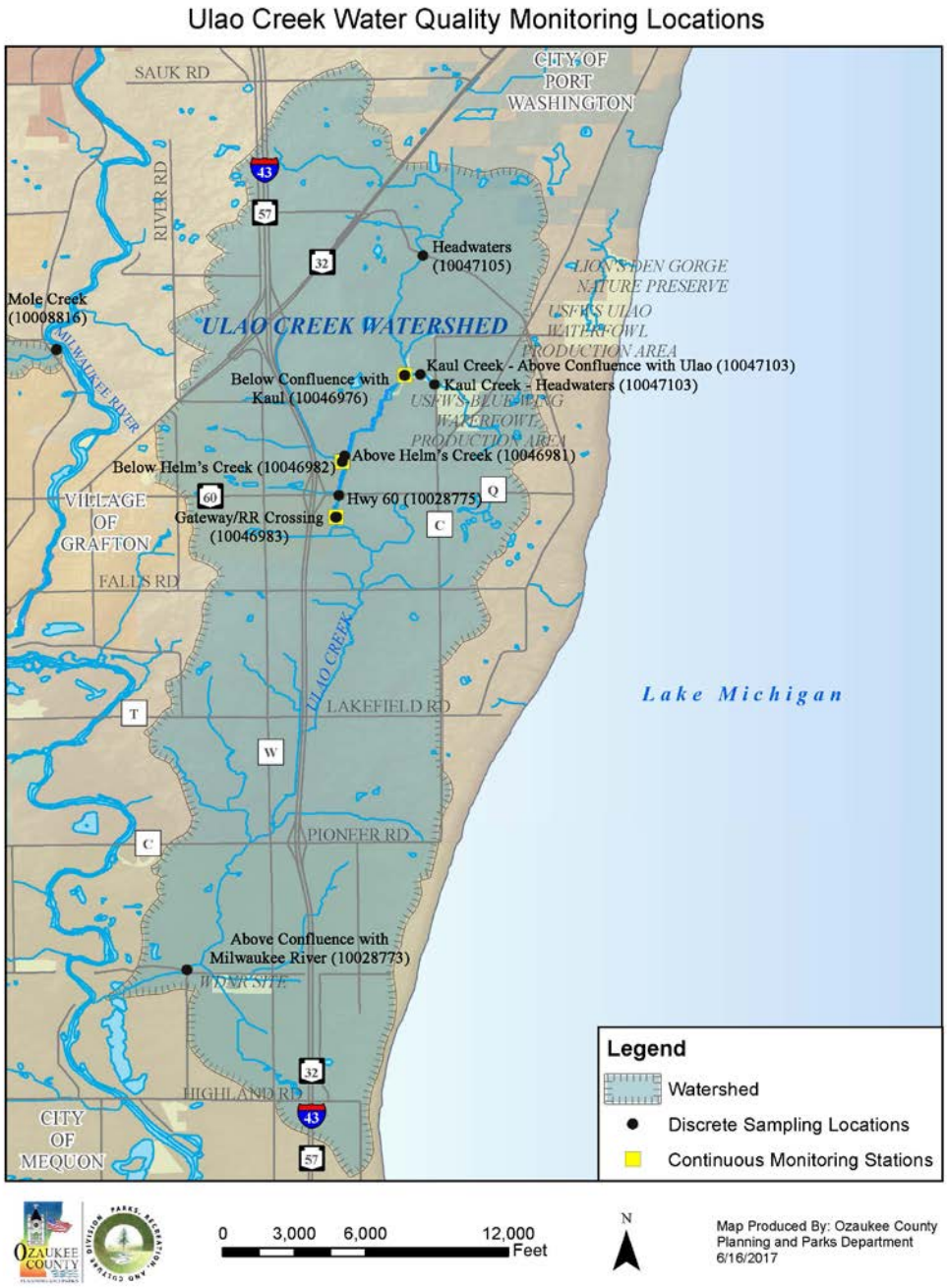

Ulao Creek Water Quality Monitoring Locations
SAUK RD
CITY OF PORT WASHINGTON
RIVER RD
43
57
32
Headwaters (10047105)
LION'S DEN GORGE NATURE PRESERVE
Mole Creek (10008816)
ULAO CREEK WATERSHED
USFWS ULAO WATERFOWL PRODUCTION AREA
MILWAUKEE RIVER
Below Confluence with Kaul (10046976)
Kaul Creek - Above Confluence with Ulao (10047103)
Kaul Creek - Headwaters (10047103)
USFWS BLUE WING WATERFOWL PRODUCTION AREA
Below Helm's Creek (10046982)
Above Helm's Creek (10046981)
60
Hwy 60 (10028775)
Q
VILLAGE OF GRAFTON
Gateway/RR Crossing (10046983)
C
FALLS RD
ULAO CREEK
Lake Michigan
LAKEFIELD RD
T
W
PIONEER RD
Above Confluence with Milwaukee River (10028773)
WDNR SITE
HIGHLAND RD
CITY OF MEQUON
Legend
Watershed
Discrete Sampling Locations
Continuous Monitoring Stations
OZAUKEE COUNTY
0 3,000 6,000 12,000 Feet
N
Map Produced By: Ozaukee County Planning and Parks Department
6/16/2017

Table 1. Water quality sampling sites, descriptions, and locations in Ozaukee County.

Station	Description	Location
10048222	*Little Menomonee River – Headwaters (Pigeon Creek), City of Mequon Property 1	At Freistadt Road, North end of City of Mequon Property (43.235941, -88.020550)
10048223	Little Menomonee River – City of Mequon Property 2	South of Freistadt, South end of City of Mequon Property (43.231950, -88.022300)
10048224	Little Menomonee River – Green Seams 1	South of Freistadt, W. Sunnyvale Rd (43.228818, -88.023493)
10048225	Little Menomonee River – North of Mequon Rd (Green Seams 2)	North of Mequon Rd (43.225031, -88.025510)
10048226	*Little Menomonee River – At Mequon Rd (Green Seams 3)	At Mequon Rd (43.221618, -88.027871)
10048228	Little Menomonee Creek – Granville Branch North (Green Seams 4)	East of Granville Rd (43.213727, -88.039081)
10048229	Little Menomonee River - Central (Green Seams 5)	Between Granville and Swan Rd (43.211828, -88.033743)
10048230	Little Menomonee Creek – Granville Branch South Above Confluence (Green Seams 6)	Between Granville and Swan Rd, Above Branch Confluence (43.210422, -88.036313)
10048231	Little Menomonee River – Below Granville Branch Confluence (Green Seams 7)	Between Granville and Swan Rd, Below Branch Confluence (43.209569, -88.035969)
10048232	*Little Menomonee River – City of Mequon Property 3	South of Donges Bay Rd (43.203445, -88.039489)
10048233	Little Menomonee River – County Line Road (Green Seams 8)	At County Line Rd (43.192476, -88.038251)
10047105	Mole Creek – "Headwaters"	Above Branch Confluence, South of State Hwy 33 (43.3875, -87.9675)
10046984	*Mole Creek – Below branch confluence, south of State Hwy 33	Below branch confluence, South of State Hwy 33 (43.3873, -87.9673)
10046985	*Mole Creek – Downstream of project site, south of Hillcrest	Downstream of project site, south of Hillcrest (43.3765, -87.9683)
10016375	*Mole Creek – Upstream of Cedar Sauk Rd.	From Cedar Sauk Rd (43.3680, -87.9686)
10008815	Mole Creek – Upstream from Pleasant Valley Road	From Pleasant Valley Road (43.3525, -87.9713)
10008816	Mole Creek – At Confluence with Milwaukee River (Co HWY O)	From Co Hwy O (43.3372, -87.9490)
10046975	Ulao Creek – Headwaters	Ulao Parkway (43.3480, -87.9071)
10047103	Kaul Creek – Headwaters	Ulao Parkway (43.3331, -87.9055)
10047104	Kaul Creek – Above Confluence with Ulao Creek	Kaul and Ulao Confluence (43.3344, -87.9087)
10046976	*Ulao Creek – Below confluence with Kaul Creek	Kaul and Ulao Confluence (43.3342, -87.9089)
10046981	Ulao Creek – Above Helm's Creek	Above Confluence of Helm's and Ulao Creek (43.3249, -87.9159)
10046982	*Ulao Creek – Below Helm's Creek	Below Confluence of Helm's and Ulao Creek (43.3242, -87.9160)
10028775	Ulao Creek – Hwy 60	Hwy 60 (43.3203, -87.9166)
10046983	*Ulao Creek – Gateway/RR Crossing	Below RR Crossing (43.3174, -87.9168)
10028773	Ulao Creek – Above Confluence with Milwaukee River	W Bonniwell Rd (43.2655, -87.9346)

** = also site of continuous monitoring unit*

Methods

General Water Quality Sampling Method Requirements & Quality Assurance/Quality Control

Per the WDNR-approved QAPP, all water samples were collected in containers, field preserved, labeled, and submitted for analysis in accordance with approved SOPs. General sampling requirements were as follows:

- Samples were collected in containers approved by the WDNR laboratory certification program (SLOH).
- Sampling was performed with an emphasis on avoiding contamination throughout the process (e.g., did not touch the inside of the container; did not put caps on the ground during sampling, fully rinsed sampling equipment between sites, wore gloves while collecting samples for *E. coli*, etc.).
- To provide accurate and reliable results, sample preservation and holding times were strictly adhered to throughout the process (e.g., labeling and preserving/icing samples immediately following collection, promptly delivering samples to the laboratory to ensure analysis within a given hold time, etc.).
- Complete sampling information was obtained and documented for most samples including location, date, time, air and water temperature, average flow velocity, cross-sectional information and other relevant field conditions at each sampling site. During extreme low flow periods, velocities could not be accurately measured at some locations.

The equipment used for continuous water quality monitoring was calibrated by Department staff prior to each deployment to confirm proper function. The stations were located at sites providing safe access and a low likelihood of tampering. The monitoring probes were either attached to heavy metal stakes within a poly-tube (to prevent damage due to objects coming downstream) and chained and locked or submerged in a poly-tube and weighted by a concrete block to ensure submersion throughout the duration of sampling and to avoid equipment theft or damage (Appendix A). Regular checks at each station included battery replacement, general maintenance, data download, and recalibration as necessary. The monitoring stations and probes were maintained and calibrated as needed in accordance with manufacturer recommendations as cited in operating manuals. Calibration data from the continuous monitoring stations was downloaded regularly by County staff onto external memory and immediately transported to the County offices and uploaded to the Ozaukee County network server.

All discrete water quality samples were sealed, preserved/iced, and transported to the laboratory in a prompt timeframe (within 24 hours of sampling) to ensure analysis occurred within necessary hold times per the SLOH SOPs. The SLOH conformed to industry-standard Level 2 requirements, including analytical reports, QA/QC reports, and chain of custody documentation (Ohio EPA 2006). The Certified Laboratory assumed custody of each sample it received and was responsible for forwarding all sample analysis results to the WDNR following the completion of analysis.

Discrete Water Quality Sampling Methods

The discrete water quality sampling methodology used in 2016-2017 included an objective to collect samples during an equal number of "baseflow" and "post rain event" conditions. “Post rain event” sampling events were scheduled around a rain event with at least 0.5 inches of precipitation no more than

48 hours (generally within 24-36 hours) prior to the start of sampling. Department staff checked the nearest available rain gauges to confirm precipitation. NOAA National Weather Service provided precipitation data for across the county. For the 2018-2019 sampling, the methods were modified (according to guidance from the WDNR for TMDL sampling) to sample once a month (e.g. >= 30 days apart) from April through October (e.g. growing season) to coincide with TMDL requirements.

Between 2017 and 2019, the LMR was sampled on 13 occasions and tested for each parameter during each event (Table 2a). Water quality monitoring on Mole and Ulao began in 2016, with discrete sampling occurring at each station over the course of 18 events (Table 2b). Department staff consistently collected samples from within the thalweg to obtain water samples representative of the flowing portions of the river at each location. Department staff collected all the water quality samples for an event on one day and drove the samples to the SLOH for analysis the following morning to ensure analysis was completed within the required time frame (e.g., 24 hours for *E. coli* samples). Department staff measured both water depth and water velocity one foot increments along a cross section at a sample station during the collection of most water quality samples in accordance to flow rate methodology established by Bain and Stevenson (1999). These measurements allow for the future calculation of discharge during sampling and estimates of pollutant loading.

Table 2. Discrete water quality sampling events.
a. Little Menomonee River, 2017-2019.

Sampling Event Date	Sampling Event Classification	Last Rain Event
10/23/2019	Normal - High Flow	10/11/2019
9/17/2019	Normal - Low Flow	9/13/2019
8/1/2019	Low Flow	7/21/2019
6/20/2019	After Rain Event	6/19-6/20/2019
5/23/2019	After Rain Event	5/22/2019
10/15/2018	After Rain Event - High Flow	Prior to sampling
9/12/2018	Low Flow	9/5/2018
7/26/2018	Low Flow	7/22/2018
6/14/2018	Low Flow	6/10/2018
5/24/2018	Low Flow	5/21/2018
9/14/2017	Low Flow	9/8/2017
7/31/2017	Low Flow	7/27/2017
7/13/2017	After Rain Event - High Flow	7/12/2017

b. Mole Creek and Ulao Creek, 2016-2019.

Sampling Event Date	Sampling Event Classification	Last Rain Event
10/16/2019	Normal	10/2/2019
9/3/2019	Prior to Sampling	9/3/2019
7/22/2019	After Rain Event	7/20/2019
5/30/2019	After Rain Event	5/28/2019
7/12/2018	High Flow/After Rain Event	Prior to sampling
10/30/2018	High Flow/After Rain Event	10/29/2018
9/27/2018	High Flow	9/25/2018
8/23/2018	High Flow	8/20/2018
10/23/2017	Rain Event/"high flow"	Prior to sampling
10/18/2017	Baseflow/"low flow"	10/15/2017
9/21/2017	Rain Event/"high flow"	Prior to sampling
8/8/2017	Baseflow/"low flow"	8/4/2017
6/27/2017	Baseflow/"low flow"	6/23/2017
4/20/2017	Rain Event/"high flow"	4/20/2017
9/19/2016	Baseflow/"low flow"	9/17/2016
9/22/2016	Rain Event/"high flow"	Prior to sampling
11/3/2016	Rain Event/"high flow"	Prior to sampling
11/10/2016	Baseflow/"low flow"	11/3/2016

Continuous Water Quality Sampling Methods

Between May 2015 and October 2019, rotating continuous water quality monitoring units were deployed at multiple locations at three separate stations on LMR, Mole Creek, and Ulao Creek (Table 3, Appendix A). The deployable systems designed to measure water temperature (accurate within 0.1°C), dissolved oxygen (DO) concentration (accurate within 0.5% saturation), hydrogen ion concentration (pH; accurate within 2% of full scale), conductivity (accurate within 20 µS/cm), nitrate (mg/L), and water depth (accurate within 0.015 ft) approximately every twenty minutes. The equipment used for continuous water quality monitoring was calibrated by the manufacturer and/or Department staff prior to each deployment to confirm proper functioning. The stations were located at an area that provided safe access and a low likelihood of tampering. The original Global Water brand water quality monitoring that were units used by the Department had cords connecting the probes and were weighted to ensure submersion throughout the duration of sampling. The newer Eureka Water Probes are cordless cylinders and were submerged within in a perforated PVC pipe attached to a sign-post secured to the streambed. The unit was then chained and locked to the sign-post to reduce the likelihood of tampering. Weekly and/or monthly checks at the stations included battery replacement, general maintenance, data download, cleaning, and recalibration as necessary. The monitoring stations and probes were maintained and calibrated as needed in accordance with manufacturer recommendations as cited in operating manuals and other supporting documents. Calibration data from the continuous monitoring station was downloaded at least every month by Department staff onto external memory and immediately transported to the County offices and uploaded to the Ozaukee County network server.

Monitoring these parameters continuously permitted the establishment of a baseline dataset and detection of trends related to various flow conditions during the sample period. The data collected from continuous monitoring can be cross referenced to the larger, discrete water quality sampling data set, allowing inference of water quality changes as they related to specific events or time periods. Water quality data collected throughout this preliminary project was consistent with other agency's data entered into WDNR's Surface Water Integrated Monitoring Systems (SWIMS), making for efficient data management and comparability (WDNR 2010).

Table 3. Summary of continuous water quality locations and deployment and removal dates.

Station #	Location	Unit Type	Deployment Date	Unit Removal Date
10048226	Little Menomonee River - Mequon Rd (Green Seams 3)	Continuous Monitoring Unit (Eureka)	4/2/2019 7/3/2019	6/20/2019 9/17/2019
10048222	Little Menomonee River- At Freistadt	Continuous Monitoring Unit (Eureka)	4/12/2019	9/17/2019
10048232	Little Menomonee River - City of Mequon Property 3	Continuous Monitoring Unit (Eureka)	4/12/2019 7/3/2019	6/20/2019 9/17/2019
10046984	Mole Creek - Below Confluence S. of Hwy 33	Continuous Monitoring Unit (Eureka)	5/30/2019 7/22/2019	7/12/2019 10/16/2019
10016375	Mole Creek - Upstream of Cedar Sauk Rd	Continuous Monitoring Unit (Eureka)	7/22/2019	10/16/2019
10046985	Mole Creek - South of Hillcrest	Continuous Monitoring Unit (Eureka)	7/22/2019	10/16/2019
10046976	Ulao Creek - Below Kaul Confluence	Continuous Monitoring Unit (Eureka)	7/22/2019	9/25/2019
10048222	Little Menomonee River - At Freistadt	Continuous Monitoring Unit (Eureka)	7/26/2018	10/23/2018
10048226	Little Menomonee River - Mequon Rd (Green Seams 3)	Continuous Monitoring Unit (Eureka)	6/5/2018 9/12/2018	7/26/2018 12/7/2018
10048232	Little Menomonee River - City of Mequon Property 3	Continuous Monitoring Unit (Eureka)	6/5/2018 9/12/2018	7/26/2018 12/7/2018
10046984	Mole Creek - Below Confluence S. of Hwy 33	Continuous Monitoring Unit (Eureka)	7/12/2018	11/16/2018
10046985	Mole Creek - South of Hillcrest	Continuous Monitoring Unit (Eureka)	7/12/2018	11/16/2018
10016375	Mole Creek - Upstream of Cedar Sauk Rd	Continuous Monitoring Unit (Eureka)	7/12/2018	11/16/2018
10046976	Ulao Creek - Below Kaul Confluence	Continuous Monitoring Unit (Eureka)	7/11/2018	11/16/2018
10046982	Ulao Creek - Below Helm's Creek	Continuous Monitoring Unit (Global Water)	7/10/2018 9/27/2018	9/17/2018 11/24/2018
10046983	Ulao Creek - Gateway/RR Crossing	Continuous Monitoring Unit (Global Water)	7/10/2018 9/27/2018	9/17/2018 12/7/2018
10048232	Little Menomonee River - City of Mequon Property 3	Continuous Monitoring Unit (Eureka)	6/21/2017	10/20/2017
10046984	Mole Creek - Below Confluence S. of Hwy 33	Continuous Monitoring Unit (Eureka)	6/13/2017	11/20/2017
10046985	Mole Creek - South of Hillcrest	Continuous Monitoring Unit (Eureka)	6/13/2017	11/20/2017
10016375	Mole Creek - Upstream of Cedar Sauk Rd	Continuous Monitoring Unit (Eureka)	6/13/2017	11/20/2017
10046976	Ulao Creek - Below Kaul Confluence	Continuous Monitoring Unit (Global Water)	6/23/2017	11/9/2017
10046984	Mole Creek - Below Confluence S. of Hwy 33	Continuous Monitoring Unit (Eureka)	8/24/2016	11/29/2016
10046985	Mole Creek - South of Hillcrest	Continuous Monitoring Unit (Eureka)	8/24/2016	11/29/2016
10016375	Mole Creek - Upstream of Cedar Sauk Rd	Continuous Monitoring Unit (Eureka)	8/24/2016	11/29/2016
10046982	Ulao Creek - Below Helm's Creek	Continuous Monitoring Unit (Global Water)	7/14/2016 10/17/2016	9/16/2016 11/10/2016
10046976	Ulao Creek - Below Kaul Confluence	Continuous Monitoring Unit (Eureka)	9/16/2016	12/6/2016
10046983	Ulao Creek - Gateway/RR Crossing	Continuous Monitoring Unit (Eureka)	7/8/2016 8/17/2016	11/25/2016 12/2/2016
10046982	Ulao Creek - Below Helm's Creek	Continuous Monitoring Unit (Global Logger)	5/28/2015	8/7/2015
	Ulao Creek - Downstream of RR Crossing	Continuous Monitoring Unit (Global Logger)	5/28/2015	8/24/2015
10046983	Ulao Creek - Gateway/RR Crossing	Continuous Monitoring Unit (Global Logger)	5/27/2015	7/30/2015

Additional Data Collection

During installation and maintenance (e.g. calibration, battery replacement) of continuous monitoring units and during discrete water quality monitoring events, Department staff used handheld instruments to collect additional measurements and observations including: water temperature, water depth (at one foot increments across the stream), dissolved oxygen (DO) concentration, hydrogen ion concentration (pH), conductivity, turbidity, velocity (at one foot increments across the stream), wet width of the stream, bankfull width of the stream, total dissolved solids, resistivity, atmospheric pressure, air temperature, water clarity, and general observations about the stream and adjacent riparian areas. Prior to data collection, handheld instruments were calibrated to factory standards. Two HOBO pressure and water temperature loggers were installed at the LMR immediately upstream of station 10048226 (Green Seams 3 – north of Mequon Road) and station 10048222 (Freistadt Road) in 2018 and 2019, for future conversion to water velocity. A permanent USGS station that collects both gauge height and discharge data is located near location 10048232 (City of Mequon Property 3), south of Donges Bay Road and adjacent to Lemke Park in the city of Mequon.

Section 1: Little Menomonee River Results

For clarity purposes, the data and subsequent discussion for each stream is presented in separate sections.

Measured values from the discrete sampling events occurring from June 2017 until September 2019 were summarized for each location and parameter. A total of 13 sampling events occurred at each of the 11 stations on the LMR: 3 in 2017, 5 in 2018, and 5 in 2019 (Table 2). Twenty-two parameters were assessed during each sampling event at every station, 5 of which were analyzed by the SLOH. The SLOH has a limit of detection and limit of quantitation for the parameters analyzed in the laboratory (Table 4). Results that were reported as "ND" (none detected) indicated the concentration of a specific parameter was below the limit of detection. For results that are below the limit of quantitation, there is a lower degree of confidence in the precision of the reported result.

Table 4. State Laboratory of Hygiene limits of detection and quantification.

Test	Limit of Detection	Limit of Quantitation
Total Phosphorus	0.005 mg/L	0.016 mg/L
E. coli	Does not apply	1 MPN/100 mL
Total Suspended Solids (TSS)	2.5 mg/L	2.5 mg/L
Orthophosphate	0.002 mg/L	0.006 mg/L
Chloride	1.0 mg/L	3.2 mg/L

The mean, median, maximum, minimum, interquartile range (IQR, or the difference between the 75th and 25th percentiles), number of samples (n), and standard deviation were calculated for the focus parameters: chloride concentration, orthophosphate, total phosphorus, total suspended solids, *E. coli* dissolved oxygen concentration, pH, conductivity, salinity, TDS, turbidity, and water temperature.

Chloride

A chloride concentration of 1-100 mg/L is considered normal in freshwater streams per the WDNR (2019). Chloride ions enter a waterway via deterioration of rocks (generally in underground aquifers), agricultural runoff, road deicers, industrial wastewater, and effluent wastewater from wastewater treatment plants. High concentrations of chloride are associated with impervious surfaces, especially those that are treated, as runoff is unable to effectively infiltrate soil prior to entering the waterbody. In areas with a high speed limit, chlorides from road salts have been observed streamside over 40 m (10 ft) from the pavement (Hunt et al. 2012). The WDNR (2019) has set the target concentration of chloride in

Wisconsin's aquatic systems as less than 395 mg/L for chronic exposure and 757 mg/L for acute exposure (Table 17).

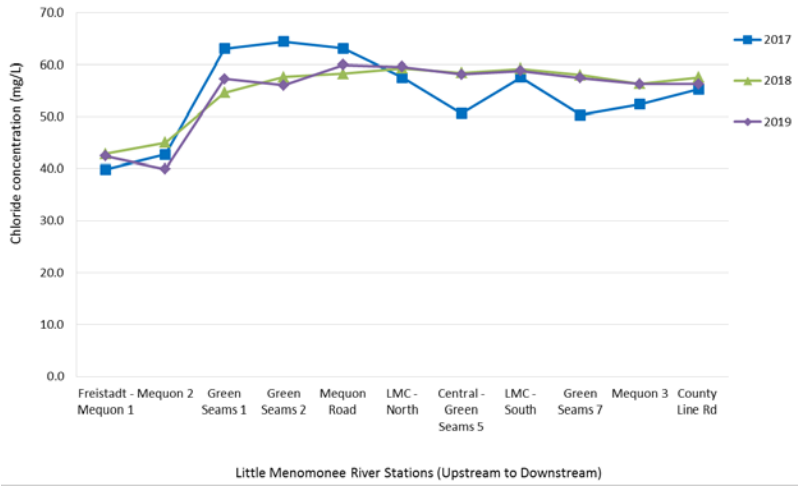
All water samples taken at the 11 stations from 2017 to 2019 had average chloride concentrations below 395 mg/L (Table 5, Figure 5).

Table 5. Chloride concentration (mg/L) summary from discrete samples analyzed by SLOH from the 11 LMR water quality sampling stations in Ozaukee County, WI.

Station	Location	Year	Median	Mean	Min	Max	IQR	n	Std Dev
10048222	Freistadt, Mequon 1	2017	39.7	39.8	39.3	40.5	0.6	3	0.5
		2018	43.0	42.8	38.0	46.0	5.3	5	2.7
		2019	37.3	42.4	36.5	48.9	4.6	5	4.4
10048223	Mequon 2	2017	42.7	42.7	40.2	45.2	5.0	2*	2.5
		2018	45.0	45.0	42.8	46.9	3.1	5	1.5
		2019	42.1	39.9	34.5	49.1	0.9	5	5.7
10048224	Green Seams 1	2017	62.7	63.1	53.7	72.8	9.6	3	7.8
		2018	51.8	54.6	50.9	66.6	8.4	5	6.0
		2019	50.6	57.3	49.0	83.3	4.0	5	14.6
10048225	Green Seams 2	2017	65.1	61.4	46.5	72.7	13.1	3	11.0
		2018	53.9	57.7	48.4	70.8	19.0	5	8.9
		2019	51.3	56.1	50.4	71.4	6.2	5	9.0
10048226	Mequon Road	2017	63.3	63.1	48.9	77.2	14.2	3	11.6
		2018	57.8	58.3	52.2	68.1	9.5	5	5.4
		2019	58.4	59.9	52.8	71.6	4.9	5	7.2
10048228	LMC - North	2017	59.9	57.5	52.6	60.1	3.8	3	3.5
		2018	60.0	59.3	52.4	66.7	9.7	5	4.8
		2019	59.6	59.6	55.2	62.9	4.9	5	3.3
10048229	Central	2017	44.6	50.6	39.3	67.6	14.3	3	12.4
		2018	66.0	58.5	44.0	70.5	24.4	5	11.6
		2019	56.0	58.1	42.0	72.7	10.6	5	11.6
10048230	LMC - South	2017	59.8	57.6	52.7	60.2	3.8	3	3.4
		2018	59.8	58.2	52.3	61.8	7.2	5	3.5
		2019	59.1	58.9	55.2	62.7	1.9	5	2.7
10048231	Green Seams 7	2017	49.4	50.3	41.4	60.1	9.4	3	7.7
		2018	62.7	58.0	48.9	64.5	13.5	5	6.5
		2019	56.0	57.4	50.0	65.4	5.8	5	5.9
10048232	Mequon 3	2017	51.4	52.3	44.3	61.3	8.5	3	7.0
		2018	61.4	56.3	47.3	62.3	14.0	5	6.8
		2019	56.0	57.4	50.0	65.4	5.8	5	5.9
10048233	County Line Road	2017	56.4	55.3	46.7	62.7	8.0	3	6.6
		2018	62.1	57.8	49.5	63.3	12.7	5	6.1
		2019	55.5	56.3	50.2	61.5	3.4	5	4.2

*no data from 7/31/2017 sample due to "insufficent volume" of laboratory sample

Figure 5. Chloride concentration (mg/L) per year per water quality sampling station on the LMR stream system in Ozaukee County, WI.



Total Phosphorus and Orthophosphate (Dissolved Reactive Phosphorus)

Phosphorus was analyzed in samples as total phosphorus and total reactive phosphorus, also called orthophosphate. Phosphorus concentrations can fluctuate annually due to the number and severity of rain events and soil-disturbing activities occurring both upstream and near a sampling station. The Wisconsin water quality standard, established under NR102 (2019), for desirable phosphorus concentration in a stream environment is less than 0.075 mg/L (Table 17).

Of the annual averages, only 4 of the 11 sampling locations had values below the 0.075 mg/L threshold in 2019 with only 1 of the 4 locations averaging below 0.075 mg/L in 2018 (Table 6a, Figure 6a). Examination of total phosphorus concentration in individual samples per year demonstrates that in 2017, 91% (30) of the 33 samples submitted to the SLOH measured above 0.075 mg/L; in 2018, 56% (31) of the 55 samples had concentrations above 0.075 mg/L; and, in 2019, 55% (30) of 55 samples were above 0.075 mg/L. The LMR watershed drains a predominantly agricultural landscape (Figures 2 and 3) and phosphorus loading is a potential issue. Runoff of phosphorus contributes to cladophora algal growth, particularly in reaches with low stream velocity, which further reduces water velocity and creates dramatic swings in dissolved oxygen concentration.

As no Wisconsin state standard exists for orthophosphate, the WDNR utilizes the federal water quality standard of a maximum level of 0.1 mg/L (USEPA 1986) (Table 17). All average values per sampling location per year had concentrations of orthophosphate below the USEPA recommendation (Table 6b, Figure 6b). Reviewing all individual measurements confirms only 1 sample in each 2017 and 2018 and 2 samples in 2019 from various locations measured above 0.1 mg/L.

Table 6. Total phosphorus and orthophosphate concentrations (mg/L) summary from discrete samples analyzed by SLOH from the 11 LMR water quality sampling stations in Ozaukee County, WI. Values in red indicate a measure concentration above the desirable phosphorus concentration of 0.075 mg/L in Wisconsin streams.

a.) Total phosphorus

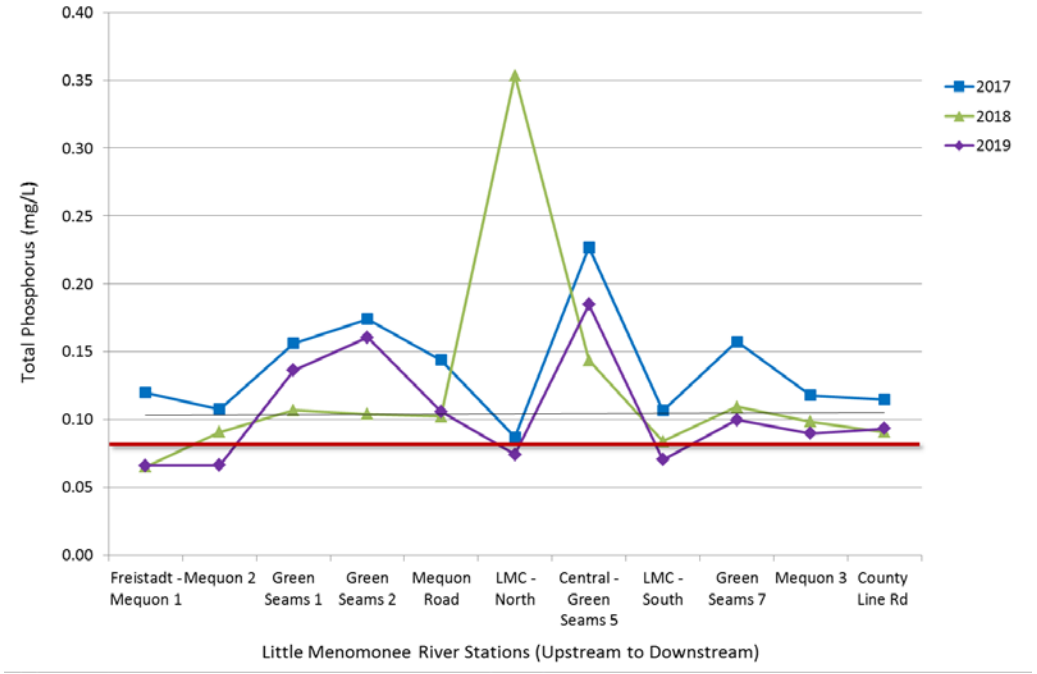
Station	Location	Year	Median	Mean	Min	Max	IQR	n	Std Dev
10048222	Freistadt, Mequon 1	2017	0.129	0.120	0.097	0.133	0.018	3	0.016
		2018	0.044	0.065	0.037	0.137	0.064	5	0.038
		2019	0.061	0.066	0.034	0.104	0.011	5	0.031
10048223	Mequon 2	2017	0.099	0.107	0.096	0.127	0.015	3	0.014
		2018	0.039	0.091	0.032	0.275	0.137	5	0.093
		2019	0.061	0.066	0.045	0.102	0.050	5	0.022
10048224	Green Seams 1	2017	0.146	0.156	0.141	0.181	0.020	3	0.018
		2018	0.096	0.107	0.066	0.164	0.070	5	0.034
		2019	0.103	0.136	0.065	0.327	0.028	5	0.108
10048225	Green Seams 2	2017	0.167	0.174	0.143	0.212	0.035	3	0.029
		2018	0.084	0.104	0.064	0.155	0.083	5	0.038
		2019	0.098	0.160	0.067	0.312	0.190	5	0.116
10048226	Mequon Road	2017	0.136	0.144	0.123	0.172	0.025	3	0.021
		2018	0.084	0.102	0.064	0.189	0.078	5	0.045
		2019	0.100	0.106	0.061	0.176	0.010	5	0.043
10048228	LMC - North	2017	0.089	0.087	0.059	0.112	0.026	3	0.022
		2018	0.146	0.353	0.066	0.988	0.679	5	0.356
		2019	0.071	0.074	0.042	0.119	0.012	5	0.028
10048229	Central	2017	0.217	0.227	0.200	0.263	0.032	3	0.027
		2018	0.135	0.144	0.076	0.255	0.126	5	0.064
		2019	0.161	0.185	0.075	0.410	0.098	5	0.135
10048230	LMC - South	2017	0.091	0.107	0.061	0.168	0.054	3	0.045
		2018	0.067	0.084	0.050	0.142	0.061	5	0.032
		2019	0.070	0.070	0.041	0.119	0.033	5	0.031
10048231	Green Seams 7	2017	0.188	0.157	0.071	0.213	0.071	3	0.062
		2018	0.102	0.109	0.069	0.157	0.081	5	0.037
		2019	0.117	0.100	0.052	0.136	0.057	5	0.037
10048232	Mequon 3	2017	0.120	0.118	0.083	0.150	0.033	3	0.027
		2018	0.090	0.098	0.064	0.142	0.072	5	0.033
		2019	0.101	0.090	0.053	0.122	0.057	5	0.032
10048233	County Line Road	2017	0.106	0.115	0.096	0.142	0.023	3	0.020
		2018	0.086	0.091	0.058	0.124	0.062	5	0.028
		2019	0.114	0.093	0.050	0.129	0.059	5	0.037

b.) Orthophosphate

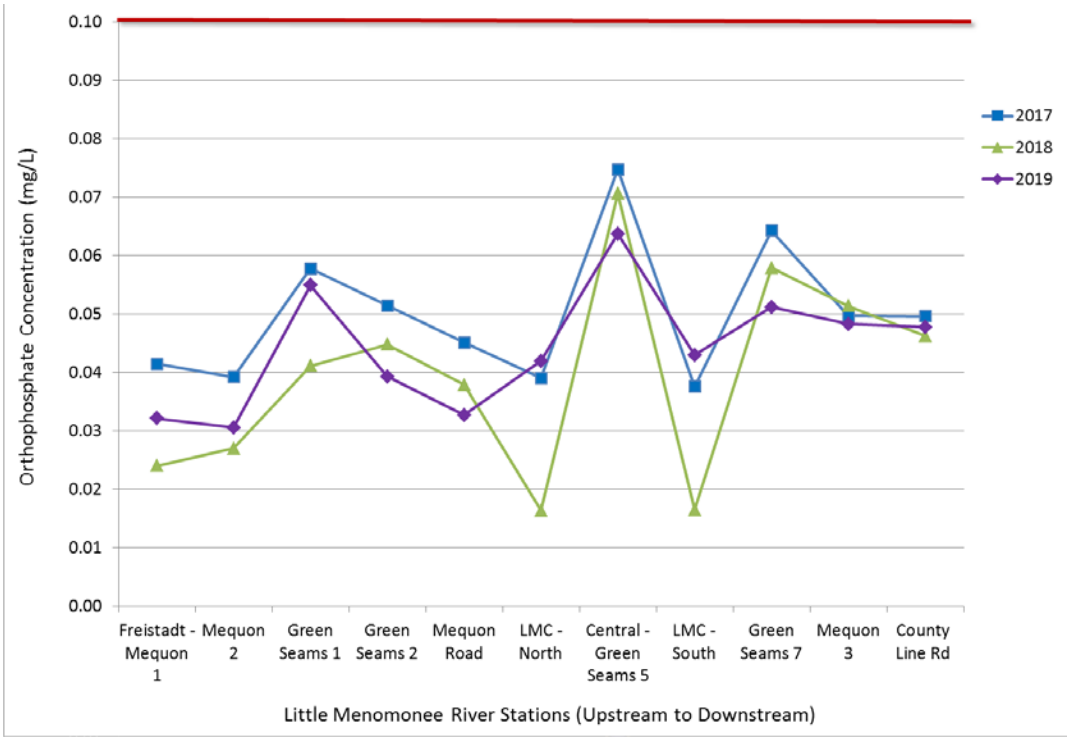
Station	Location	Year	Median	Mean	Min	Max	IQR	n	Std Dev
10048222	Freistadt, Mequon 1	2017	0.041	0.041	0.030	0.053	0.011	3	0.009
		2018	0.016	0.024	0.009	0.057	0.029	5	0.017
		2019	0.026	0.032	0.009	0.076	0.006	5	0.025
10048223	Mequon 2	2017	0.036	0.039	0.030	0.051	0.010	3	0.009
		2018	0.017	0.027	0.010	0.064	0.036	5	0.020
		2019	0.025	0.031	0.012	0.068	0.003	5	0.022
10048224	Green Seams 1	2017	0.053	0.058	0.045	0.075	0.015	3	0.013
		2018	0.041	0.041	0.028	0.060	0.024	5	0.012
		2019	0.031	0.055	0.024	0.161	0.009	5	0.059
10048225	Green Seams 2	2017	0.051	0.051	0.038	0.065	0.014	3	0.011
		2018	0.042	0.045	0.028	0.064	0.033	5	0.015
		2019	0.033	0.039	0.021	0.079	0.006	5	0.023
10048226	Mequon Road	2017	0.049	0.045	0.027	0.060	0.017	3	0.014
		2018	0.043	0.038	0.021	0.055	0.025	5	0.012
		2019	0.029	0.033	0.015	0.064	0.005	5	0.018
10048228	LMC - North	2017	0.037	0.039	0.033	0.047	0.007	3	0.006
		2018	0.045	0.016	0.028	0.070	0.040	5	0.018
		2019	0.042	0.042	0.017	0.071	0.018	5	0.020
10048229	Central	2017	0.070	0.075	0.050	0.104	0.027	3	0.022
		2018	0.081	0.071	0.025	0.111	0.060	5	0.030
		2019	0.046	0.064	0.021	0.111	0.055	5	0.038
10048230	LMC - South	2017	0.035	0.038	0.033	0.045	0.006	3	0.005
		2018	0.046	0.017	0.028	0.070	0.040	5	0.018
		2019	0.043	0.043	0.018	0.072	0.016	5	0.020
10048231	Green Seams 7	2017	0.067	0.064	0.035	0.091	0.028	3	0.023
		2018	0.060	0.058	0.026	0.091	0.049	5	0.023
		2019	0.051	0.051	0.018	0.084	0.022	5	0.024
10048232	Mequon 3	2017	0.045	0.050	0.037	0.067	0.015	3	0.013
		2018	0.054	0.051	0.024	0.077	0.043	5	0.020
		2019	0.046	0.048	0.019	0.080	0.027	5	0.023
10048233	County Line Road	2017	0.042	0.050	0.039	0.068	0.015	3	0.013
		2018	0.049	0.046	0.020	0.072	0.039	5	0.019
		2019	0.043	0.048	0.018	0.081	0.027	5	0.024

Figure 6. Total phosphorus and orthophosphate concentration (mg/L) per year per water quality sampling station on the LMR stream system in Ozaukee County, WI. The red line is set at the established Wisconsin desirable concentration of 0.075 mg/L.

a.) Total phosphorus



b.) Orthophosphate



Total Suspended Solids

Currently, there are no set water quality criteria for total suspended solids (TSS) by either the State of Wisconsin or Federal government; however, the WDNR in conjunction with MMSD (2018) implement the regional Total Maximum Daily Load (TMDL) value of 12 mg/L as the allowable load and target concentration (Table 17). High concentrations of total suspended solids increase turbidity of the water, negatively impacting biological, chemical, and physical properties of a stream. While the TMDL allows for an adequate establishment of a baseline in waterbody, the chronic level and target number need further examination through additional studies.

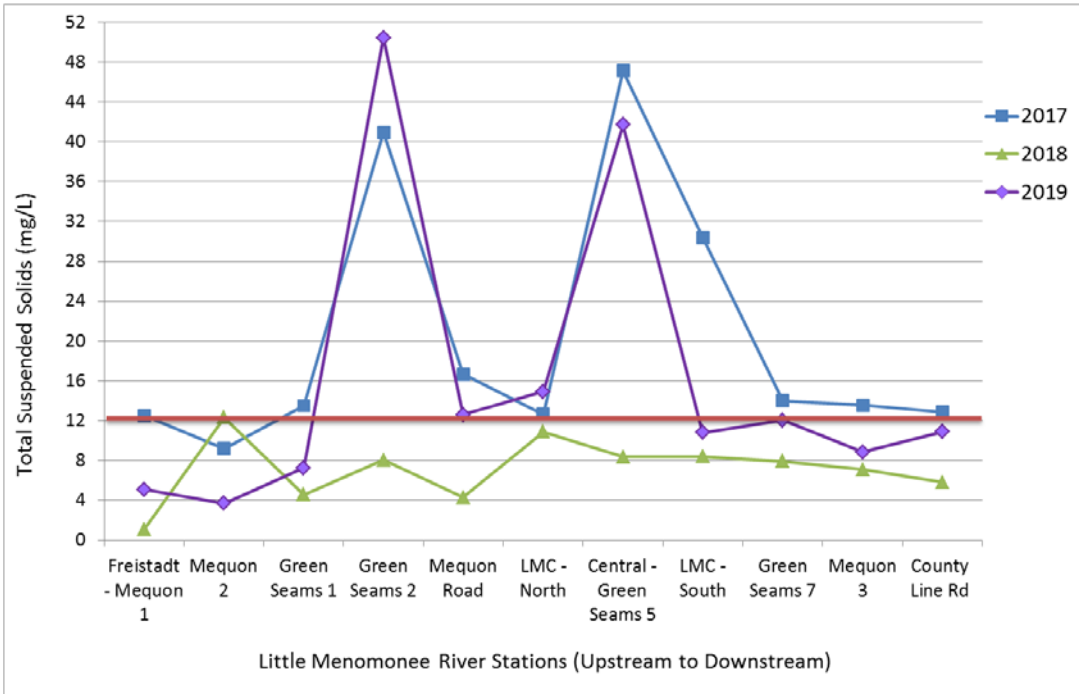
Average TSS concentrations at 10 of the 11 locations exceeded 12 mg/L in 2017; only Mequon 2, an upstream location, had a mean concentration below the TMDL of 9.2 mg/L. In 2018, the only location to exceed 12 mg/L was Mequon 2. In 2019, 5 of the 11 stations, all located in the middle of the sampling reach, exceeded the 12 mg/L target concentration in 2019 (Table 7, Figure 7).

Table 7. TSS concentration (mg/L) summary from discrete samples analyzed by SLOH from the 11 water quality sampling stations on LMR in Ozaukee County, WI. Values in red represent an average concentration above the recommended 12 mg/L regional TMDL.

Station	Location	Year	Median	Mean	Min	Max	IQR	n	Std Dev
10048222	Freistadt, Mequon 1	2017	10.8	12.5	10.2	16.5	3.2	3	2.8
		2018	0.0	1.0	0.0	5.3	2.7	5*	2.1
		2019	3.0	5.1	2.6	8.0	0.2	5	2.8
10048223	Mequon 2	2017	10.4	9.2	6.2	11.0	2.4	3	2.1
		2018	0.0	12.3	0.0	61.5	30.8	5*	24.6
		2019	4.9	3.7	3.0	6.2	4.5	5	1.4
10048224	Green Seams 1	2017	13.4	13.5	11.0	16.0	2.5	3	2.0
		2018	4.7	4.6	2.2	8.7	4.5	5	9.2
		2019	5.8	7.3	4.4	14.8	1.3	5	4.3
10048225	Green Seams 2	2017	30.0	40.9	13.7	79.0	32.7	3	27.8
		2018	5.0	8.1	3.4	14.7	9.6	5	4.6
		2019	10.6	50.4	5.8	179.0	37.9	5	73.8
10048226	Mequon Road	2017	20.5	16.7	6.0	23.5	8.8	3	7.6
		2018	3.8	4.3	0.0	13.7	8.9	5*	5.0
		2019	11.0	12.6	6.0	24.0	1.2	5	6.7
10048228	LMC - North	2017	10.8	12.6	6.0	21.1	7.6	3	6.3
		2018	3.8	10.5	2.6	37.5	19.4	5	13.4
		2019	7.6	14.9	4.2	29.2	23.1	5	12.7
10048229	Central	2017	15.7	47.1	13.6	112.0	49.2	3	45.9
		2018	7.3	8.4	2.2	17.0	10.7	5	5.2
		2019	11.0	41.7	4.0	167.0	10.3	5	70.3
10048230	LMC - South	2017	13.2	30.4	8.0	70.0	31.0	3	28.1
		2018	4.4	8.4	2.8	25.8	12.0	5	8.7
		2019	5.8	10.8	4.6	29.2	4.8	5	10.5
10048231	Green Seams 7	2017	13.1	14.0	11.0	17.9	3.5	3	2.9
		2018	5.6	7.9	0.0	21.0	12.0	5	7.0
		2019	9.4	12.0	4.4	26.6	5.8	5	8.7
10048232	Mequon 3	2017	13.5	13.5	8.5	18.6	5.1	3	4.1
		2018	4.0	7.1	2.4	17.7	10.0	5	5.6
		2019	7.4	8.9	4.5	17.4	4.0	5	5.1
10048233	County Line Road	2017	14.2	12.9	9.1	15.3	3.1	3	2.7
		2018	4.6	5.8	2.0	11.5	7.5	5	3.6
		2019	14.2	10.9	5.0	15.2	9.6	5	5.3

*one or more samples were below level of detection

Figure 7. TSS concentration (mg/L) per year per water quality sampling station on the LMR stream system in Ozaukee County, WI. The red line indicates the TMDL target concentration of 12 mg/L.



E. coli

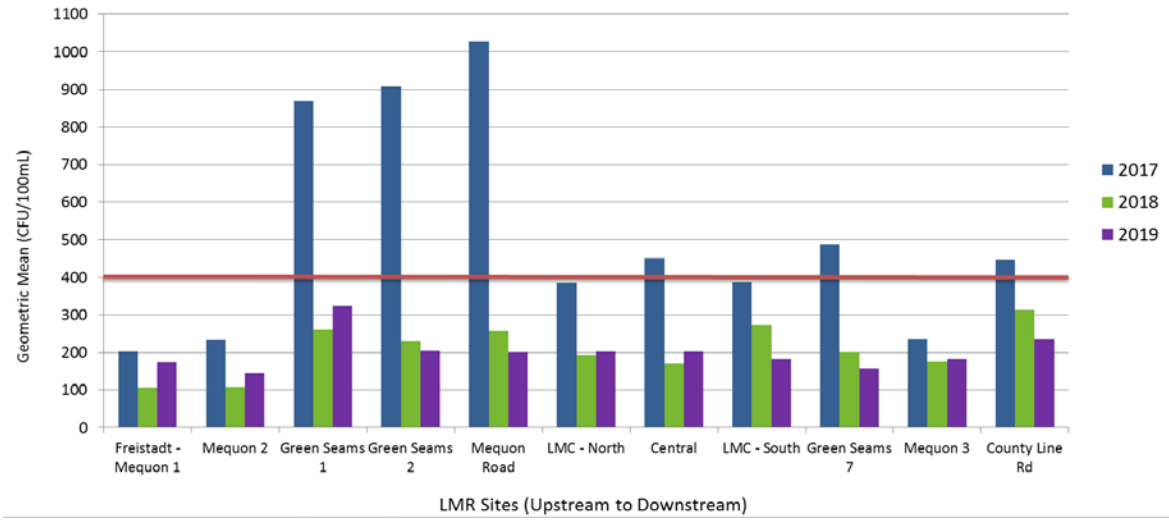
High bacteria concentrations can have a negative effect on streams as well as human health. Wisconsin State Recreational Use Standards state that fecal coliform levels are "not to exceed 400 CFU/100 mL" (colony forming units/100 milliliter sample; WDNR 1973, WDNR & MMSD 2018). WDNR recommended retesting for sites with results higher than 400 CFU/100 mL; retesting was not done for individual samples in this study. The USEPA has established recommended minimum criteria for *E. coli* that suggest that the geometric mean of all samples should not exceed 126 colony forming units (CFU) per 100 mL and not more than 10 percent of samples to exceed 400 CFU/100 mL (USEPA 1986a) (Table 17).

The geometric mean was used when summarizing the *E. coli* data as the bacteria naturally exhibits exponential growth. Means at 6 of the 11 locations were above 400 CFU/100 mL in 2017. Geometric means at the sampling locations did not exceed 400 CFU/100 mL in subsequent years (Table 8, Figure 8).

Table 8. *E. coli* concentration (CFU/100 mL) summary from discrete samples analyzed by SLOH from the 11 LMR water quality sampling stations in Ozaukee County, WI. Values in red represent a geometric mean above 400 CFU/100 mL.

Station	Location	Year	Median	Geo Mean	Min	Max	IQR	n	Std Dev (P)
10048222	Freistadt, Mequon 1	2017	219.0	201.9	144.0	261.0	58.5	3	48.4
		2018	112.0	107.1	38.0	248.0	139.5	5	71.1
		2019	49.0	173.6	49.0	816.0	334.0	5	350.1
10048223	Mequon 2	2017	261.0	233.1	186.0	261.0	37.5	3	35.4
		2018	77.0	108.4	36.0	365.0	231.0	5	107.2
		2019	91.0	144.2	65.0	970.0	209.0	5	290.2
10048224	Green Seams 1	2017	689.0	868.9	613.0	1553.0	470.0	3	426.3
		2018	261.0	260.5	0.0	387.0	313.5	4*	146.8
		2019	248.0	324.6	119.0	866.0	684.0	5	335.9
10048225	Green Seams 2	2017	816.0	908.1	649.0	1414.0	382.5	3	328.4
		2018	345.0	229.8	105.0	435.0	306.0	5	142.0
		2019	238.0	204.3	75.0	548.0	166.0	5	165.4
10048226	Mequon Road	2017	1203.0	1027.7	750.0	1203.0	226.5	3	213.5
		2018	196.0	256.9	124.0	613.0	341.0	5	178.1
		2019	150.0	200.2	83.0	727.0	169.0	5	236.8
10048228	LMC - North	2017	365.0	385.4	140.0	1120.0	490.0	3	419.1
		2018	248.0	194.2	41.0	548.0	353.5	5	194.6
		2019	228.0	202.8	105.0	436.0	187.0	5	120.4
10048229	Central	2017	435.0	450.2	214.0	980.0	383.0	3	321.9
		2018	199.0	171.0	44.0	313.0	202.0	5	99.2
		2019	204.0	202.1	179.0	219.0	17.0	5	14.1
10048230	LMC - South	2017	365.0	387.2	152.0	1046.0	477.0	3	381.3
		2018	488.0	274.0	54.0	816.0	589.5	5	280.9
		2019	199.0	183.4	68.0	517.0	189.0	5	161.0
10048231	Green Seams 7	2017	313.0	487.7	285.0	1300.0	507.5	3	472.0
		2018	308.0	201.6	89.0	345.0	237.0	5	112.4
		2019	185.0	157.9	69.0	276.0	101.0	5	73.0
10048232	Mequon 3	2017	206.0	235.2	205.0	308.0	51.5	3	48.3
		2018	201.0	174.8	91.0	291.0	153.0	5	71.2
		2019	218.0	182.4	86.0	387.0	106.0	5	104.7
10048233	County Line Road	2017	345.0	447.9	249.0	1046.0	398.5	3	355.3
		2018	326.0	313.0	206.0	461.0	215.0	5	97.9
		2019	270.0	234.8	104.0	649.0	188.0	5	195.8

Figure 8. *E. coli* concentration (CFU/100 mL) per year per water quality sampling station on the LMR stream system in Ozaukee County, WI. The red line indicates the Wisconsin State Recreational Use Standards adapted for *E. coli* at 400 CFU/100 mL.



Dissolved Oxygen

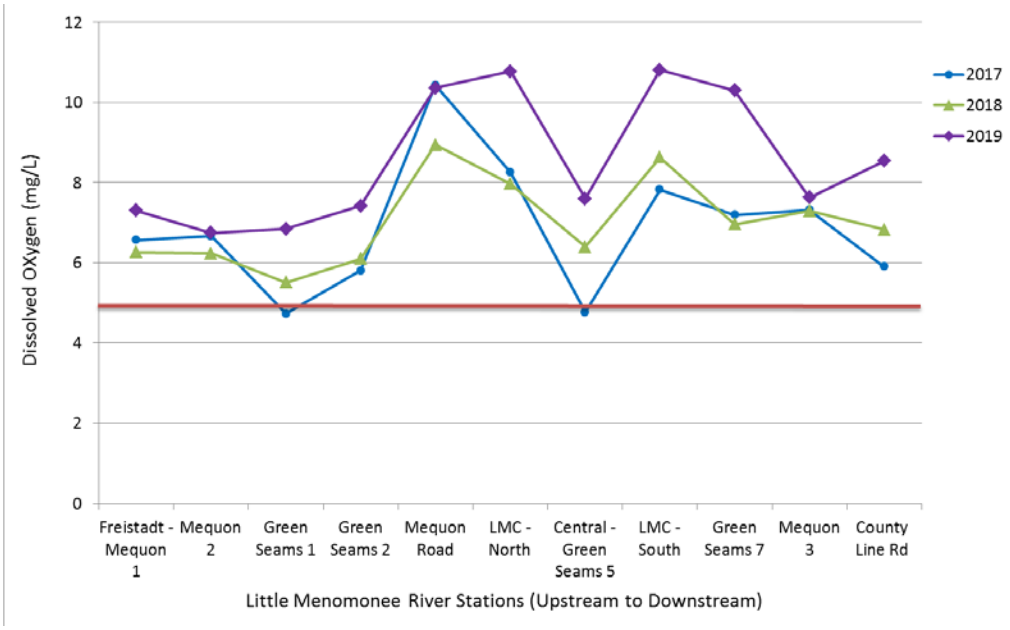
Dissolved oxygen concentration varies greatly with time of day and photosynthetic activity. WDNR Administrative Rule 102.04 (4a) states: "the dissolved oxygen content in many surface waters (including waters designated as a Warm Water Sport Fishery) may not be lowered to less than 5 mg/L at any time (WDNR 1973)" (Table 17).

Dissolved oxygen was measured at the time of discrete water sampling using a held-hand multi-parameter water quality instrument. In 2017 there were 2 stations with average dissolved oxygen concentrations that fell below the criteria of a Warm Water Sport Fishery (Green Seams 1 and Central), with mean concentrations of 4.73 and 4.76 mg/L respectively. There were no average concentrations at any stations that fell below 5 mg/L in 2018 or 2019 (Table 9, Figure 9).

Table 9. Dissolved oxygen concentration (mg/L) summary, measured at the time of discrete water sampling using a handheld instrument, from the 11 LMR water quality sampling stations in Ozaukee County, WI. Values in red indicate concentrations below the Warm Water Sport Fisheries standard of a minimum of 5 mg/L.

Station	Location	Year	Median	Mean	Min	Max	IQR	n	Std Dev
10048222	Freistadt, Mequon 1	2017	6.98	6.34	4.73	7.32	1.30	3	1.15
		2018	6.17	6.26	4.44	9.11	3.11	5	1.62
		2019	6.41	7.30	5.58	9.87	3.05	5	1.80
10048223	Mequon 2	2017	7.41	6.67	4.88	7.72	1.42	3	1.27
		2018	6.02	6.24	4.42	8.09	2.80	5	1.32
		2019	7.56	6.75	4.77	9.40	2.31	6	1.95
10048224	Green Seams 1	2017	4.75	4.73	3.62	5.81	1.10	3	0.89
		2018	4.95	5.51	3.72	9.23	3.63	5	1.99
		2019	7.22	6.85	4.06	9.60	3.27	5	2.29
10048225	Green Seams 2	2017	5.32	5.81	4.28	7.83	1.78	3	1.49
		2018	5.47	6.10	4.58	9.41	2.84	5	1.71
		2019	7.77	7.42	4.99	9.50	3.49	5	2.03
10048226	Mequon Road	2017	8.31	10.27	5.27	17.23	5.98	3	5.08
		2018	7.94	8.94	4.96	12.27	5.64	5	2.73
		2019	11.06	10.36	4.08	14.04	1.29	6	3.35
10048228	LMC - North	2017	8.03	8.25	6.50	10.22	1.86	3	1.53
		2018	7.43	7.96	5.57	11.17	3.78	5	1.91
		2019	9.99	10.77	8.11	14.37	2.40	5	2.43
10048229	Central	2017	5.16	4.76	3.88	5.25	0.69	3	0.63
		2018	4.29	6.40	3.56	10.47	6.23	5	2.99
		2019	7.00	7.60	4.06	11.22	2.31	5	2.64
10048230	LMC - South	2017	7.20	7.82	6.47	9.79	1.66	3	1.42
		2018	8.90	8.63	6.62	11.11	3.51	5	1.66
		2019	10.74	10.80	8.15	14.11	3.16	5	2.41
10048231	Green Seams 7	2017	7.30	7.19	5.10	9.18	2.04	3	1.67
		2018	6.83	6.96	4.08	10.53	3.46	5	2.06
		2019	10.52	10.30	6.97	14.07	1.68	5	2.60
10048232	Mequon 3	2017	5.85	6.49	5.17	8.44	1.64	3	1.41
		2018	6.67	7.30	5.48	10.36	2.99	5	1.88
		2019	7.59	7.62	4.22	10.89	2.92	5	2.58
10048233	County Line Road	2017	5.62	5.91	4.22	7.88	0.18	3	1.51
		2018	6.80	6.83	4.63	9.34	2.48	5	1.50
		2019	8.00	8.54	7.19	10.32	2.04	5	1.36

Figure 9. Dissolved oxygen concentration (mg/L) per year per water quality sampling station on the LMR stream system in Ozaukee County, WI. The red line indicates the minimum dissolved oxygen concentration for classification as a Warm Water Sport Fisheries.



Conductivity

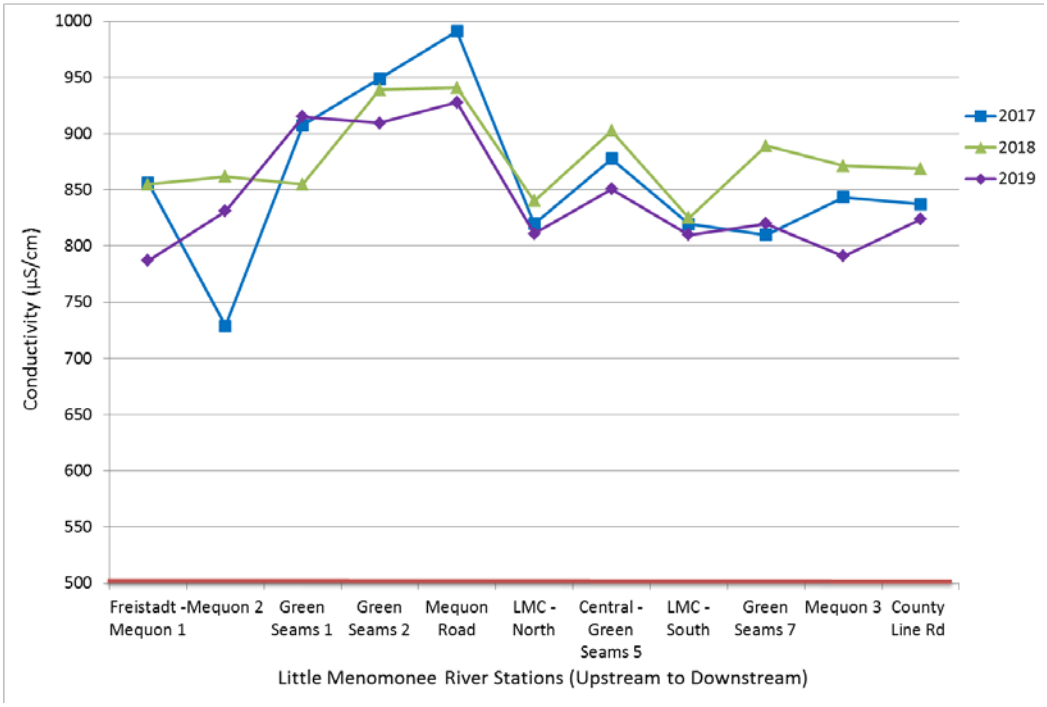
Conductivity in streams is naturally affected by geology is influenced by the bedrock, soils, and ground water passing through. It can also be affected by discharges to streams such as chlorides, heavy metals, sewage, and nutrients (phosphates and nitrates). A conductivity reading of 150-500 µS/cm can provide for a healthy aquatic ecosystem and conductivity outside of this range could indicate the waterbody is not suitable for certain aquatic species (USEPA 2012) (Table 17).

In all 3 study years, the average daily maximum and mean conductivity values were significantly above the maximum recommended by USEPA (2012). Very few average daily minimum values were closer to the maximum conductivity recommended by USEPA; the majority of the lowest values were above 500 µS/cm (Table 10, Figure 10). These high measurements require additional investigation, but may indicate high levels of nutrients or other pollutants entering the waterbody (Appendix B).

Table 10. Conductivity (µS/cm) summary, measured at the time of discrete water sampling using a handheld instrument, from the 11 LMR water quality sampling stations in Ozaukee County, WI. Values in red indicate means above 500 µS/cm.

Station	Location	Year	Median	Mean	Min	Max	IQR	n	Std Dev
10048222	Freistadt, Mequon 1	2017	868.0	856.7	829.0	873.0	22.0	3	9.7
		2018	852.0	855.0	840.0	888.0	29.5	5	17.3
		2019	801.0	787.1	633.0	882.0	37.2	7	77.4
10048223	Mequon 2	2017	859.0	729.0	462.0	866.0	202.0	3	188.8
		2018	867.0	861.8	839.0	885.0	33.0	5	16.1
		2019	830.0	830.8	804.0	863.0	25.5	6	21.9
10048224	Green Seams 1	2017	929.0	907.3	710.0	1083.0	186.5	3	153.0
		2018	924.0	855.0	540.0	1021.0	272.5	5	165.4
		2019	877.0	915.1	836.3	1117.0	34.3	6	101.9
10048225	Green Seams 2	2017	957.0	948.7	880.0	1009.0	64.5	3	53.0
		2018	934.0	938.8	878.0	1017.0	74.0	5	44.6
		2019	892.0	909.3	847.0	1033.0	31.0	6	64.7
10048226	Mequon Road	2017	966.0	956.0	890.0	1012.0	61.0	3	50.3
		2018	946.0	940.8	898.0	985.0	67.0	5	31.4
		2019	952.0	927.7	663.0	998.0	45.8	36	65.5
10048228	LMC - North	2017	825.0	819.7	809.0	825.0	8.0	3	7.5
		2018	823.0	840.2	804.0	914.0	74.0	5	40.0
		2019	814.0	811.0	778.8	836.0	28.8	6	21.8
10048229	Central	2017	839.0	877.7	805.0	999.0	92.0	3	79.9
		2018	897.0	902.6	795.0	993.0	127.0	5	65.7
		2019	864.0	850.6	651.0	987.0	69.5	6	112.6
10048230	LMC - South	2017	824.0	819.3	807.0	827.0	10.0	3	8.8
		2018	831.0	825.2	803.0	848.0	34.5	5	16.5
		2019	816.5	809.9	777.4	836.0	34.0	6	23.9
10048231	Green Seams 7	2017	824.0	810.0	779.0	827.0	24.0	3	22.0
		2018	881.0	889.0	864.0	934.0	47.0	5	24.8
		2019	823.0	819.2	778.0	850.0	28.3	6	25.8
10048232	Mequon 3	2017	816.0	823.3	785.0	869.0	42.0	3	34.7
		2018	872.0	871.2	864.0	876.0	8.0	5	4.1
		2019	852.0	790.8	592.0	872.0	63.7	5	118.8
10048233	County Line Road	2017	816.0	823.3	785.0	869.0	42.0	3	34.7
		2018	847.0	837.3	786.0	879.0	46.5	3	38.6
		2019	833.0	823.8	746.0	865.0	41.8	6	43.6

Figure 10. Conductivity (µS/cm) per year per water quality sampling station on the LMR stream system in Ozaukee County, WI. The red line indicates the maximum recommended conductivity per the USEPA.



pH

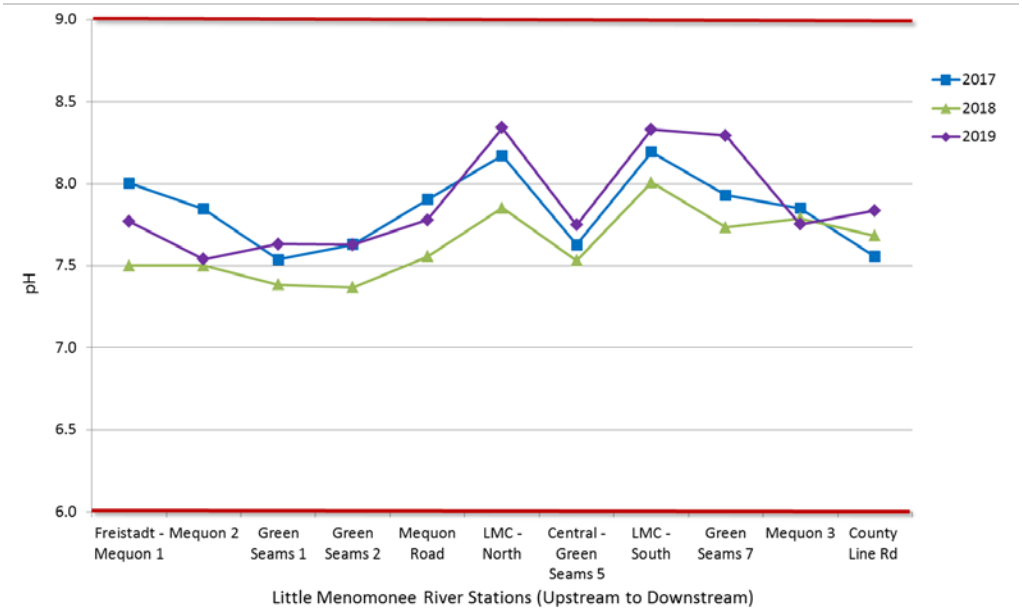
Most streams have a neutral to slightly basic pH, which is dependent upon abiotic factors such as the composition of the stream bed, water temperature, dissolved oxygen concentration, time of day, and weather activities. Wisconsin Administrative Rule 102.04(4) states that the pH shall be within the range 6.0 to 9.0, with no change greater than 0.5 units outside the estimated natural seasonal maximum and minimum (Table 17). A pH of 7.5 is considered ideal and values are generally higher during the summer months, when primary production is greatest.

All measured values were within the Wisconsin state criteria (6.0 - 9.0) set for maintaining aquatic life in a stream (Table 11, Figure 11).

Table 11. pH summary, measured at the time of discrete water sampling using a handheld instrument, from the 11LMR water quality sampling stations in Ozaukee County, WI.

Station	Location	Year	Median	Mean	Min	Max	IQR	n	Std Dev
10048222	Freistadt, Mequon 1	2017	7.82	7.76	7.63	7.83	0.10	3	0.09
		2018	7.60	7.50	7.15	7.60	0.25	5	0.18
		2019	7.56	7.77	7.49	8.23	0.14	6	0.25
10048223	Mequon 2	2017	7.93	7.85	7.64	7.97	0.17	3	0.15
		2018	7.53	7.50	7.20	7.69	0.31	5	0.17
		2019	7.76	7.54	7.22	7.74	0.16	6	0.18
10048224	Green Seams 1	2017	7.50	7.54	7.47	7.64	0.09	3	0.07
		2018	7.41	7.38	7.13	7.50	0.23	5	0.13
		2019	7.50	7.63	7.38	8.21	0.32	6	0.32
10048225	Green Seams 2	2017	7.65	7.63	7.35	7.89	0.27	3	0.22
		2018	7.40	7.37	7.12	7.55	0.33	5	0.16
		2019	7.57	7.63	7.36	8.14	0.19	6	0.28
10048226	Mequon Road	2017	7.81	7.84	7.44	8.26	0.41	3	0.34
		2018	7.76	7.56	7.10	7.82	0.60	5	0.29
		2019	7.78	7.78	7.14	8.31	0.27	36	0.23
10048228	LMC - North	2017	8.19	8.17	8.12	8.20	0.04	3	0.04
		2018	7.98	7.85	7.28	8.28	0.62	5	0.33
		2019	8.27	8.34	8.13	8.64	0.37	6	0.23
10048229	Central	2017	7.50	7.63	7.47	7.91	0.22	3	0.20
		2018	7.51	7.53	7.15	7.97	0.43	5	0.26
		2019	7.65	7.75	7.46	8.29	0.29	6	0.30
10048230	LMC - South	2017	8.22	8.19	8.13	8.23	0.05	3	0.04
		2018	8.00	8.01	7.77	8.28	0.27	5	0.16
		2019	8.27	8.33	8.14	8.64	0.31	6	0.21
10048231	Green Seams 7	2017	8.17	7.93	7.38	8.24	0.43	3	0.39
		2018	7.75	7.73	7.44	7.91	0.35	5	0.17
		2019	8.28	8.29	8.14	8.50	0.23	6	0.15
10048232	Mequon 3	2017	7.72	7.83	7.69	8.07	0.19	3	0.21
		2018	7.83	7.79	7.47	8.02	0.34	5	0.18
		2019	7.83	7.75	7.32	7.95	0.06	5	0.25
10048233	County Line Road	2017	7.65	7.56	7.33	7.69	0.18	3	0.16
		2018	7.68	7.68	7.45	8.07	0.43	5	0.22
		2019	7.80	7.84	7.78	8.02	0.05	6	0.09

Figure 11. pH values per year per water quality sampling station on the LMR stream system in Ozaukee County, WI. Red lines indicated the minimum and maximum set State criteria for pH values.



Salinity

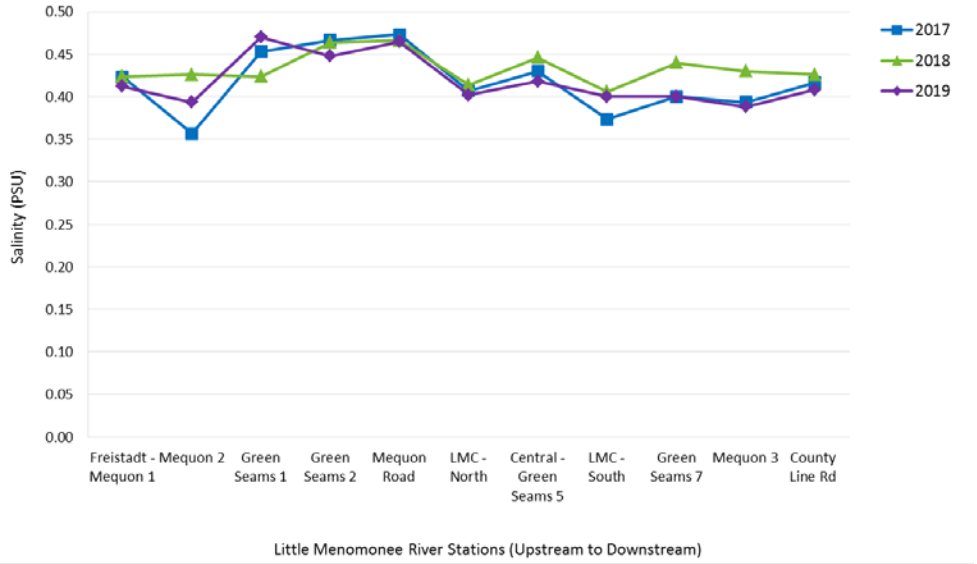
Salinity, the measure of ionic concentrations of soluble salts, fluctuates seasonally due to distribution of deicing road salt and precipitation. There are no Wisconsin-specific set criteria for ideal salinity concentration; however, USEPA states the average salinity of freshwater is freshwater is 0.5 PSU, with 0-1 PSU the acceptable range for freshwater (Ohrel and Register 2006, USEPA 2020).

Mean salinity concentration has been consistent across LMR study locations and between years, with means between 0.36 and 0.47 PSU which is below the USEPA average.

Table 12. Salinity concentration (PSU) summary, measured at the time of discrete water sampling using a handheld instrument, from the 11 LMR water quality sampling stations in Ozaukee County, WI.

Station	Location	Year	Median	Mean	Min	Max	IQR	n	Std Dev
10048222	Freistadt, Mequon 1	2017	0.43	0.42	0.41	0.43	0.01	3	0.01
		2018	0.42	0.42	0.42	0.44	0.01	5	0.01
		2019	0.40	0.41	0.40	0.43	0.01	5	0.02
10048223	Mequon 2	2017	0.42	0.36	0.22	0.43	0.11	3	0.10
		2018	0.43	0.43	0.41	0.44	0.02	5	0.01
		2019	0.40	0.39	0.31	0.44	0.03	6	0.04
10048224	Green Seams 1	2017	0.46	0.45	0.36	0.54	0.09	3	0.07
		2018	0.46	0.42	0.26	0.51	0.14	5	0.09
		2019	0.45	0.47	0.43	0.56	0.04	4	0.06
10048225	Green Seams 2	2017	0.47	0.47	0.43	0.50	0.04	3	0.03
		2018	0.46	0.46	0.43	0.50	0.04	5	0.02
		2019	0.45	0.45	0.40	0.51	0.02	5	0.04
10048226	Mequon Road	2017	0.48	0.47	0.44	0.50	0.03	3	0.02
		2018	0.47	0.47	0.44	0.49	0.04	5	0.02
		2019	0.50	0.46	0.32	0.50	0.10	33	0.05
10048228	LMC - North	2017	0.41	0.41	0.40	0.41	0.00	3	0.00
		2018	0.40	0.41	0.40	0.45	0.04	5	0.02
		2019	0.40	0.40	0.39	0.41	0.01	5	0.01
10048229	Central	2017	0.41	0.43	0.39	0.49	0.05	3	0.04
		2018	0.44	0.45	0.39	0.49	0.07	5	0.03
		2019	0.43	0.42	0.32	0.49	0.05	5	0.06
10048230	LMC - South	2017	0.41	0.37	0.30	0.41	0.06	3	0.05
		2018	0.41	0.41	0.39	0.42	0.02	5	0.01
		2019	0.40	0.40	0.38	0.41	0.01	5	0.01
10048231	Green Seams 7	2017	0.41	0.40	0.38	0.41	0.02	3	0.01
		2018	0.44	0.44	0.43	0.46	0.02	5	0.01
		2019	0.40	0.40	0.38	0.41	0.01	5	0.01
10048232	Mequon 3	2017	0.39	0.39	0.36	0.43	0.04	3	0.03
		2018	0.43	0.43	0.43	0.43	0.00	5	0.00
		2019	0.41	0.39	0.29	0.43	0.05	5	0.06
10048233	County Line Road	2017	0.42	0.42	0.39	0.44	0.03	3	0.02
		2018	0.43	0.43	0.41	0.43	0.01	5	0.01
		2019	0.41	0.41	0.37	0.43	0.03	5	0.02

Figure 12. Salinity concentration (PSU) per year per water quality sampling station on the LMR stream system in Ozaukee County, WI.



Total Dissolved Solids

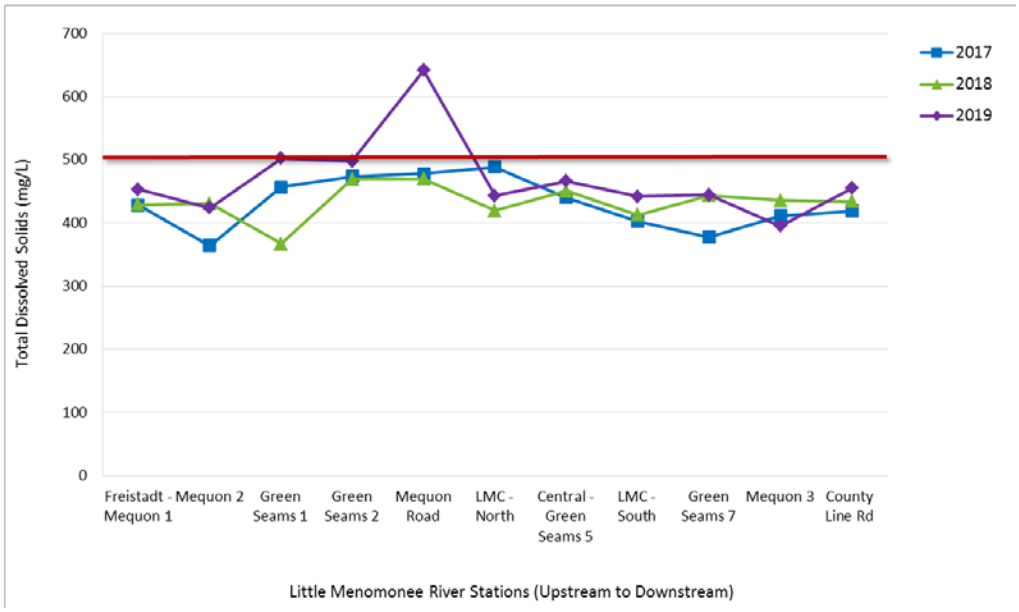
There is no State or Federal set standard for TDS concentration, but the National Secondary Drinking Water Regulations are a maximum value of 500 mg/L for aesthetic reasons (e.g. corrosion of plumbing, bad taste) (Table 17). Studies have found variable results on the effects of TDS on aquatic organisms, indicating that various combinations of ions are more toxic than others and organisms may be more sensitive at one life stage than another (Brix et al. 2010, Sorensen et al. 1977, Timpano et al. 2010).

Mean TDS concentrations only surpassed 500 mg/L at two sample locations, Green Seems 1 and Mequon Road, both in 2019 (Table 13, Figure 13). The Mequon Road sampling station is adjacent to agricultural fields and State Highway 167, which may have a negative impact on TDS levels. With the exception of the two high measurements, annual means at all other locations are fairly stable from upstream to downstream and between years, with values ranging from 364 to 498 mg/L.

Table 13. Total dissolved solids concentration (mg/L) , measured at the time of discrete water sampling using a handheld instrument, from the 11 LMR water quality sampling stations in Ozaukee County, WI. Values in red are above the 500 mg/L maximum set by the National Secondary Drinking Water Regulations.

Station	Location	Year	Median	Mean	Min	Max	IQR	n	Std Dev
10048222	Freistadt, Mequon 1	2017	434.0	428.0	414.0	436.0	11.0	3	9.9
		2018	426.0	429.0	421.0	445.0	13.5	5	8.3
		2019	415.0	453.4	408.0	598.0	39.0	5	81.4
10048223	Mequon 2	2017	430.0	364.0	229.0	433.0	102.0	3	95.5
		2018	433.0	430.8	420.0	442.0	16.5	5	7.9
		2019	421.0	423.8	318.0	566.0	22.0	6	81.0
10048224	Green Seams 1	2017	465.0	456.7	364.0	541.0	88.5	3	72.5
		2018	431.0	367.2	162.0	511.0	272.5	5	131.2
		2019	457.0	502.6	435.0	621.0	118.0	5	83.1
10048225	Green Seams 2	2017	478.0	474.0	440.0	504.0	32.0	3	26.3
		2018	467.0	469.6	439.0	508.0	36.5	5	22.1
		2019	458.0	498.2	439.0	628.0	66.0	5	78.4
10048226	Mequon Road	2017	483.0	478.0	445.0	506.0	30.5	3	25.2
		2018	473.0	470.2	449.0	492.0	33.0	5	15.5
		2019	675.5	642.0	331.0	700.0	21.0	34	84.4
10048228	LMC - North	2017	412.0	489.0	404.0	417.0	6.5	3	5.4
		2018	411.0	419.6	402.0	456.0	36.5	5	19.7
		2019	416.5	443.2	397.0	580.0	48.0	5	76.9
10048229	Central	2017	420.0	440.0	405.0	495.0	45.0	3	39.4
		2018	448.0	451.0	399.0	496.0	63.5	5	32.4
		2019	455.0	466.4	325.0	627.0	63.0	5	109.5
10048230	LMC - South	2017	412.0	402.7	383.0	413.0	15.0	3	13.9
		2018	416.0	412.6	401.0	424.0	17.5	5	8.4
		2019	414.0	442.0	391.0	579.0	10.0	5	77.3
10048231	Green Seams 7	2017	412.0	378.0	309.0	413.0	52.0	3	48.8
		2018	440.0	443.8	431.0	467.0	23.5	5	12.6
		2019	415.0	444.2	389.0	590.0	11.0	5	82.3
10048232	Mequon 3	2017	408.0	411.7	392.0	435.0	21.5	3	17.7
		2018	437.0	435.8	432.0	438.0	4.0	5	2.1
		2019	426.0	395.6	296.0	437.0	51.0	5	59.7
10048233	County Line Road	2017	426.0	419.0	393.0	441.0	24.0	3	19.8
		2018	439.0	433.8	417.0	440.0	14.0	5	8.7
		2019	433.0	455.0	378.0	610.0	16.0	5	89.6

Figure 13. Total dissolved solids concentration (mg/L) per year per water quality sampling station on the LMR stream system in Ozaukee County, WI. Values in red are above the 500 mg/L maximum set by the National Secondary Drinking Water Regulations.



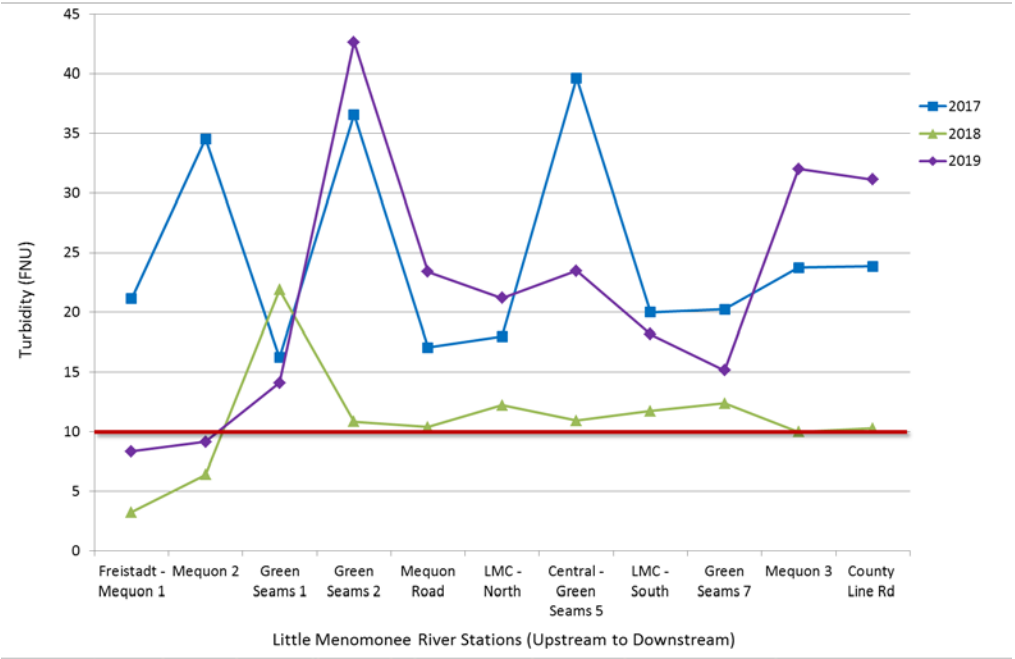
Turbidity

Per Milwaukee Riverkeeper (2016), the ideal turbidity readings for the Milwaukee River drainage basin is 10 FNU and below (Table 17). All LMR sampling locations exceeded this criterion in 2017, with average values ranging from 14.9 FNU at the furthest upstream (Freistadt Road) sampling station to 39.7 FNU at LMR Central. In 2018, eight of the 11 stations continued to have a mean turbidity measurement above 10 FNU, with the 2 most upstream locations averaging at 3.3 and 6.4 FNU, respectively, and the 2 furthest downstream stations at or just exceeding 10 FNU. The 2 upstream sampling locations again had the lowest mean values, below 10 FNU, in 2019, while the other 9 stations had values exceeding 10 FNU (Table 14, Figure 14).

Table 14. Turbidity (FNU) summary, measured at the time of discrete water sampling using a handheld instrument, from the 11 LMR water quality sampling stations in Ozaukee County, WI. Values in red indicate means above the maximum recommended turbidity value (10 FNU) for the study region.

Station	Location	Year	Median	Mean	Min	Max	IQR	n	Std Dev
10048222	Freistadt, Mequon 1	2017	16.0	14.9	12.5	16.3	1.9	3	1.7
		2018	3.1	3.3	1.5	6.0	2.8	5	1.5
		2019	8.6	8.3	2.4	15.2	3.4	4	5.4
10048223	Mequon 2	2017	22.3	34.5	21.3	60.0	19.4	3	18.0
		2018	2.3	6.4	2.1	22.5	10.6	5	8.1
		2019	7.9	9.1	1.2	18.1	5.2	5	6.1
10048224	Green Seams 1	2017	14.9	16.2	12.8	21.0	4.1	3	3.5
		2018	12.4	21.9	5.1	60.3	38.1	5	20.7
		2019	11.9	14.1	5.8	26.9	5.8	4	9.0
10048225	Green Seams 2	2017	32.1	36.6	24.7	53.0	14.2	3	12.0
		2018	8.9	10.8	4.5	17.8	12.2	5	5.6
		2019	44.4	42.6	6.7	75.0	56.1	4	35.1
10048226	Mequon Road	2017	22.0	19.2	10.4	25.1	7.4	3	6.3
		2018	7.8	10.4	4.7	251.1	11.8	5	6.1
		2019	25.6	23.4	15.3	27.1	3.3	4	5.4
10048228	LMC - North	2017	11.9	18.0	9.3	32.7	11.7	3	10.5
		2018	7.8	12.2	4.5	33.6	16.6	5	10.8
		2019	19.3	21.2	10.4	35.7	16.2	4	11.8
10048229	Central	2017	26.0	39.7	21.5	71.5	25.0	3	22.6
		2018	7.9	10.9	3.1	24.7	14.2	5	7.6
		2019	21.2	23.5	10.4	41.2	8.1	4	12.9
10048230	LMC - South	2017	21.0	20.0	9.1	21.8	10.4	3	8.5
		2018	5.6	11.7	3.4	36.6	18.1	5	12.5
		2019	9.8	18.2	5.3	47.8	15.7	4	20.1
10048231	Green Seams 7	2017	22.0	20.2	10.2	28.5	9.2	3	7.6
		2018	7.7	12.4	3.8	28.2	16.2	5	8.7
		2019	10.5	15.2	5.4	34.2	12.2	4	13.2
10048232	Mequon 3	2017	24.2	30.1	19.5	46.7	13.6	3	11.9
		2018	6.7	10.0	4.1	23.0	11.6	5	6.8
		2019	26.2	32.0	6.2	75.1	25.7	5	27.2
10048233	County Line Road	2017	23.7	23.9	15.2	32.7	8.8	3	7.1
		2018	8.1	10.3	4.1	23.4	10.3	5	6.7
		2019	31.5	31.1	21.5	40.1	7.1	4	7.7

Figure 14. Turbidity (FNU) measurements per year per water quality sampling station on the LMR stream system in Ozaukee County, WI. The red line indicates the maximum recommended turbidity value (10 FNU) for the study region.



Water Temperature

The WDNR Chapter NR102 Water Quality Standards for Wisconsin Surface Waters (WDNR 1973) sets a water temperature maximum for a Warm Water Sport Fishery (Milwaukee River) of 31.7°C (Table 17). Daily maximums were measured against this standard.

Water temperature was recorded at the time of each sampling event at all stations using a handheld instrument and was variable with season, water depth, riparian vegetation cover, and time of day. Mean temperatures ranges from 14.7 at Mequon 3 to 18.7 at Central in 2017; 16.8 at LMC South to 15.1 at the furthest downstream site, County Line Road in 2018; and, 14.5 at Mequon Road to 16.6 at both Freistadt Road/Mequon 1 and Central locations (Table 15, Figure 15). All average maximum values were below the criteria for a Warm Water Sport Fishery.

Table 15. Water temperature (°C) summary, measured at the time of discrete water sampling using a handheld instrument, discrete samples analyzed by SLOH from the 11 LMR water quality sampling stations in Ozaukee County, WI.

Station	Location	Year	Median	Mean	Min	Max	IQR	n	Std Dev
10048222	Freistadt, Mequon 1	2017	19.7	20.0	19.1	21.3	1.1	3	0.9
		2018	17.0	16.0	9.9	18.9	4.8	5	3.1
		2019	16.5	16.6	9.5	22.5	1.8	5	5.5
10048223	Mequon 2	2017	19.3	19.8	19.3	21.0	0.9	3	0.8
		2018	17.8	16.5	9.6	19.8	5.5	5	3.6
		2019	16.1	15.7	9.3	18.7	2.3	6	3.4
10048224	Green Seams 1	2017	19.8	19.6	18.3	20.6	1.2	3	1.0
		2018	17.9	16.8	10.3	20.1	5.2	5	3.4
		2019	16.6	16.1	9.7	19.4	1.9	6	3.4
10048225	Green Seams 2	2017	20.0	19.7	18.5	20.8	1.1	3	0.9
		2018	17.7	16.7	11.1	20.5	5.4	5	3.1
		2019	16.1	16.2	10.9	20.1	1.9	6	3.1
10048226	Mequon Road	2017	21.4	21.6	20.7	22.8	1.0	3	0.9
		2018	18.6	17.9	10.9	23.5	6.5	5	4.0
		2019	14.7	14.5	9.1	21.8	4.4	32	3.0
10048228	LMC - North	2017	20.4	19.7	17.9	20.9	1.5	3	1.3
		2018	18.5	16.8	9.8	19.4	6.0	5	3.6
		2019	16.6	16.2	10.1	19.4	1.6	6	3.3
10048229	Central	2017	20.7	20.7	18.7	22.6	1.9	3	1.6
		2018	17.9	16.7	9.4	20.4	6.5	5	3.8
		2019	16.9	16.6	9.5	21.3	1.3	6	3.9
10048230	LMC - South	2017	20.3	19.8	17.7	21.4	1.4	3	1.5
		2018	18.5	16.8	9.7	19.2	5.5	5	3.6
		2019	16.6	16.1	10.1	19.5	1.7	6	3.2
10048231	Green Seams 7	2017	20.0	19.6	17.4	21.5	2.1	3	1.7
		2018	17.0	16.3	9.5	19.7	6.0	5	3.6
		2019	16.1	16.0	10.1	19.5	1.6	6	3.2
10048232	Mequon 3	2017	15.8	14.7	10.1	18.2	4.0	3	3.4
		2018	16.2	15.6	9.5	18.7	5.3	5	3.2
		2019	17.5	16.1	9.8	19.9	3.4	5	4.0
10048233	County Line Road	2017	17.4	17.9	16.6	19.7	1.5	3	1.3
		2018	15.8	15.1	9.7	18.2	5.0	5	2.9
		2019	14.5	14.9	10.0	18.6	2.7	6	3.0

Figure 15. Water temperature (°C) measurements per year per water quality sampling station on the LMR stream system in Ozaukee County, WI.

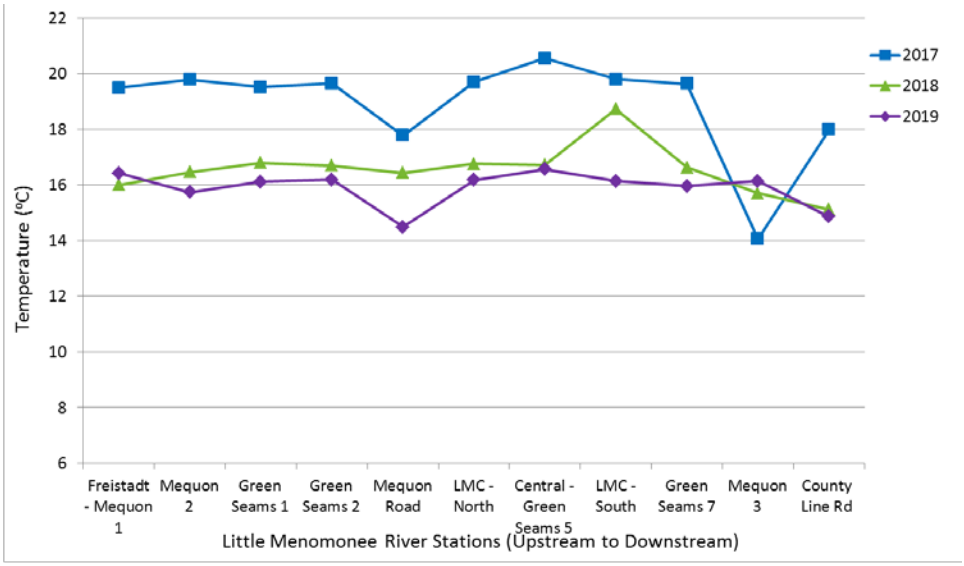


Table 17. Wisconsin State, Federal, and/or regional water quality criteria for streams.

Parameter	Criteria	Reference(s)	Note
Chloride	395 mg/L (chronic) 757 mg/L (acute)	WDNR 2019	
Conductivity	150 - 500 µS/cm	USEPA 2012	No criteria set by State or Federal; USEPA recommendation
Dissovled Oxygen	> 3 mg/L	NR 102.04(4) , 104.02(3)(a) Wis. Adm. Code	
E. coli	200 not to exceed 400 MPN/100 mL	WDNR & MMSD 2018	No state standard set for *E. coli*; value based on fecal coliform translator for TMDL
Orthophosphate	0.1 mg/L	USEPA 1986	No criteria set by State; implement Federal critera
pH	6.0 - 9.0	NR 102.04(4) , 104.02(3)(a) Wis. Adm. Code	
Phosphorus	0.075 mg/L	Section NR 102.06, Wis. Adm. Code; WDNR & MMSD 2018	
Temperature	31.7°C	Section NR 102.245 Wis. Adm. Code	
Total Suspended Solids (TSS)	12 mg/L	WDNR & MMSD 2018	No criteria set by State or Federal; implement TMDL criteria
Turbidity	10 NTU (FNU)	Milwaukee Riverkeeper 2018	TMDL

Continuous Data

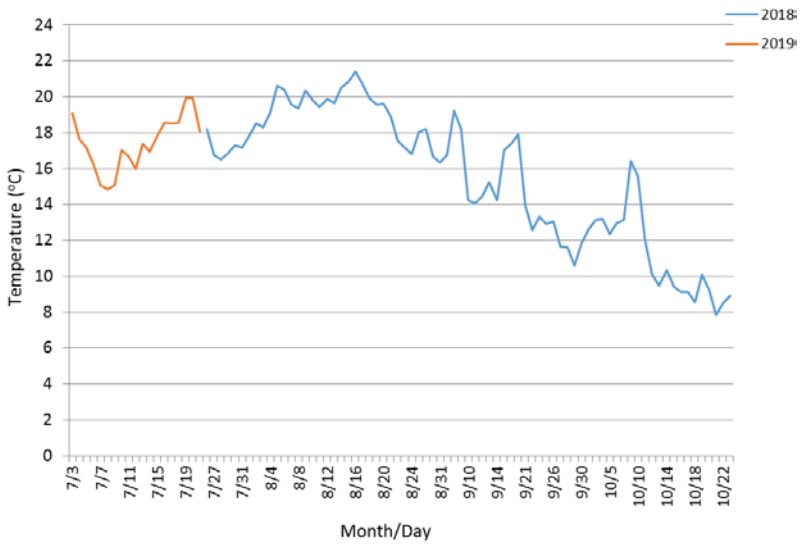
Eureka brand continuous water quality monitoring units were deployed, maintained, and collected data at a mid (Green Seams 3 at Mequon Road) and downstream (Mequon Property 3 at Lemke Park) station between the months of April and November in 2017, 2018, and 2019 (Table 3). A third monitoring station near the LMR headwaters at City of Mequon Property 1 at Freistadt Road was established and maintained during July through October in 2018 and 2019 (Table 3). Due to fluctuations in water level, velocity, battery supply, and tampering by aquatic animals, data from all probes may not have recorded continuously during the entire deployment of the monitoring unit, as seen below.

City of Mequon 1 at Freistadt Road

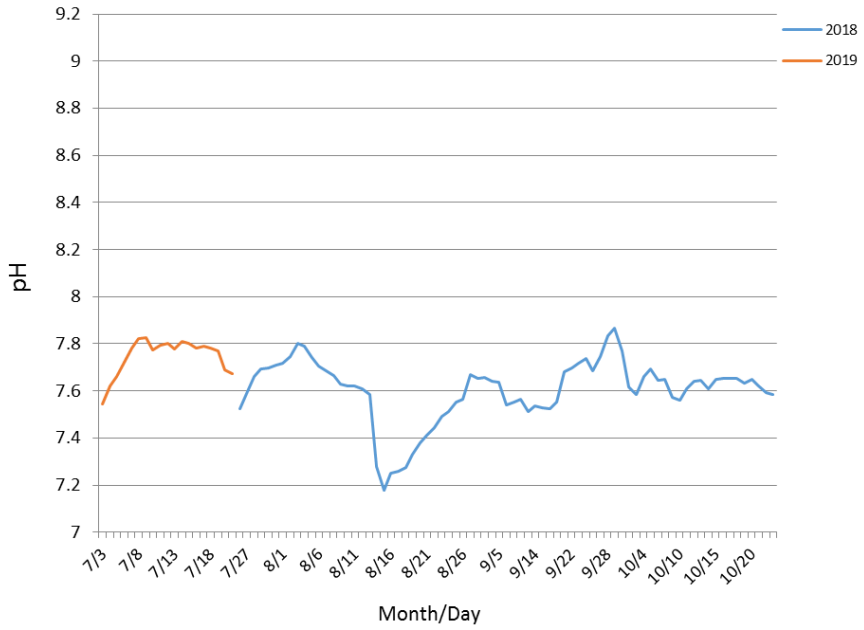
Continuous data was collected at the furthest upstream station at Freistdat Road during summer and early fall months in 2018 and 2019 (Figure 16). Dissolved oxygen data is only available from July 2019 due to a faulty probe (Figure 16d).

Figure 16. Measure parameters from the Eureka continuous monitoring unit deployed on the LMR at the furthest upstream sampling station at Freistadt Road, on the north end of the City of Mequon Property 1.

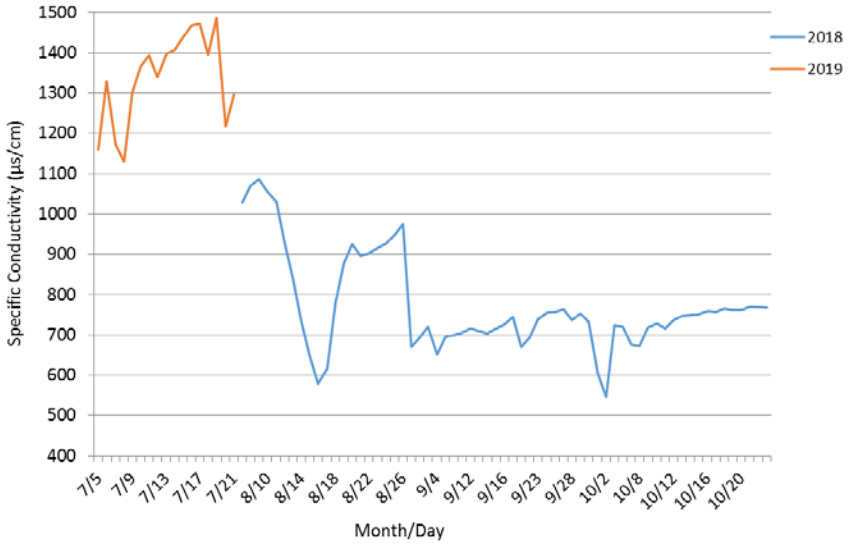
a.) Temperature (^{o}C)



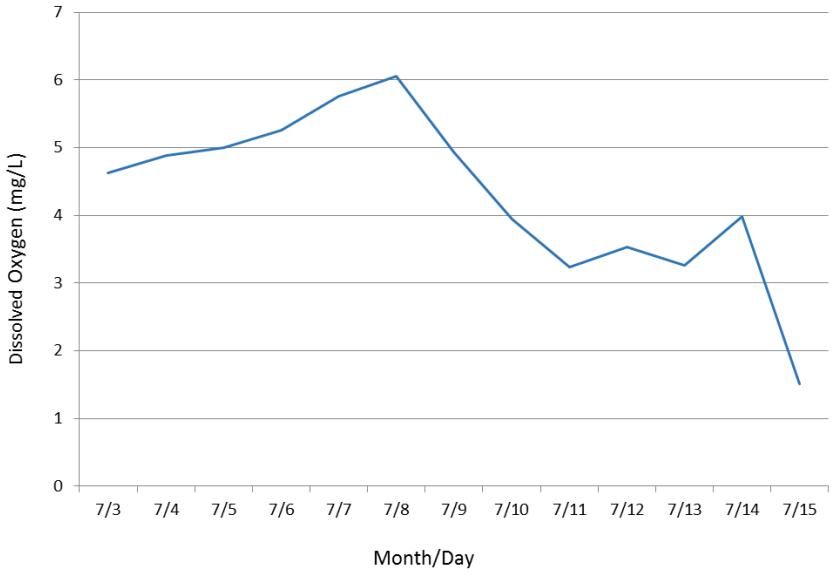
b.) pH



c.) Specific conductivity (µs/cm)



d.) Dissolved oxygen concentration (mg/L) and percent saturation from 2019 only.

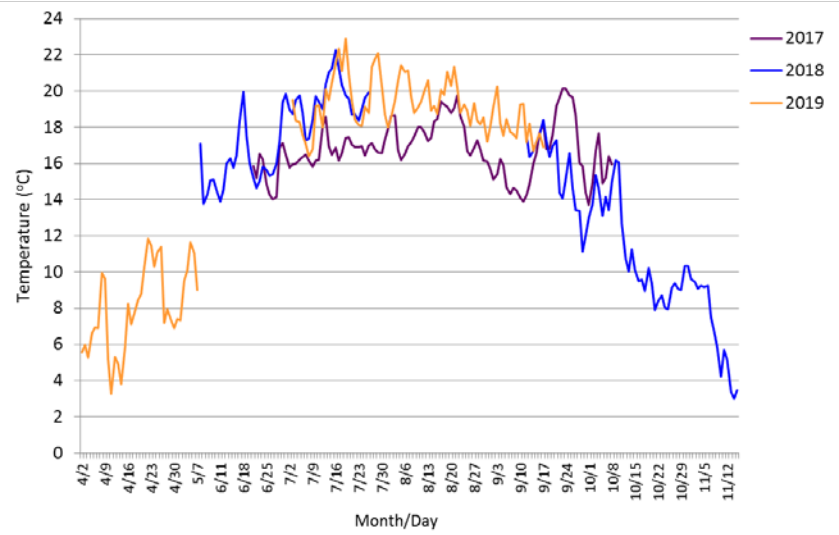


Green Seams 3 at Mequon Road

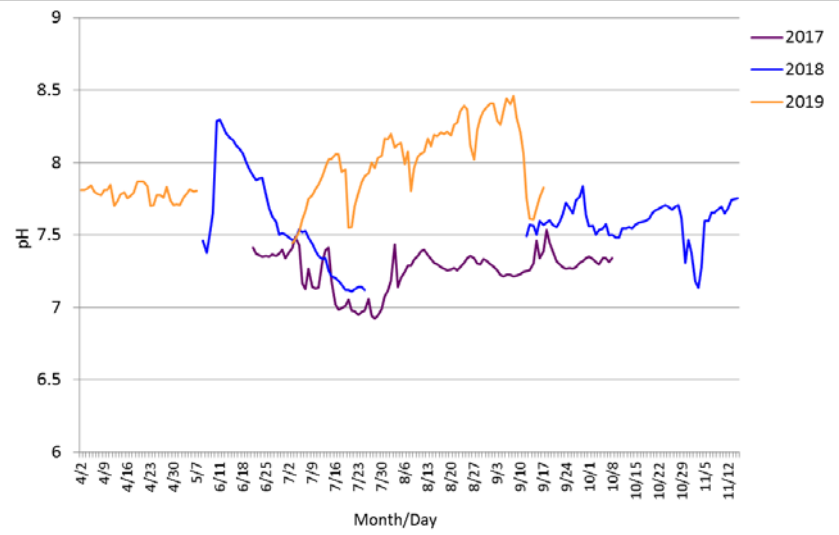
The continuous monitoring station located on the Green Seam 3 property was approximately mid-way between the 11 established discrete water quality sampling locations. Located upstream of the confluence with the Little Menomonee Creek, stormwater runoff from the surrounding agricultural fields and state highway may contribute to the fluctuations in specific conductivity seen within and between years (Figure 17).

Figure 17. Measure parameters from the Eureka continuous monitoring unit deployed on the LMR at the Green Seams 3 property at Mequon Road.

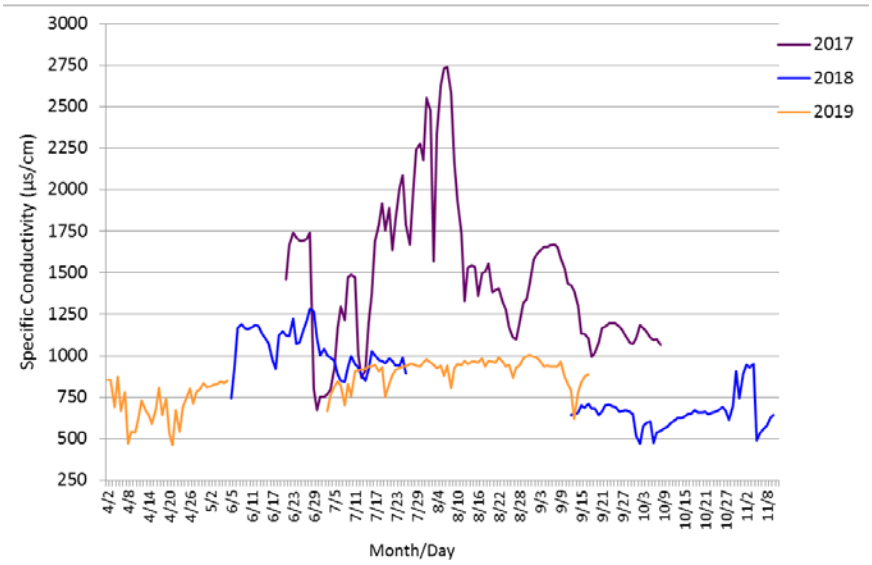
a.) Temperature (^{o}C)



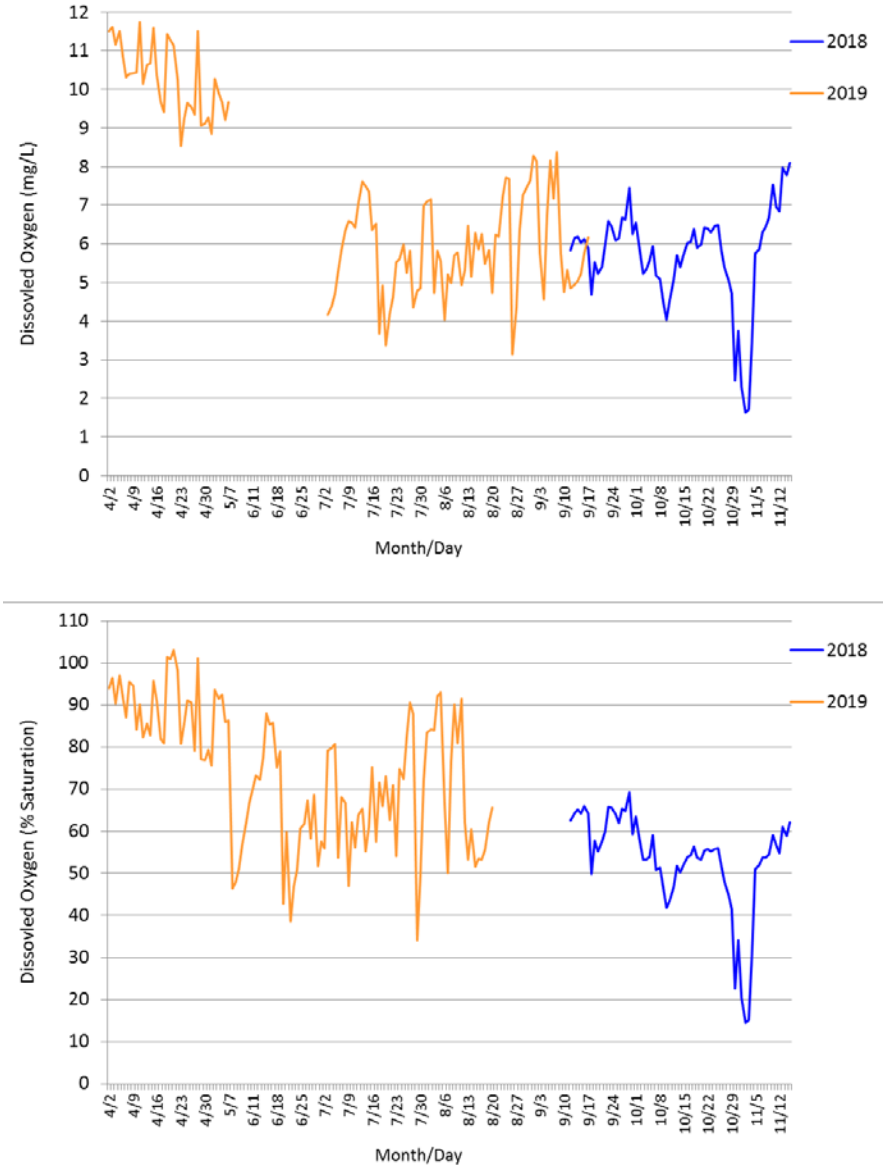
b.) pH



c.) Specific conductivity (µs/cm)



d.) Dissolved oxygen concentration (mg/L) and percent saturation, respectively.

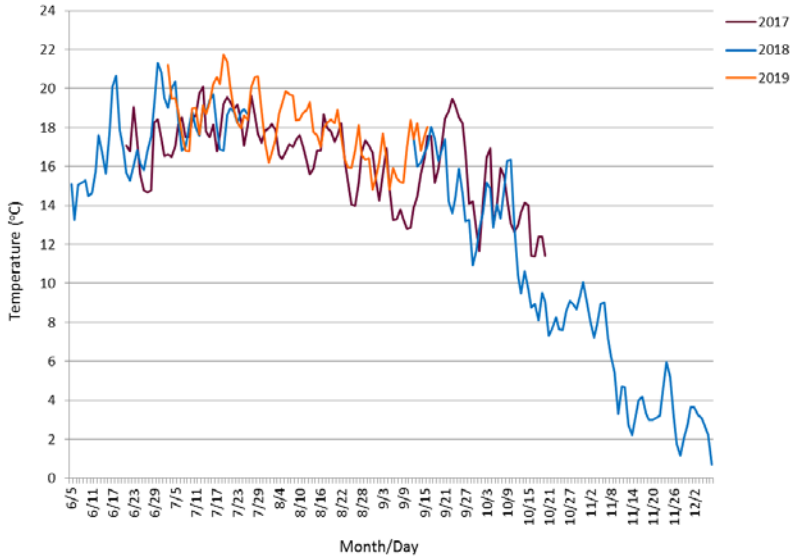


City of Mequon Property 3 (Lemke Park)

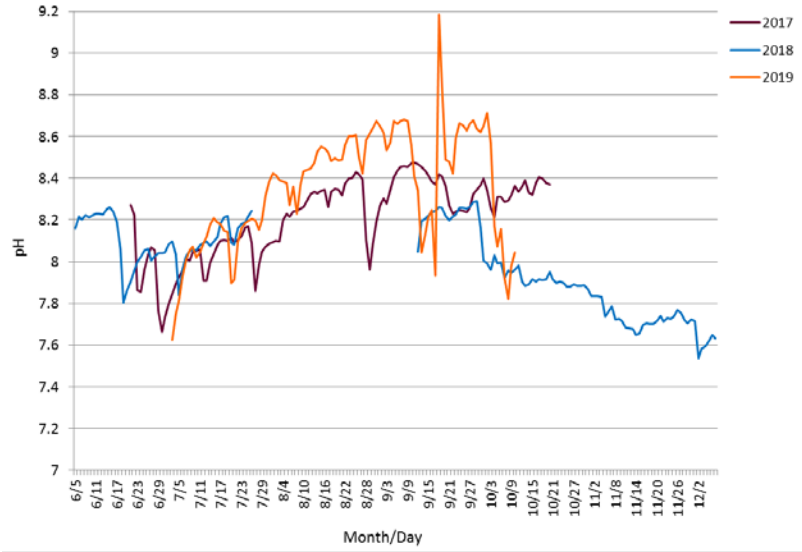
The furthest downstream continuous water quality station was located near a USGS real-time monitoring station measuring gauge height and discharge since 2004. The continuous monitoring unit was located downstream of the confluence with the Little Menomonee Creek. Recorded levels of dissolved oxygen were consistently high and fluctuated less than the recorded measurements at the Mequon Road or Friestadt Road station (Figure 18).

Figure 18. Measure parameters from the Eureka continuous monitoring unit deployed on the LMR at the City of Mequon Property 3 (Lemke Park), located south of Donges Bay Road.

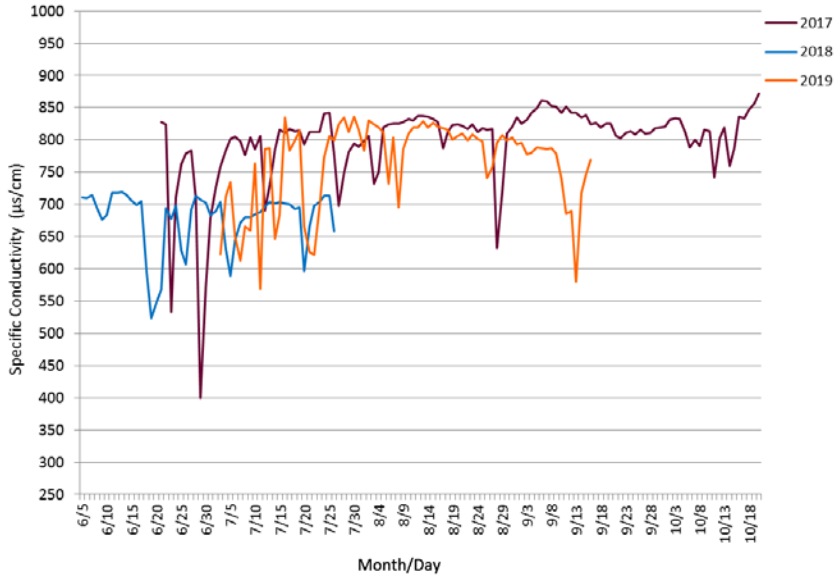
a.) Temperature (^{o}C)



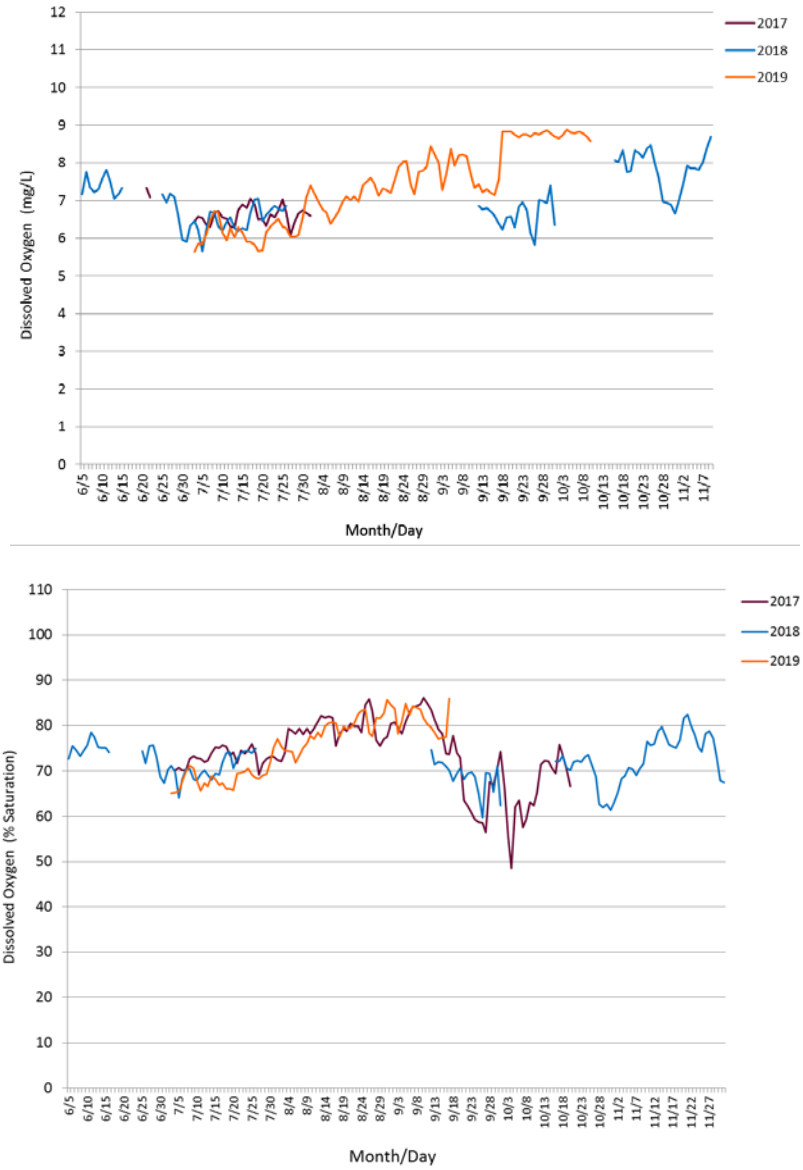
b.) pH



c.) Specific conductivity (µs/cm)



d.) Dissolved oxygen concentration (mg/L) and percent saturation, respectively.



Investigating dissolved oxygen levels recorded by the continuous monitoring units at the 3 locations on the LMR demonstrates the average concentration and percent saturation is the most stable at Mequon 3 (Figures 16-18). A number of factors may contribute to this finding including placement of the monitoring unit, riparian vegetation and shading, and stream gradient, which influences water velocity and consequently water temperature and turbidity.

Overall averages and standard deviations for each recorded parameter in the LMR system for each year are presented in Appendix A.

E. coli Analysis

Enteric bacteria, such as *E. coli*, is a useful metric when assessing the potential for enteric pathogens in streams. A bacterium belonging to the Enterobacteriaceae family, *E. coli* resides in the intestines of humans and other warm blooded animals. In general, E. coli counts are significantly higher when streams are sampled immediately following a significant (0.5") rain event than during base flow events, indicating fecal contamination is entering the system through storm water runoff. The state of Wisconsin has not yet adopted a standard for *E. coli*; instead it has criteria for fecal coliform as an indicator of fecal contamination (WDNR & MMSD 2018). The USEPA has established recommended minimum criteria for *E. coli* that suggest that the geometric mean of all samples should not exceed 126 colony forming units (CFU) per 100 mL and not more than 10 percent of samples to exceed 400 CFU/100 mL (USEPA 1986a).

Of the 11 discrete water quality sampling stations, 6 had a geometric mean of *E. coli* above 400 CFU/100 mL in 2017. Means were highest at locations Green Seams 1, 2, and Mequon Road (Table 19, Figure 8), which are primarily surrounded by agricultural fields. No geometric means above 400 CFU/100 mL were detected among the average 2018 and 2019 sample (Table 19, Figure 8). The current data does not suggest any obvious point source of *E. coli* in the LMR system.

Table 19. *E. coli* geometric mean (100 CFU/100 mL) of all discrete water quality sampling stations on the LMR stream system from 2017-2019. Values in red indicate results higher than the criterion set by WDNR and MMSD (2018) and USEPA. Stations are listed from furthest upstream to furthest downstream.

Site	Location	Year	Geometric Mean
10048222	Freistadt Mequon 1	2017	201.91
		2018	107.07
		2019	173.59
10048223	Mequon 2	2017	233.13
		2018	108.35
		2019	144.20
10048224	Green Seams 1	2017	868.86
		2018	260.55
		2019	324.64
10048225	Green Seams 2	2017	908.09
		2018	229.76
		2019	204.29
10048226	Mequon Road	2017	1027.69
		2018	256.88
		2019	200.17
10048228	LMC - North	2017	385.37
		2018	194.17
		2019	202.77
10048229	Central	2017	450.17
		2018	170.96
		2019	202.10
10048230	LMC - South	2017	387.16
		2018	273.98
		2019	183.43
10048231	Green Seams 7	2017	487.65
		2018	201.60
		2019	157.95
10048232	Mequon 3	2017	235.17
		2018	174.82
		2019	182.39
10048233	County Line Rd	2017	447.90
		2018	312.97
		2019	234.76

Closer investigation of monthly and geometric mean results only for July 2017 measurements reveal a potential correlation between water temperature and *E. coli* growth (Table 20). Measured values were generally highest with water temperatures above 18°C; however, many abiotic factors influence measured *E. coli* values including precipitation, wind velocity, and water velocity.

Table 20. Geometric mean of *E. coli* counts (CFU/100 mL) per sampling location per year as measured by the SLOH versus monthly average water temperature (°C) for the discrete water quality sampling stations on the LMR stream system. Values in red indicate a result above 400 CFU/100 mL suggested by WDNR and MMSD (2018) and USEPA.

	2017			
Location	July		September	
	E. coli	Water Temp	*E. coli*	Water Temp
Freistadt	202.5	20.5	219.0	19.0
Mequon 2	223.5	20.1	261.0	19.2
Green Seams 1	1121.0	20.2	613.0	18.2
Green Seams 2	732.5	20.1	1414.0	18.4
Mequon Rd.	976.5	21.7	1203.0	22.9
LMC - North	742.5	20.6	140.0	17.8
Central - Green Seams 5	597.0	21.5	435.0	18.6
LMC - South	705.5	20.7	152.0	17.6
Green Seams 7	806.5	20.8	285.0	17.3
Mequon 3	256.5	16.6	206.0	15.8
County Line	695.5	18.6	249.0	16.8
Geomean/Average	**558.0**	**20.1**	**344.3**	**18.3**

	2018									
Location	May		June		July		September		October	
	E. coli	Water Temp	*E. coli*	Water Temp	*E. coli*	Water Temp	*E. coli*	Water Temp	*E. coli*	Water Temp
Freistadt	38.0	17.0	155.0	17.4	248.0	18.9	112.0	16.8	86.0	9.9
Mequon 2	36.0	17.8	72.0	18.0	365.0	19.8	205.0	17.3	77.0	9.6
Green Seams 1	125.0	18.2	261.0	17.6	365.0	20.1	387.0	17.9		10.3
Green Seams 2	105.0	16.5	387.0	17.8	435.0	20.5	345.0	17.7	105.0	11.1
Mequon Rd.	196.0	15.4	194.0	17.1	613.0	23.5	387.0	18.6	124.0	10.9
LMC - North	144.0	19.4	344.0	18.5	548.0	19.2	248.0	16.9	41.0	9.8
Central - Green Seams 5	44.0	17.0	313.0	19.0	199.0	20.4	308.0	17.9	173.0	9.4
LMC - South	131.0	19.4	488.0	18.5	548.0	19.1	816.0	17.7	54.0	9.7
Green Seams 7	89.0	17.7	345.0	18.5	326.0	19.7	308.0	16.8	108.0	9.5
Mequon 3	91.0	15.5	201.0	16.8	291.0	18.7	236.0	16.2	130.0	9.5
County Line	236.0	15.3	461.0	16.7	206.0	18.2	326.0	15.8	411.0	9.7
Geomean/Average	**94.8**	**16.4**	**260.0**	**17.3**	**352.0**	**19.8**	**299.7**	**17.2**	**106.7**	**9.9**

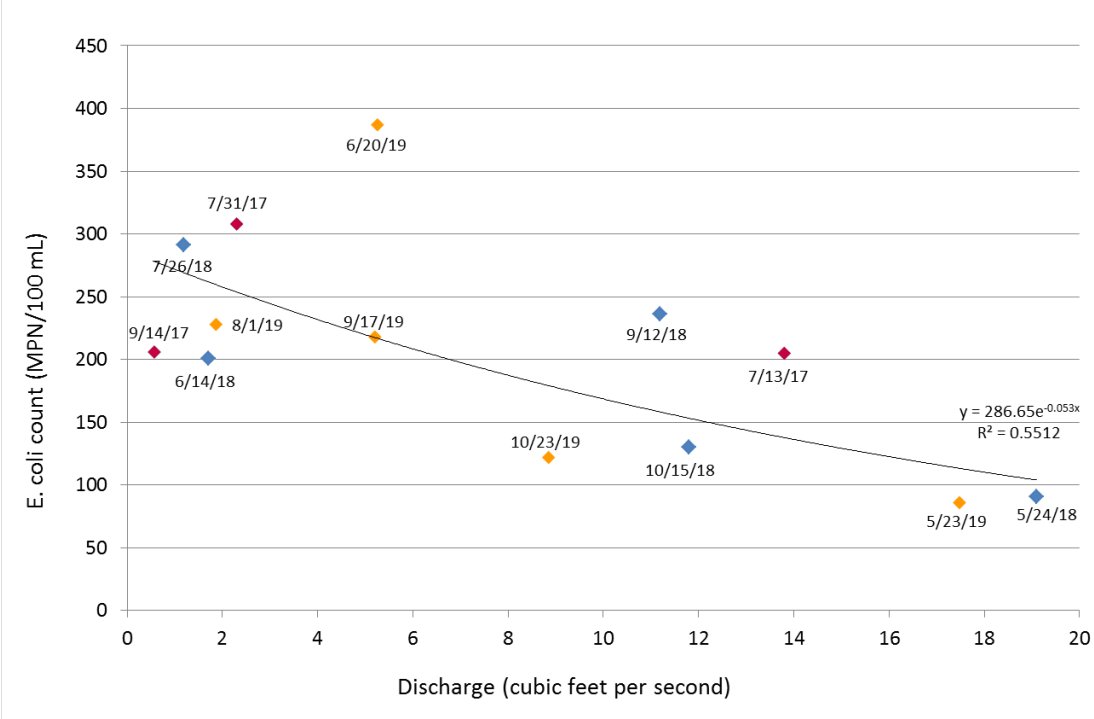
	2019									
Location	May		June		August		September		October	
	E. coli	Water Temp	*E. coli*	Water Temp	*E. coli*	Water Temp	*E. coli*	Water Temp	*E. coli*	Water Temp
Freistadt	77.0	16.3	65.0	16.5	970.0	17.5	411.0	18.7	79.0	9.5
Mequon 2	49.0	15.8	63.0	16.3	816.0	18.7	272.0	18.6	91.0	9.3
Green Seams 1	119.0	16.6	248.0	15.9	850.0	19.4	866.0	18.4	166.0	9.7
Green Seams 2	125.0	15.9	238.0	16.1	291.0	20.1	548.0	18.3	75.0	10.9
Mequon Rd.	122.0	12.3	291.0	14.6	150.0	21.8	727.0	19.9	83.0	11.1
LMC - North	105.0	16.6	276.0	16.2	436.0	19.4	228.0	18.3	119.0	10.0
Central - Green Seams 5	179.0	16.7	204.0	17.0	214.0	21.3	197.0	18.2	219.0	9.5
LMC - South	68.0	16.6	291.0	16.0	517.0	19.5	199.0	18.2	102.0	10.1
Green Seams 7	69.0	16.1	225.0	15.9	276.0	19.5	185.0	18.1	124.0	10.1
Mequon 3	86.0		387.0	15.1	228.0	18.5	218.0	17.5	122.0	9.8
County Line	125.0	14.1	649.0	15.0	313.0	18.6	270.0	17.4	104.0	10.0
Geomean/Average	**96.1**	**14.7**	**222.2**	**15.1**	**385.4**	**19.5**	**321.2**	**18.3**	**110.9**	**10.0**

Utilizing the permanent USGS discharge gage station located near the sampling station number 10048232 (Mequon 3) allowed for comparison of mean *E. coli* concentrations on a given sampling date and discharge (Table 19). *E. coli* exhibit an exponential growth rate, with fastest growth occurring between 25° and 30°C. Additionally, bacterial growth is directly proportional to algal growth in freshwater environments (Byappanahalli et al. 2003, Nyguyen 2006). In the Little Menomonee system, *E coli* counts decrease with increasing stream discharge. Counts are highest during periods of low discharge (Table 19), with the highest values occurring at the end of June and end of July all three years (Figure 20). Water temperatures are generally highest July through September in Ozaukee County streams (Table 20). Fitting an exponential regression model to the data results in an R^2 value of 0.55, however additional data is needed to establish an adequate baseline (Figure 20).

Table 19. Daily discharge statistics for the USGS gauge located at Lemke Park on the LMR, Ozaukee County.

Sampling Event Date	Discharge (cubic feet per second)			
	Min	Max	Median	Mean
7/13/2017	10.00	17.70	13.80	13.67
7/31/2017	2.08	2.46	2.30	2.29
9/14/2017	0.51	0.61	0.58	0.57
5/24/2018	17.90	20.50	19.10	19.18
6/14/2018	1.40	1.94	1.71	1.70
7/26/2018	1.02	1.34	1.19	1.18
9/12/2018	9.00	11.40	11.20	10.93
10/15/2018	1.20	12.20	11.80	1.75
5/23/2019	14.70	19.80	17.80	17.48
6/20/2019	4.38	5.60	5.47	5.26
8/1/2019	1.64	2.07	1.90	1.87
9/17/2019	4.65	5.60	5.30	5.20
10/23/2019	8.21	9.45	8.88	8.85

Figure 20. Comparison of *E. coli* results (geometric mean of all sites) and discharge per data from the USGS gauge site stationed at Lemke Park near the Mequon 3 water quality sampling station.



Section 2: Mole Creek Results

Measured values from the discrete sampling events occurring from September 2016 to October 2019 on Mole Creek were summarized for each location and parameter. A total of 18 sampling events occurred at each of the 6 stations on Mole Creek: 4 in 2016, 6 in 2017, 4 in 2018, and 4 in 2019 (Figure 4, Tables 1-2). Twenty-two parameters were assessed during each sampling event at every station, 5 of which were analyzed by the SLOH. The SLOH has a limit of detection and limit of quantitation for the parameters analyzed in the laboratory (Table 4). Results that were reported as "ND" (none detected) indicated the concentration of a specific parameter was below the limit of detection. For results that are below the limit of quantitation, there is a lower degree of confidence in the precision of the reported result.

The mean, median, maximum, minimum, interquartile range (IQR, or the difference between the 75th and 25th percentiles), number of samples (n), and standard deviation were calculated for the focus parameters: chloride concentration, orthophosphate, total phosphorus, total suspended solids, *E. coli* dissolved oxygen concentration, pH, conductivity, salinity, TDS, turbidity, and water temperature.

Chloride

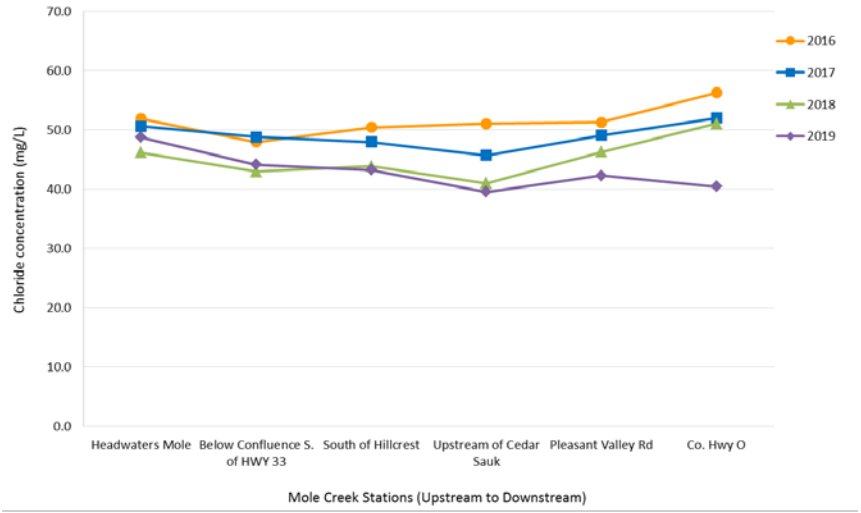
The WDNR (2019) has set the target concentration of chloride in Wisconsin's aquatic systems as less than 395 mg/L for chronic exposure and 757 mg/L for acute exposure (Table 17).

All water samples taken at the 6 Mole Creek stations from 2016 to 2019 had average chloride concentrations below 395 mg/L (Table 20, Figure 21).

Table 20. Chloride concentration (mg/L) summary from discrete samples analyzed by SLOH from the 6 water quality sampling stations on Mole Creek in Ozaukee County, WI.

Station	Location	Year	Median	Mean	Min	Max	IQR	n	Std Dev
10047105	Headwaters	2016	51.4	52.0	47.9	57.1	2.45	4	3.8
		2017	54.0	50.6	38.8	60.8	17.1	6	8.5
		2018	45.5	46.2	43.9	49.9	3.1	4	2.2
		2019	43.7	48.8	42.0	65.8	6.0	4	11.4
10046984	Below Confluence S. of Hwy 33	2016	47.4	48.0	43.6	53.7	2.9	4	4.2
		2017	48.6	45.8	35.2	53.7	14.7	6	7.3
		2018	41.4	43.0	39.6	49.7	5.8	4	4.6
		2019	39.1	44.2	38.1	60.5	7.0	4	10.9
10046985	South of Hillcrest	2016	50.7	50.5	45.7	54.8	3.3	4	3.8
		2017	49.9	48.0	38.7	55.7	16.2	6	7.4
		2018	43.0	43.9	41.4	48.3	5.0	4	2.8
		2019	40.1	43.3	38.7	54.3	5.3	4	7.4
10016375	Upstream of Cedar Sauk	2016	47.7	48.4	43.1	54.9	8.1	4	5.6
		2017	47.8	45.7	37.1	53.1	14.4	6	6.7
		2018	40.2	41.1	39.0	44.9	3.5	4	2.3
		2019	37.1	39.6	35.9	48.3	3.9	4	5.9
10008815	Pleasant Valley Rd	2016	51.0	51.3	45.9	57.3	8.0	4	5.4
		2017	49.1	49.1	44.1	54.9	8.3	6	4.0
		2018	43.4	46.3	42.9	55.6	6.4	4	5.4
		2019	41.0	42.3	36.4	50.8	4.2	4	6.1
10008816	County Hwy O	2016	56.6	56.3	49.8	62.2	8.4	4	5.8
		2017	50.8	52.0	47.1	59.2	8.0	6	4.3
		2018	48.0	51.1	44.3	64.1	10.0	4	7.7
		2019	44.5	40.5	17.9	55.6	7.6	4	14.0

Figure 21. Chloride concentration (mg/L) per year per Mole Creek water quality sampling station in Ozaukee County, WI.



Total Phosphorus and Orthophosphate (Dissolved Reactive Phosphorus)

Phosphorus was analyzed in samples as total phosphorus and total reactive phosphorus, also called orthophosphate. Phosphorus concentrations can fluctuate annually due to the number and severity of rain events and soil-disturbing activities occurring both upstream and near a sampling station. The Wisconsin water quality standard, established under NR102 (2019), for desirable phosphorus concentration in a stream environment is less than 0.075 mg/L (Table 17).

In 2016, the mean concentration of phosphorous in the water samples collected at the 6 Mole Creek stations did not exceeded 0.075 mg/L. All stations exhibited an increase in mean phosphorous concentrations in 2017, with 3 stations having an average value above the 0.075 mg/L standard. Mean values decrease at all stations except Pleasant Valley Road (10008815) in 2018, where the mean increase to 0.076 mg/L. In 2019, 2 of the 6 sampling locations had average phosphorus concentrations above 0.075 mg/L (Below Confluence and Upstream of Cedar Sauk) (Table 21a, Figure 22a).

As no Wisconsin state standard exists for orthophosphate, the WDNR utilizes the federal water quality standard of a maximum level of 0.1 mg/L (USEPA 1986) (Table 17). All average values per sampling location per year had concentrations of orthophosphate below the USEPA recommendation (Table 21b, Figure 22b). Reviewing the individual measurements confirms 10 of the 216 collected water samples (4.6%) had orthophosphate values above 0.1 mg/L: 4 samples in 2017, and 3 samples in both 2018 and 2019. Of the 10 samples exceeding the federal water quality standard, two locations (County Hwy O and Upstream of Cedar Sauk) had water samples with orthophosphate concentrations above 0.1 mg/L in the 2017, 2018, and 2019 sampling years.

Table 21. Total phosphorus and orthophosphate concentrations (mg/L) summary from discrete samples analyzed by SLOH from the 6 water quality sampling stations on Mole Creek in Ozaukee County, WI. Values in red indicate a measure concentration above the desirable phosphorus concentration of 0.075 mg/L in Wisconsin streams.

a.) Total phosphorus

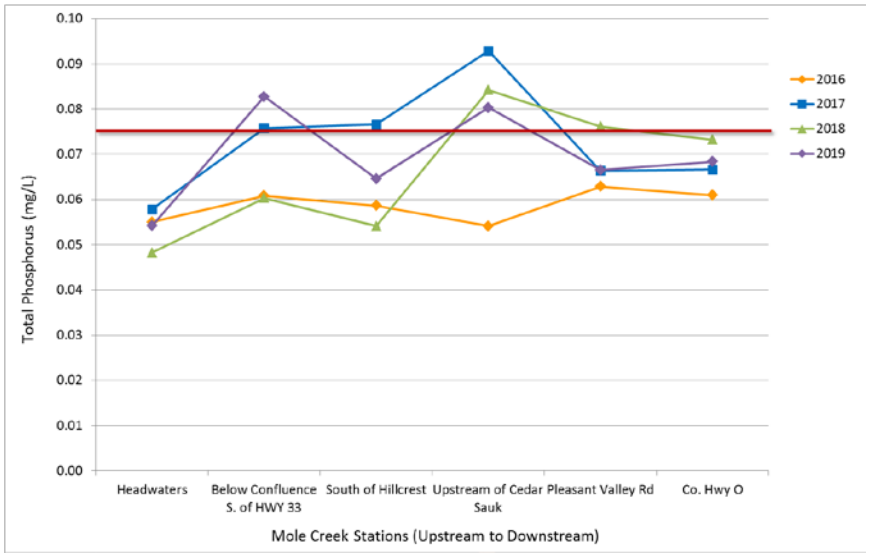
Station	Location	Year	Median	Mean	Min	Max	IQR	n	Std Dev
10047105	Headwaters	2016	0.053	0.055	0.050	0.063	0.007	4*	0.007
		2017	0.059	0.058	0.044	0.070	0.016	6	0.009
		2018	0.045	0.048	0.027	0.016	0.031	4	0.018
		2019	0.055	0.054	0.042	0.065	0.017	4	0.011
10046984	Below Confluence S. of Hwy 33	2016	0.059	0.061	0.050	0.076	0.010	4	0.011
		2017	0.069	0.076	0.060	0.117	0.012	6	0.019
		2018	0.055	0.060	0.034	0.098	.0.395	4	0.024
		2019	0.081	0.083	0.080	0.090	0.004	4	0.005
10046985	South of Hillcrest	2016	0.054	0.059	0.044	0.082	0.020	4	0.017
		2017	0.070	0.077	0.053	0.129	0.023	6	0.026
		2018	0.053	0.054	0.036	0.075	0.023	4	0.014
		2019	0.064	0.065	0.049	0.082	0.010	4	0.014
10016375	Upstream of Cedar Sauk	2016	0.068	0.072	0.054	0.098	0.015	4	0.019
		2017	0.093	0.093	0.042	0.159	0.022	6	0.035
		2018	0.076	0.084	0.050	0.135	0.061	4	0.034
		2019	0.079	0.080	0.064	0.100	0.025	4	0.017
10008815	Pleasant Valley Rd	2016	0.060	0.063	0.039	0.092	0.013	4	0.022
		2017	0.071	0.066	0.034	0.091	0.013	6	0.017
		2018	0.084	0.076	0.033	0.104	0.051	4	0.029
		2019	0.057	0.067	0.045	0.107	0.025	4	0.028
10008816	County Hwy O	2016	0.057	0.061	0.034	0.096	0.016	4	0.026
		2017	0.064	0.067	0.029	0.104	0.019	6	0.022
		2018	0.077	0.073	0.025	0.115	0.058	4	0.033
		2019	0.053	0.068	0.048	0.120	0.025	4	0.035

b.) Orthophosphate

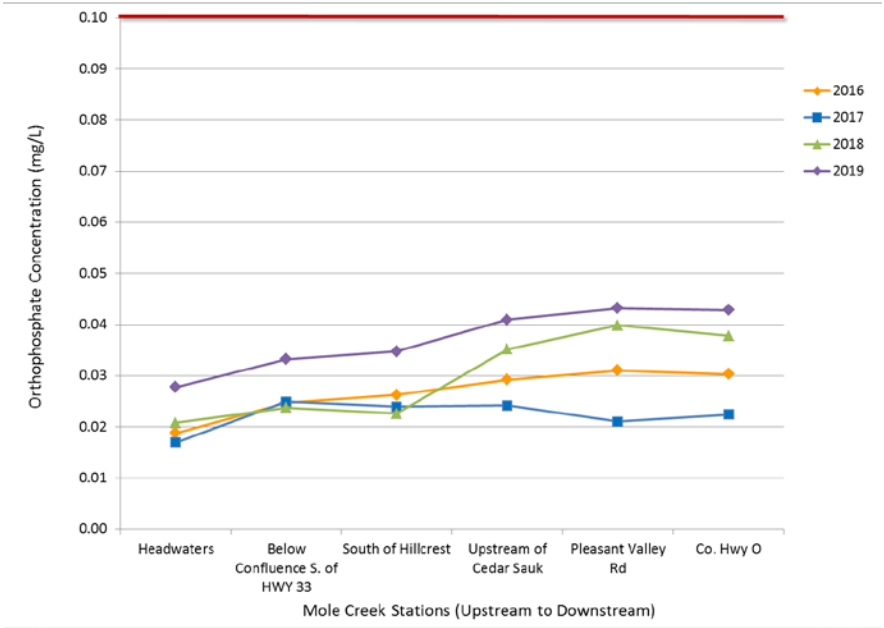
Station	Location	Year	Median	Mean	Min	Max	IQR	n	Std Dev
10047105	Headwaters	2016	0.02	0.019	0.01	0.025	0.0051	4	0.00633
		2017	0.018	0.017	0.013	0.019	0.002	6	0.002
		2018	0.019	0.021	0.010	0.036	0.017	4	0.010
		2019	0.027	0.028	0.012	0.046	0.010	4	0.014
10046984	Below Confluence S. of Hwy 33	2016	0.026	0.025	0.014	0.034	0.010	4	0.009
		2017	0.023	0.025	0.014	0.042	0.015	6	0.009
		2018	0.025	0.024	0.016	0.029	0.009	4	0.005
		2019	0.033	0.034	0.014	0.055	0.014	4	0.017
10046985	South of Hillcrest	2016	0.023	0.026	0.013	0.046	0.019	4	0.015
		2017	0.019	0.024	0.007	0.045	0.018	6	0.013
		2018	0.020	0.023	0.036	0.016	0.014	4	0.008
		2019	0.035	0.035	0.015	0.054	0.012	4	0.016
10016375	Upstream of Cedar Sauk	2016	0.028	0.029	0.012	0.049	0.019	4	0.016
		2017	0.021	0.024	0.004	0.045	0.016	6	0.013
		2018	0.036	0.035	0.017	0.052	0.031	4	0.016
		2019	0.035	0.041	0.016	0.077	0.017	4	0.026
10008815	Pleasant Valley Rd	2016	0.030	0.031	0.012	0.052	0.011	4	0.016
		2017	0.024	0.021	0.004	0.029	0.004	6	0.008
		2018	0.043	0.040	0.012	0.061	0.032	4	0.018
		2019	0.034	0.043	0.016	0.088	0.020	4	0.031
10008816	County Hwy O	2016	0.030	0.030	0.010	0.052	0.013	4	0.017
		2017	0.024	0.022	0.005	0.030	0.006	6	0.008
		2018	0.043	0.038	0.008	0.058	0.035	4	0.020
		2019	0.036	0.043	0.015	0.083	0.019	4	0.029

Figure 22. Total phosphorus and orthophosphate concentration (mg/L) per year per water quality sampling station on Mole Creek in Ozaukee County, WI. The red line is set at the established Wisconsin desirable concentration of 0.075 mg/L.

a.) Total phosphorus



b.) Orthophosphate



Total Suspended Solids

Currently, there are no set water quality criteria for total suspended solids (TSS) by either the State of Wisconsin or Federal government; however, the WDNR in conjunction with MMSD (2018) implement the regional Total Maximum Daily Load (TMDL) value of 12 mg/L as the allowable load and target concentration (Table 17). High concentrations of total suspended solids increase turbidity of the water, negatively impacting biological, chemical, and physical properties of a stream. While the TMDL allows

for an adequate establishment of a baseline in a waterbody, the chronic level and target number need further examination through additional studies.

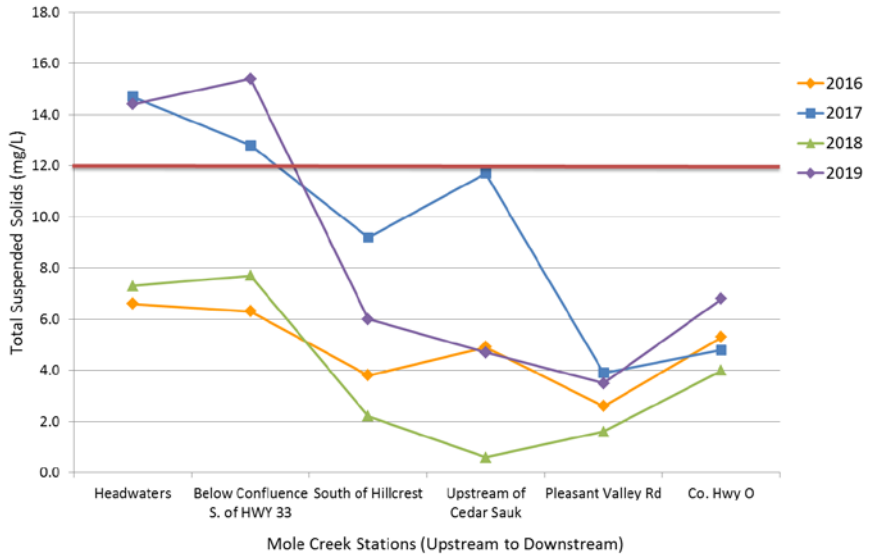
Annual mean TSS concentrations only exceeded the 12 mg/L target concentration at 2 sampling locations (Headwaters and Below Confluence, which is immediately downstream) in both 2017 and 2019 (Table 22, Figure 23). TSS average values were fairly consistent at the 2 sampling stations furthest downstream (Pleasant Valley Road and County Hwy O) over the course of the 4 year sampling period.

Table 22. TSS concentration (mg/L) summary from discrete samples analyzed by SLOH from the 6 water quality sampling stations on Mole Creek in Ozaukee County, WI. Values in red represent an average concentration above the recommended 12 mg/L regional TMDL.

Station	Location	Year	Median	Mean	Min	Max	IQR	n	Std Dev
10047105	Headwaters	2016	5.8	6.6	4.6	10.3	2.6	4	2.6
		2017	11.6	14.7	6.3	32.5	13.1	6	9.3
		2018	5.7	7.3	4.4	13.3	5.6	4	3.6
		2019	14.7	14.4	12.3	15.7	2.4	4	1.7
10046984	Below Confluence S. of Hwy 33	2016	6.1	6.3	4.0	9.0	3.5	4	2.4
		2017	9.8	12.8	5.0	26.5	13.0	6	7.7
		2018	3.7	7.7	2.0	21.5	10.7	4	8.0
		2019	14.3	15.4	13.0	20.0	2.9	4	3.2
10046985	South of Hillcrest	2016	3.4	3.8	3.0	5.6	1.3	4	1.3
		2017	6.6	9.2	5.7	23.3	1.8	6	6.3
		2018	2.6	2.2	0.0	3.6	2.4	4*	1.4
		2019	6.9	6.0	2.5	7.8	1.5	4	2.4
10016375	Upstream of Cedar Sauk	2016	4.6	4.9	4.4	5.8	0.7	4	0.7
		2017	11.8	11.7	4.8	22.3	9.1	6*	6.0
		2018	0.0	0.6	0.0	2.2	1.1	4*	1.0
		2019	3.8	4.7	3.4	7.0	1.8	4	2.0
10008815	Pleasant Valley Rd	2016	2.6	2.6	2.4	2.8	0.2	4*	0.2
		2017	3.3	3.9	0.0	8.8	5.3	6	2.9
		2018	1.4	1.6	0.0	3.5	3.2	4*	1.6
		2019	3.4	3.5	2.8	4.3	1.0	4	0.7
10008816	County Hwy O	2016	5.3	5.3	3.0	7.7	2.3	4*	3.3
		2017	4.0	4.8	2.8	7.5	4.0	6	1.9
		2018	3.8	4.0	0.0	8.4	6.0	4*	3.2
		2019	5.0	6.8	3.0	14.0	4.3	4	5.0

*one or more samples were below level of detection

Figure 23. TSS concentration (mg/L) per year per water quality sampling station on Mole Creek in Ozaukee County, WI. The red line indicates the TMDL target concentration of 12 mg/L.



E. coli

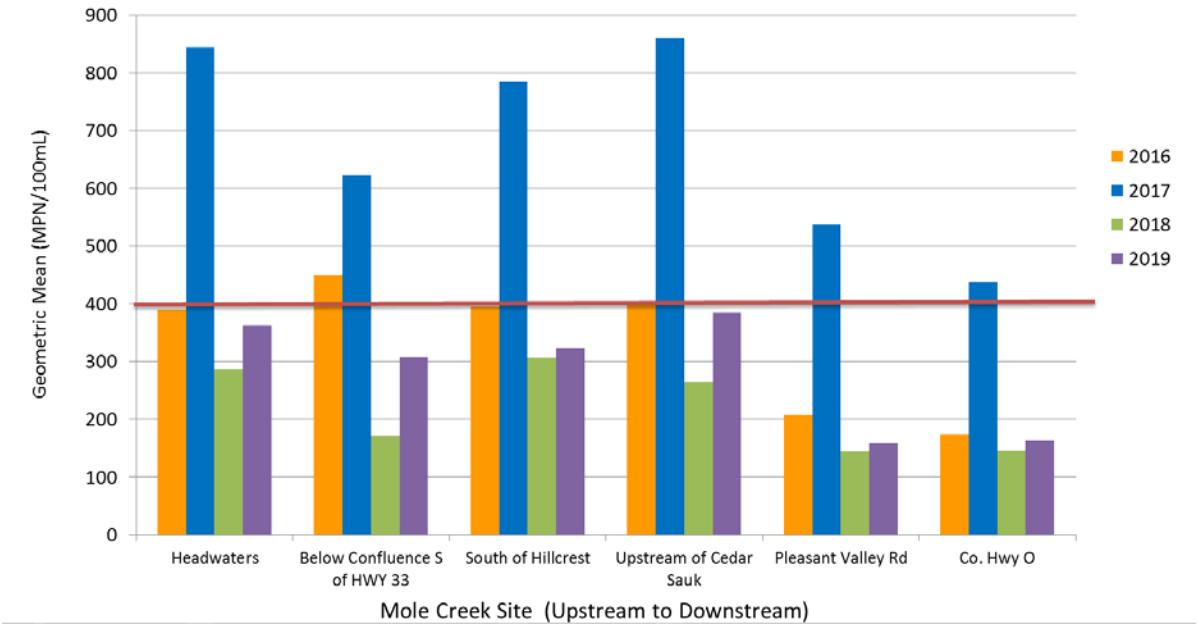
High bacteria concentrations can have a negative effect on streams as well as human health. Wisconsin State Recreational Use Standards state that fecal coliform levels are "not to exceed 400 CFU/100 mL" (colony forming units/100 milliliter sample; WDNR 1973, WDNR & MMSD 2018). WDNR recommended retesting for sites with results higher than 400 CFU/100 mL; retesting was not done for individual samples in this study. The USEPA has established recommended minimum criteria for *E. coli* that suggest that the geometric mean of all samples should not exceed 126 colony forming units (CFU) per 100 mL and not more than 10 percent of samples to exceed 400 CFU/100 mL (USEPA 1986a) (Table 17).

The geometric mean was used when summarizing the *E. coli* data as the bacteria naturally exhibits exponential growth. Means at all 6 Mole Creek locations were above 400 CFU/100 mL in 2017. Geometric means at the sampling locations only exceeded 400 CFU/100 mL at 2 stations (Below Confluence and Upstream Cedar Sauk) in 2016; average annual values did not exceed the criteria in subsequent years (Table 23, Figure 24).

Table 23. *E. coli* concentration (CFU/100 mL) summary from discrete samples analyzed by SLOH from the 6 water quality sampling stations on Mole Creek in Ozaukee County, WI. Values in red represent a geometric mean above 400 CFU/100 mL.

Station	Location	Year	Median	Geo Mean	Min	Max	IQR	n	Std Dev(P)
10047105	Headwaters	2016	477.5	389.6	70.0	1986.0	853.3	4	752.2
		2017	441.0	844.8	308.0	18600.0	455.0	6	6750.4
		2018	512.0	286.9	24.0	1120.0	425.5	4	395.2
		2019	317.5	362.9	91.0	1986.0	578.0	4	762.4
10046984	Below Confluence S. of Hwy 33	2016	750.0	449.2	54.0	1414.0	596.5	4	495.9
		2017	380.0	623.5	219.0	11120.0	454.5	6	4000.8
		2018	260.0	171.2	35.0	548.0	354.8	4	211.1
		2019	199.0	307.1	115.0	1986.0	497.8	4	786.8
10046985	South of Hillcrest	2016	448.0	394.9	70.0	1733.0	435.3	4	630.2
		2017	356.5	784.9	219.0	23590.0	783.3	6	8612.4
		2018	491.5	307.1	31.0	1203.0	377.8	4	421.0
		2019	272.0	322.9	96.0	1733.0	548.8	4	665.2
10016375	Upstream of Cedar Sauk	2016	637.5	400.3	70.0	921.0	347.0	4	315.5
		2017	388.0	860.8	228.0	34480.0	620.5	6	12672.1
		2018	312.5	264.1	33.0	1553.0	458.8	4	589.8
		2019	286.0	385.6	138.0	2420.0	758.0	4	951.5
10008815	Pleasant Valley Rd	2016	313.5	207.9	50.0	488.0	330.8	4	188.0
		2017	247.5	538.0	105.0	12590.0	1354.0	6	4544.0
		2018	211.5	143.9	35.0	276.0	89.5	4	90.7
		2019	177.5	158.6	58.0	411.0	194.0	4	137.4
10008816	County Hwy O	2016	154.0	173.4	66.0	579.0	140.3	4	200.1
		2017	180.0	437.7	115.0	26130.0	264.0	6	9655.9
		2018	213.0	145.3	28.0	488.0	284.5	4	182.6
		2019	211.0	163.5	70.0	326.0	236.5	4	121.8

Figure 24. *E. coli* concentration (CFU/100 mL) per year per water quality sampling station on Mole Creek in Ozaukee County, WI. The red line indicates the Wisconsin State Recreational Use Standards adapted for *E. coli* at 400 CFU/100 mL.



Dissolved Oxygen

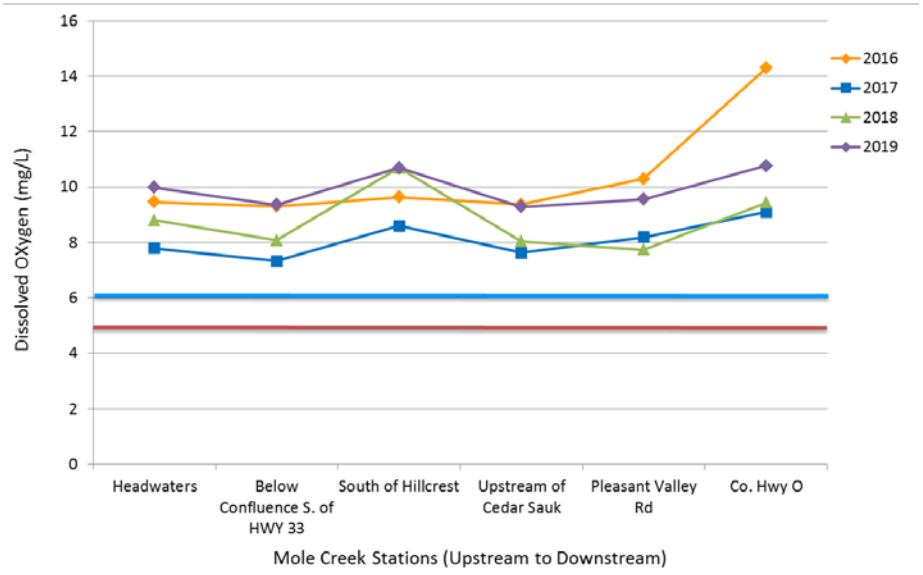
Dissolved oxygen concentration varies greatly with time of day and photosynthetic activity. Although Mole Creek is a cool-cold water stream, it is not officially categorized as a cold water (e.g., "trout") stream. WDNR Administrative Rule 102.04 (4a) states: "the dissolved oxygen content in many surface waters (including waters designated as a Warm Water Sport Fishery) may not be lowered to less than 5 mg/L at any time (WDNR 1973)" (Table 17). For cold water streams, the dissolved oxygen cannot be lower than 6.0 mg/L at any time per Administrative Rule 102.04(4b).

Dissolved oxygen was measured at the time of discrete water sampling using a held-hand multi-parameter water quality instrument. There were no average dissolved oxygen concentrations at any sampling station on Mole Creek that fell below 5 or 6 mg/L in any year (Table 24, Figure 25).

Table 24. Dissolved oxygen concentration (mg/L) summary, measured at the time of discrete water sampling using a handheld instrument, from the 6 water quality sampling stations on Mole Creek in Ozaukee County, WI.

Station	Location	Year	Median	Mean	Min	Max	IQR	n	Std Dev
10047105	Headwaters	2016	9.5	9.5	9.4	9.5	0.1	2	0.1
		2017	7.8	7.8	6.7	8.9	1.9	6	0.8
		2018	8.8	8.8	8.1	9.6	0.8	4	0.5
		2019	9.7	10.0	7.6	13.0	2.0	4	2.2
10046984	Below Confluence S. of Hwy 33	2016	9.3	9.3	9.2	9.4	0.1	2	0.1
		2017	7.2	7.3	6.6	8.1	1.1	6	0.6
		2018	7.9	8.1	7.6	8.8	0.9	4	0.5
		2019	9.5	9.4	6.6	11.9	1.9	4	2.2
10046985	South of Hillcrest	2016	9.6	9.6	9.5	9.8	0.1	2	0.2
		2017	8.6	8.6	7.7	9.6	1.2	6	0.7
		2018	9.2	10.7	9.0	15.3	3.3	4	2.7
		2019	11.7	10.7	7.1	12.3	1.6	4	2.4
10016375	Upstream of Cedar Sauk	2016	9.4	9.4	9.4	9.4	0.0	1	N/A
		2017	7.6	7.6	7.0	8.6	0.6	6	0.5
		2018	7.6	8.0	6.0	11.0	3.1	4	1.9
		2019	9.6	9.3	5.7	12.2	1.8	4	2.7
10008815	Pleasant Valley Rd	2016	10.3	10.3	10.3	10.3	0.0	1	N/A
		2017	8.4	8.2	7.3	8.9	1.1	6	0.6
		2018	8.3	7.7	5.9	8.4	1.4	4	1.1
		2019	10.1	9.6	5.9	12.1	2.7	4	2.7
10008816	County Hwy O	2016	14.3	14.3	14.3	14.3	0.0	1	N/A
		2017	9.5	9.1	7.8	9.9	1.7	6	0.8
		2018	9.5	9.4	8.3	10.6	1.9	4	1.0
		2019	11.0	10.8	7.7	13.5	3.6	4	2.7

Figure 25. Dissolved oxygen concentration (mg/L) per year per water quality sampling station on Mole Creek in Ozaukee County, WI. The red line indicates the minimum dissolved oxygen concentration for classification as a Warm Water Sport Fisheries and the blue line indicates the minimum dissolved oxygen concentration for classification as a Cold Water Fisheries.



Conductivity

Conductivity in streams is naturally affected by geology that is influenced by the bedrock, soils, and ground water passing through. It can also be affected by discharges to streams such as chlorides, heavy metals, sewage, and nutrients (phosphates and nitrates). A conductivity reading of 150-500 µS/cm can

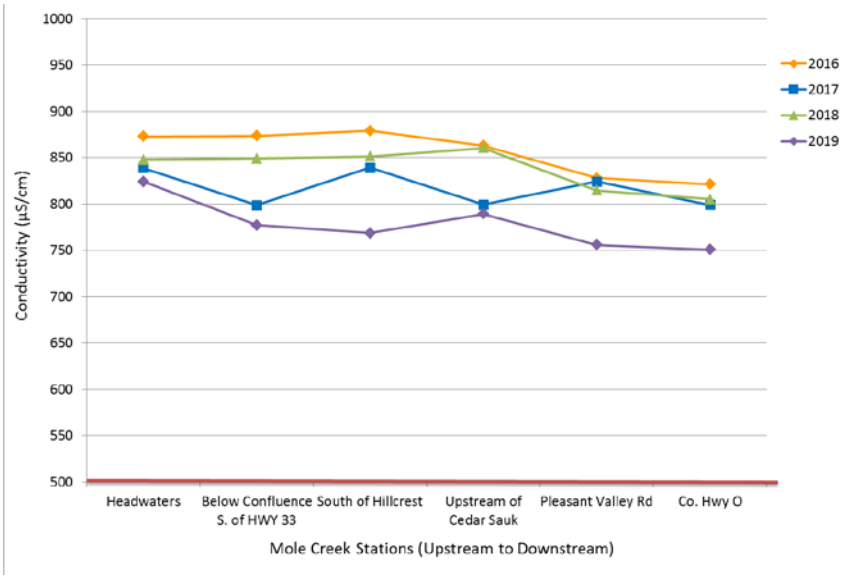
provide for a healthy aquatic ecosystem and conductivity outside of this range could indicate the waterbody is not suitable for certain aquatic species (USEPA 2012) (Table 17).

In all 4 study years, the average daily maximum and mean conductivity values were significantly above the maximum recommended by USEPA (2012). All but one of the mean minimum values, measured at the Upstream of Cedar Sauk location in 2017, was below 500 µS/cm (Table 25, Figure 26). These high measurements require additional investigation, but may indicate high levels of nutrients or other pollutants entering the waterbody (Appendix B).

Table 25. Conductivity (µS/cm) summary, measured at the time of discrete water sampling using a handheld instrument, from the 6 water quality sampling stations on Mole Creek in Ozaukee County, WI. Values in red indicate means above 500 µS/cm.

Station	Location	Year	Median	Mean	Min	Max	IQR	n	Std Dev
10047105	Headwaters	2016	868.0	872.8	837.0	917.0	16.0	5	29.1
		2017	841.0	838.8	746.0	930.0	109.0	6	65.7
		2018	851.5	847.5	822.0	865.0	34.0	4	18.0
		2019	830.0	824.2	773.0	865.0	11.0	5	33.1
10046984	Below Confluence S. of Hwy 33	2016	872.5	873.3	841.0	906.0	35.3	6	25.3
		2017	798.5	798.7	681.0	918.0	122.0	6	77.0
		2018	840.0	849.0	833.0	883.0	31.0	4	20.3
		2019	769.0	777.1	738.7	824.0	34.0	5	32.9
10046985	South of Hillcrest	2016	872.0	879.0	850.0	925.0	39.3	6	29.3
		2017	846.0	839.2	753.0	932.0	106.0	6	63.8
		2018	848.5	851.3	845.0	863.0	9.5	4	6.9
		2019	799.0	768.6	653.0	834.0	45.0	5	70.3
10016375	Upstream of Cedar Sauk	2016	846.0	863.0	815.0	945.0	37.0	4	56.6
		2017	860.0	799.3	490.0	958.0	168.0	6	155.6
		2018	864.5	860.3	831.0	881.0	27.5	4	18.3
		2019	787.0	789.2	742.9	842.0	20.0	5	35.9
10008815	Pleasant Valley Rd	2016	822.0	828.0	783.0	885.0	33.0	4	42.4
		2017	815.0	824.0	764.0	898.0	78.0	6	47.9
		2018	827.0	814.5	770.0	834.0	36.0	4	26.0
		2019	762.0	755.7	734.6	776.0	24.0	5	17.3
10008816	County Hwy O	2016	823.5	821.0	774.0	863.0	29.0	4	39.6
		2017	800.0	799.0	673.0	879.0	80.0	6	67.1
		2018	819.0	805.3	753.0	830.0	45.5	4	30.9
		2019	759.0	750.5	716.0	778.0	26.4	5	24.3

Figure 26. Conductivity (µS/cm) per year per water quality sampling station on Mole Creek in Ozaukee County, WI. The red line indicates the maximum recommended conductivity per the USEPA.



pH

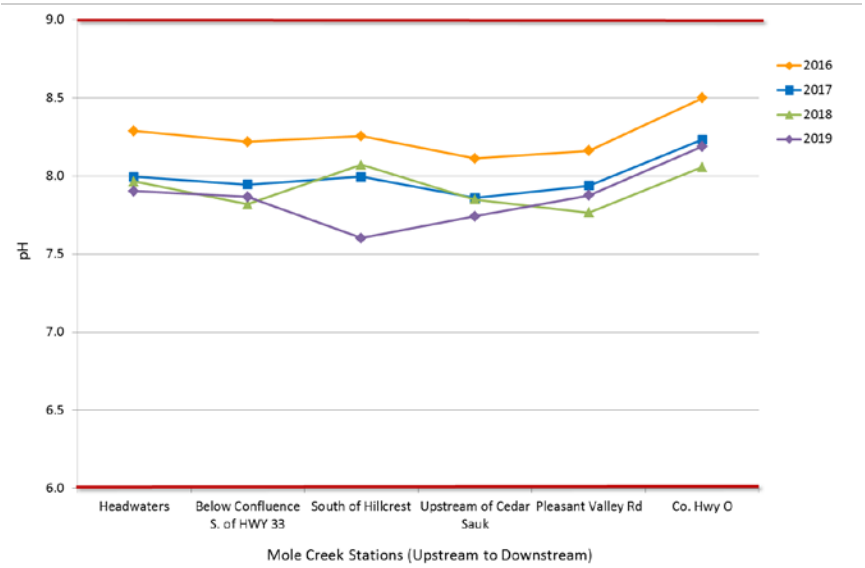
Most streams have a neutral to slightly basic pH, which is dependent upon abiotic factors such as the composition of the stream bed, water temperature, dissolved oxygen concentration, time of day, and weather activities. Wisconsin Administrative Rule 102.04(4) states that the pH shall be within the range 6.0 to 9.0, with no change greater than 0.5 units outside the estimated natural seasonal maximum and minimum (Table 17). A pH of 7.5 is considered ideal and values are generally higher during the summer months, when primary production is greatest.

All measured values were within the Wisconsin state criteria (6.0 - 9.0) set for maintaining aquatic life in a stream (Table 11, Figure 11).

Table 26. pH summary, measured at the time of discrete water sampling using a handheld instrument, from the 6 water quality sampling stations on Mole Creek in Ozaukee County, WI.

Station	Location	Year	Median	Mean	Min	Max	IQR	n	Std Dev
10047105	Headwaters	2016	8.30	8.29	8.05	8.54	0.37	5	0.22
		2017	7.98	8.00	7.93	8.10	0.11	6	0.06
		2018	7.99	7.97	7.45	8.44	0.66	4	0.37
		2019	7.92	7.90	7.76	8.00	0.11	5	0.09
10046984	Below Confluence S. of Hwy 33	2016	8.20	8.22	8.05	8.42	0.26	6	0.16
		2017	7.95	7.95	7.83	8.17	0.14	6	0.11
		2018	7.81	7.82	7.61	8.05	0.23	4	0.16
		2019	7.90	7.87	7.67	7.95	0.03	5	0.11
10046985	South of Hillcrest	2016	8.21	8.26	8.10	8.58	0.22	6	0.19
		2017	7.98	8.00	7.85	8.18	0.20	6	0.11
		2018	8.04	8.07	7.72	8.50	0.62	4	0.32
		2019	7.69	7.60	6.69	8.02	0.29	5	0.53
10016375	Upstream of Cedar Sauk	2016	8.11	8.11	7.99	8.25	0.12	4	0.11
		2017	7.81	7.86	7.75	8.17	0.08	6	0.14
		2018	7.85	7.85	7.64	8.07	0.37	4	0.19
		2019	7.79	7.74	7.57	7.94	0.25	5	0.16
10008815	Pleasant Valley Rd	2016	8.15	8.16	8.06	8.30	0.19	4	0.12
		2017	7.92	7.94	7.78	8.23	0.19	6	0.15
		2018	7.71	7.77	7.70	7.94	0.12	4	0.10
		2019	7.95	7.88	7.61	7.98	0.08	5	0.15
10008816	County Hwy O	2016	8.48	8.50	8.37	8.67	0.14	4	0.13
		2017	8.24	8.23	8.06	8.50	0.23	6	0.15
		2018	8.06	8.06	8.02	8.10	0.06	4	0.03
		2019	8.17	8.19	7.94	8.39	0.11	5	0.17

Figure 27. pH values per year per water quality sampling station on Mole Creek in Ozaukee County, WI. Red lines indicated the minimum and maximum set State criteria for pH values.



Salinity

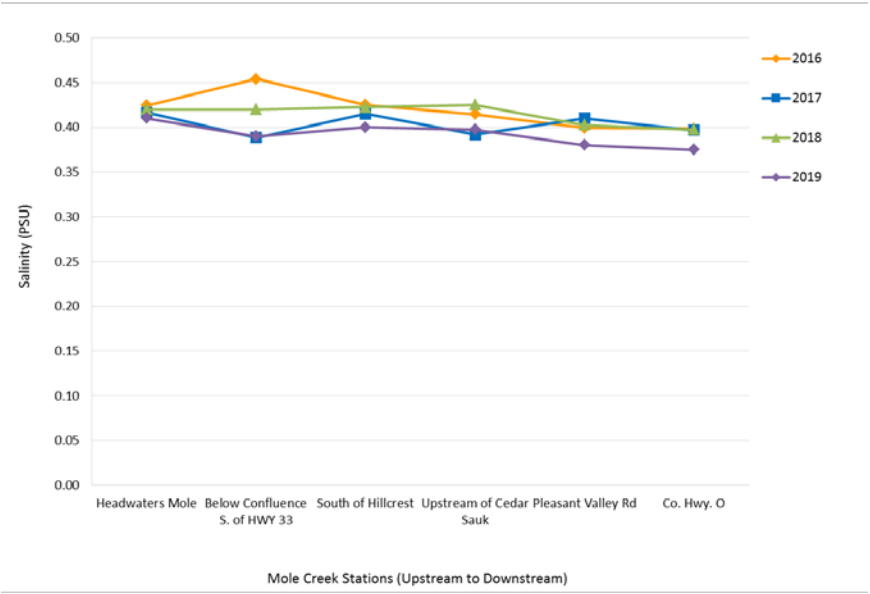
Salinity, the measure of ionic concentrations of soluble salts, fluctuates seasonally due to distribution of deicing road salt and precipitation. There are no Wisconsin-specific set criteria for ideal salinity concentration; however, USEPA states the average salinity of freshwater is 0.5 PSU, with 0-1 PSU the acceptable range for freshwater (Ohrel and Register 2006, USEPA 2020).

Mean salinity concentration has been consistent across Mole Creek study locations and between years with means between 0.38 and 0.45 PSU, below the USEPA average.

Table 27. Salinity concentration (PSU) summary, measured at the time of discrete water sampling using a handheld instrument, from the 6 water quality sampling stations on Mole Creek in Ozaukee County, WI.

Station	Location	Year	Median	Mean	Min	Max	IQR	n	Std Dev
10047105	Headwaters	2016	0.43	0.42	0.41	0.43	0.00	5	0.01
		2017	0.42	0.42	0.37	0.46	0.05	6	0.03
		2018	0.42	0.42	0.41	0.43	0.02	4	0.01
		2019	0.41	0.41	0.40	0.43	0.02	4	0.01
10046984	Below Confluence S. of Hwy 33	2016	0.43	0.45	0.40	0.60	0.01	6	0.07
		2017	0.40	0.39	0.31	0.45	0.06	6	0.04
		2018	0.42	0.42	0.41	0.44	0.02	4	0.01
		2019	0.40	0.39	0.36	0.41	0.02	4	0.02
10046985	South of Hillcrest	2016	0.42	0.43	0.41	0.45	0.02	6	0.02
		2017	0.42	0.42	0.37	0.46	0.06	6	0.03
		2018	0.42	0.42	0.42	0.43	0.01	4	0.00
		2019	0.40	0.40	0.39	0.41	0.01	4	0.01
10016375	Upstream of Cedar Sauk	2016	0.41	0.41	0.39	0.45	0.03	4	0.02
		2017	0.43	0.39	0.22	0.48	0.08	6	0.08
		2018	0.43	0.43	0.41	0.43	0.01	4	0.01
		2019	0.40	0.40	0.39	0.41	0.01	4	0.01
10008815	Pleasant Valley Rd	2016	0.40	0.40	0.38	0.43	0.02	4	0.02
		2017	0.41	0.41	0.38	0.45	0.04	6	0.03
		2018	0.41	0.40	0.38	0.41	0.02	4	0.01
		2019	0.38	0.38	0.36	0.40	0.01	4	0.02
10008816	County Hwy O	2016	0.40	0.40	0.37	0.42	0.02	4	0.02
		2017	0.40	0.40	0.33	0.44	0.04	6	0.04
		2018	0.41	0.40	0.37	0.41	0.03	4	0.02
		2019	0.38	0.38	0.35	0.40	0.02	4	0.02

Figure 28. Salinity concentration (PSU) per year per water quality sampling station on Mole Creek in Ozaukee County, WI.



Total Dissolved Solids

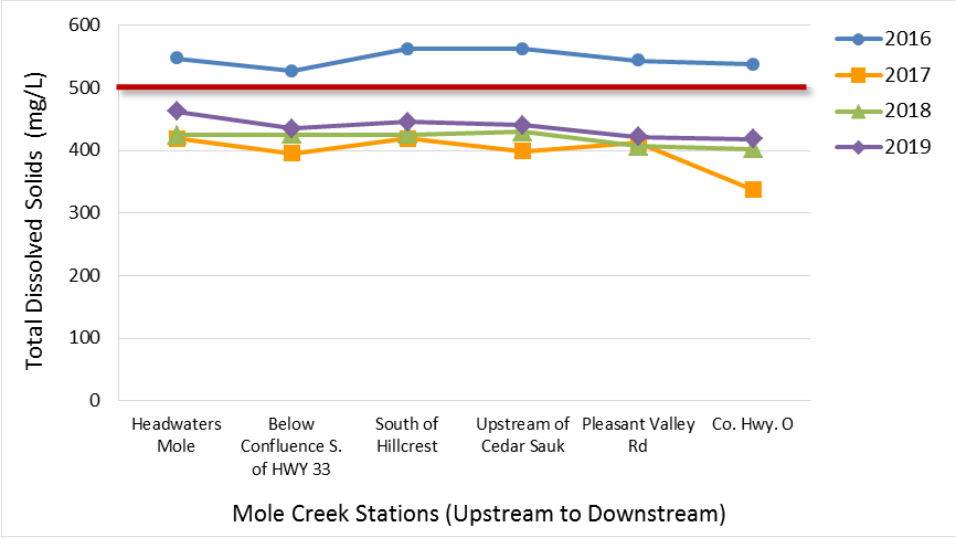
There is no State or Federal set standard for TDS concentration, but the National Secondary Drinking Water Regulations are a maximum value of 500 mg/L for aesthetic reasons (e.g. corrosion of plumbing, bad taste) (Table 17). Studies have found variable results on the effects of TDS on aquatic organisms, indicating that various combinations of ions are more toxic than others and organisms may be more sensitive at one life stage than another (Brix et al. 2010, Sorensen et al. 1977, Timpano et al. 2010).

Mean TDS concentrations only surpassed 500 mg/L in 2016 (Table 28, Figure 29). The TDS concentrations in the 2017-2019 samples remained relatively steady, between 337-463 mg/L.

Table 28. Total dissolved solids concentration (mg/L), measured at the time of discrete water sampling using a handheld instrument, from the 6 water quality sampling stations on Mole Creek in Ozaukee County, WI. Values in red are above the 500 mg/L maximum set by the National Secondary Drinking Water Regulations.

Station	Location	Year	Median	Mean	Min	Max	IQR	n	Std Dev
10047105	Headwaters	2016	595.0	547.0	431.0	651.0	190.0	5	106.4
		2017	420.5	419.3	373.0	465.0	55.0	6	32.9
		2018	426.5	424.3	411.0	433.0	17.5	4	9.3
		2019	424.5	462.5	410.0	591.0	58.0	4	86.2
10046984	Below Confluence S. of Hwy 33	2016	526.5	526.7	407.0	642.0	188.8	6	109.7
		2017	399.5	395.3	320.0	459.0	62.0	6	44.2
		2018	420.5	425.3	417.0	443.0	15.5	4	10.5
		2019	405.5	435.0	365.0	564.0	61.0	4	88.3
10046985	South of Hillcrest	2016	608.0	562.0	427.0	657.0	130.0	6	97.3
		2017	423.0	419.7	377.0	466.0	53.0	6	31.7
		2018	424.0	425.5	426.0	431.0	4.0	4	3.2
		2019	408.0	445.8	399.0	568.0	55.8	4	81.9
10016375	Upstream of Cedar Sauk	2016	589.0	562.3	421.0	650.0	73.8	4	98.9
		2017	430.0	399.2	242.0	479.0	84.0	6	78.8
		2018	431.5	430.0	416.0	441.0	13.0	4	9.0
		2019	409.5	440.8	393.0	551.0	56.8	4	74.5
10008815	Pleasant Valley Rd	2016	570.5	544.0	408.0	627.0	78.0	4	95.3
		2017	407.5	411.8	382.0	449.0	37.0	6	23.7
		2018	413.5	407.3	385.0	417.0	18.5	4	13.0
		2019	381.5	421.5	371.0	552.0	46.0	4	87.1
10008816	County Hwy O	2016	565.0	537.8	409.0	612.0	85.3	4	90.6
		2017	400.5	337.0	337.0	440.0	40.0	6	33.4
		2018	409.5	402.8	376.0	416.0	23.5	4	15.9
		2019	380.5	418.0	359.0	552.0	50.5	4	89.9

Figure 29. Total dissolved solids concentration (mg/L) per year per water quality sampling station on Mole Creek in Ozaukee County, WI. Values in red are above the 500 mg/L maximum set by the National Secondary Drinking Water Regulations.



Turbidity

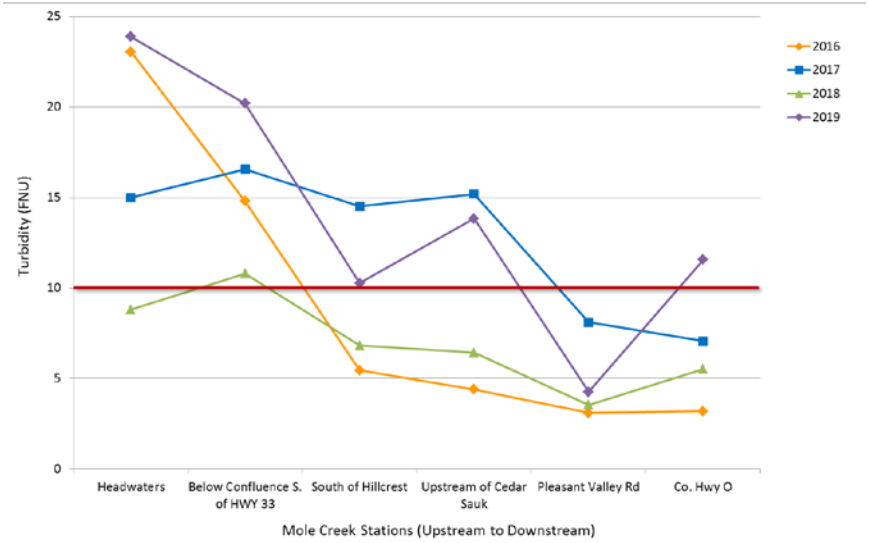
Per Milwaukee Riverkeeper (2016), the ideal turbidity readings for the Milwaukee River drainage basin is 10 FNU and below (Table 29). The 2 furthest upstream stations, located at the Headwaters and below the confluence of Hwy 33, have mean values that surpassed 10 FNU in 2016. The following year saw mean values above 10 FNU at 4 of the 6 sampling stations. In 2018, only the sampling station located below the confluence of Hwy 33 had a mean average above the recommended criteria, while 5 of 6 stations surpassed a mean value of 10 FNU (Table 29, Figure 30). No turbidity data was collected during the first (May 30) 2019 sampling run due to equipment malfunction.

Per Göransson et al. (2013), a complex relationship exists between turbidity, precipitation, discharge, and size of the watershed. It was concluded high turbidity values are associated with heavy rainfall and high discharge while periods of dry weather results lower levels of turbidity in a regulated river system. A similar phenomenon may be occurring in the Mole Creek Watershed, where almost 50% of land use is agricultural (Figure 3); however, additional sampling and analysis is needed to correlate the conditions measured during a sampling and precipitation.

Table 29. Turbidity (FNU) summary, measured at the time of discrete water sampling using a handheld instrument, from the 6 water quality sampling stations on Mole Creek in Ozaukee County, WI. Values in red indicate means above the maximum recommended turbidity value (10 FNU) for the study region.

Station	Location	Year	Median	Mean	Min	Max	IQR	n	Std Dev
10047105	Headwaters	2016	23.1	23.1	6.9	39.2	16.2	2	22.8
		2017	14.3	15.0	8.2	23.7	11.9	6	6.2
		2018	6.5	8.8	6.4	15.8	4.8	4	4.0
		2019	21.0	23.9	17.3	33.3	8.0	3	8.4
10046984	Below Confluence S. of Hwy 33	2016	14.8	14.8	5.1	24.5	9.7	2	13.7
		2017	16.3	16.6	11.9	21.1	6.2	6	3.3
		2018	5.4	10.8	4.3	28.1	12.9	4	10.0
		2019	20.3	20.2	17.4	22.9	2.8	3	2.8
10046985	South of Hillcrest	2016	5.5	5.5	4.4	6.5	1.1	2	1.5
		2017	13.0	14.5	8.0	27.6	9.3	6	6.9
		2018	7.4	6.8	4.0	8.5	2.4	4	1.7
		2019	11.9	10.3	6.7	12.2	2.8	3	3.1
10016375	Upstream of Cedar Sauk	2016	4.4	4.4	4.4	4.4	0.0	1	N/A
		2017	14.4	15.2	4.4	28.8	11.2	6	7.9
		2018	7.2	6.4	1.6	9.8	4.5	4	3.0
		2019	10.7	13.8	1.8	29.0	13.6	3	13.9
10008815	Pleasant Valley Rd	2016	3.1	3.1	3.1	3.1	0.0	1	N/A
		2017	8.4	8.1	3.8	12.7	6.3	6	3.2
		2018	3.2	3.6	2.5	5.4	1.7	4	1.1
		2019	4.3	4.3	3.2	5.3	1.1	3	1.1
10008816	County Hwy O	2016	3.2	3.2	3.2	3.2	0.0	1	N/A
		2017	6.4	7.1	4.3	10.9	3.7	6	2.3
		2018	5.5	5.5	1.9	9.3	4.4	4	2.7
		2019	13.0	11.6	4.4	17.3	6.5	3	6.6

Figure 30. Turbidity (FNU) measurements per year per water quality sampling station on Mole Creek in Ozaukee County, WI. The red line indicates the maximum recommended turbidity value (10 FNU) for the study region.



Water Temperature

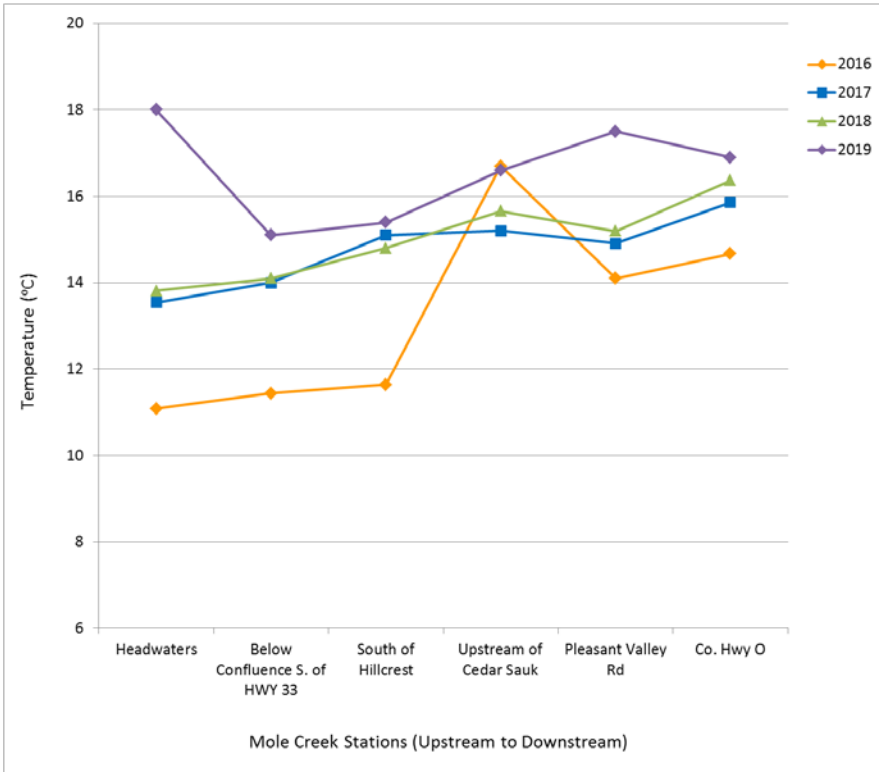
The WDNR Chapter NR102 Water Quality Standards for Wisconsin Surface Waters (WDNR 1973) sets a water temperature maximum for a Warm Water Sport Fishery (Milwaukee River) of 31.7°C (Table 17). Daily maximums were measured against this standard.

Water temperature was recorded at the time of each sampling event at all stations using a handheld instrument and was variable with season, water depth, riparian vegetation cover, and time of day. Mean temperatures ranges from 7.9 at the Headwaters to 20.4 at the Hillcrest station in 2016; 9.3 at the Headwaters to 20.7 at County Hwy O in 2017; 8.2 below the confluence of Hwy 33 to 22.4 upstream of Cedar Sauk road in 2018; and, 9.1 south of Hillcrest to 22.7 at the Headwaters in 2019 (Table 30, Figure 31). All average maximum values were below the criteria for a Warm Water Sport Fishery and the thermal tolerance limit for inland brook, brown, and rainbow trout of 24.2^{o}C over a 3-day period (Wehrly et al. 2007 *in* WDNR 2019b).

Table 30. Water temperature (°C) summary, measured at the time of discrete water sampling using a handheld instrument, discrete samples analyzed by SLOH from the 6 water quality sampling stations on Mole Creek in Ozaukee County, WI.

Station	Location	Year	Median	Mean	Min	Max	IQR	n	Std Dev
10047105	Headwaters	2016	9.7	11.1	7.9	17.0	5.0	7	4.0
		2017	13.3	13.5	9.3	17.4	4.6	6	2.8
		2018	14.7	13.8	8.3	17.5	7.1	4	3.8
		2019	15.5	18.0	9.5	22.7	5.0	5	5.1
10046984	Below Confluence S. of Hwy 33	2016	9.0	11.4	7.8	17.6	7.4	6	4.7
		2017	13.8	14.0	9.5	17.9	5.4	6	3.0
		2018	14.9	14.1	8.2	18.5	7.8	4	4.2
		2019	14.9	15.1	9.2	20.0	2.6	4	4.6
10046985	South of Hillcrest	2016	10.0	11.6	8.0	20.4	3.1	8	4.6
		2017	15.6	15.1	9.9	19.0	6.6	6	3.5
		2018	15.9	14.8	8.4	18.9	8.2	4	4.4
		2019	16.4	15.4	9.1	20.5	2.7	5	4.2
10016375	Upstream of Cedar Sauk	2016	18.6	16.7	9.8	19.9	4.3	4	4.7
		2017	15.7	15.2	10.1	19.0	6.9	6	3.4
		2018	15.9	15.7	8.5	22.4	9.6	4	5.3
		2019	17.8	16.6	9.2	22.0	2.5	5	4.8
10008815	Pleasant Valley Rd	2016	14.0	14.1	10.0	18.5	7.9	4	4.7
		2017	14.8	14.9	10.5	19.0	6.8	6	3.3
		2018	15.9	15.2	8.5	20.5	8.5	4	4.6
		2019	17.3	17.5	9.4	22.4	1.9	5	4.9
10008816	County Hwy O	2016	14.5	14.7	10.7	19.1	7.6	4	4.6
		2017	15.6	15.9	10.9	20.7	7.8	6	3.8
		2018	17.3	16.4	9.1	21.9	9.4	4	5.1
		2019	18.3	16.9	9.3	21.9	8.2	5	4.7

Figure 31. Water temperature (°C) measurements per year per water quality sampling stations on Mole Creek in Ozaukee County, WI.



Continuous Data

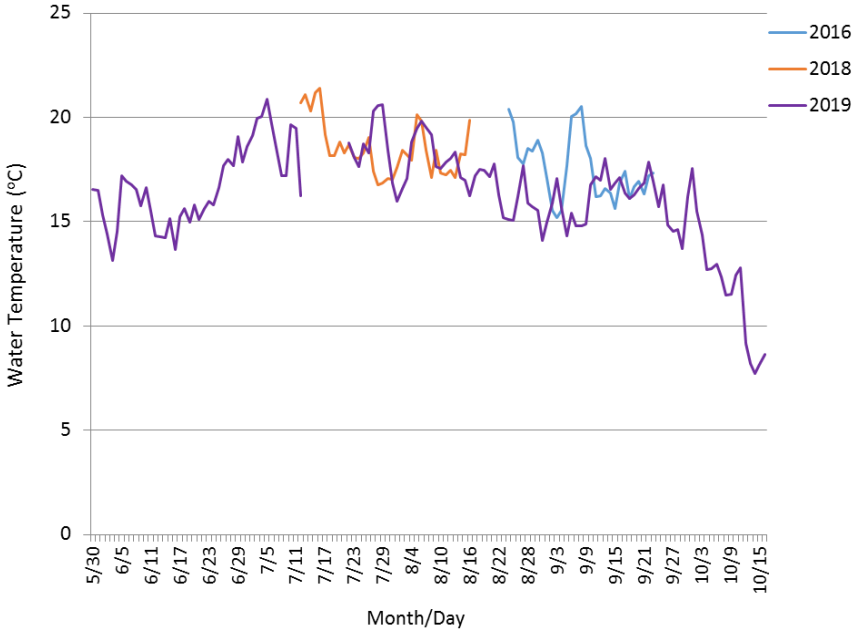
Eureka brand continuous water quality monitoring units were deployed, maintained, and collected data at 3 water quality sampling locations (below confluence south of Hwy 33, South of Hillcrest, and upstream of Cedar Sauk Rd) between the months of August and November in 2016 and July to November in both 2018 and 2019, with the exception of the unit located below the confluence of Hwy 33 (installed in May 2019) (Table 3). Due to fluctuations in water level, velocity, battery supply, and tampering by aquatic animals, data from all probes may not have recorded continuously during the entire deployment of the monitoring unit, as seen below.

Below Confluence South of Highway 33

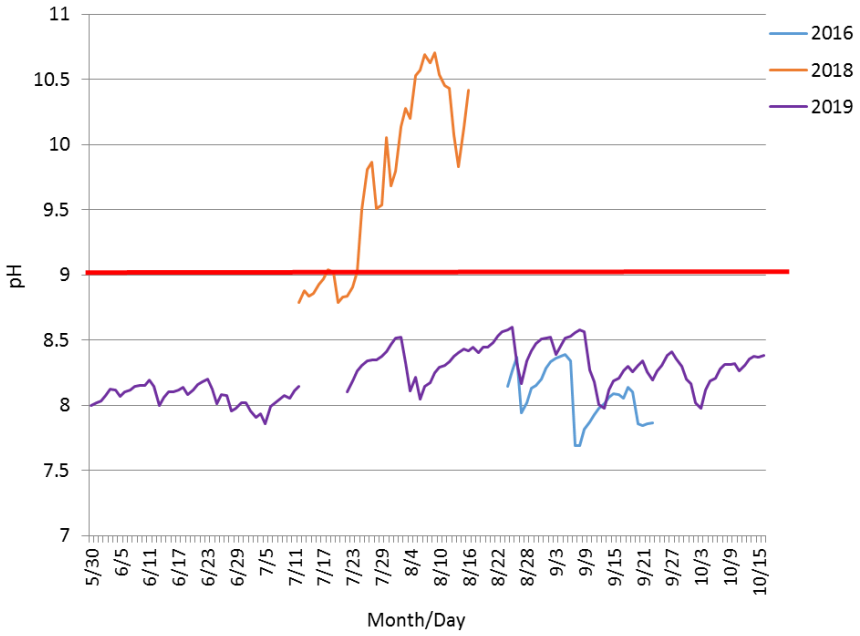
Continuous data was collected at the furthest upstream station south of Highway 33 during summer and early fall months in 2016 and 2018-2019 (Figure 32). Dissolved oxygen data is only available for a few days in July 2018 due to a faulty probe (Figure 32d).

Figure 32. Measure parameters from the Eureka continuous monitoring unit deployed on the Mole Creek sampling station located south of Highway 33 and below the confluence of Mole Creek with the Milwaukee River in Ozaukee County, WI.

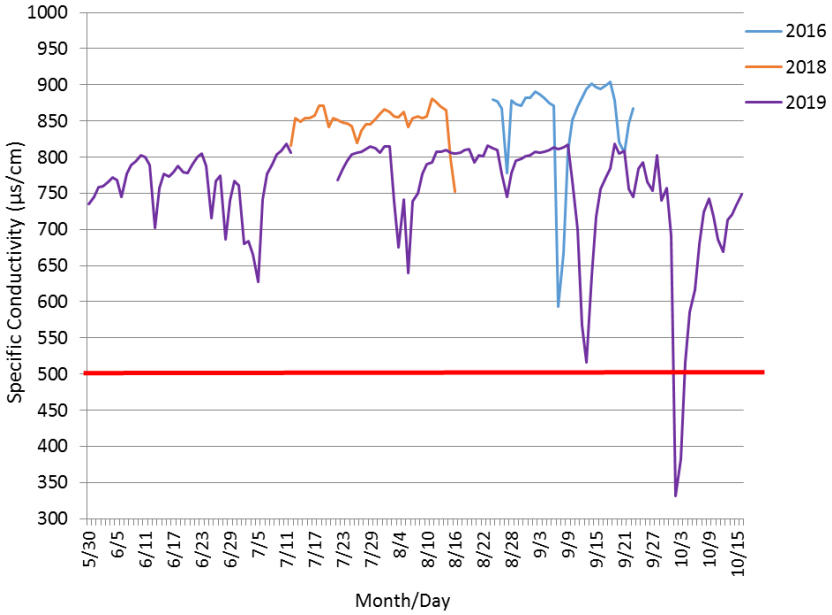
a.) Temperature (^{o}C)



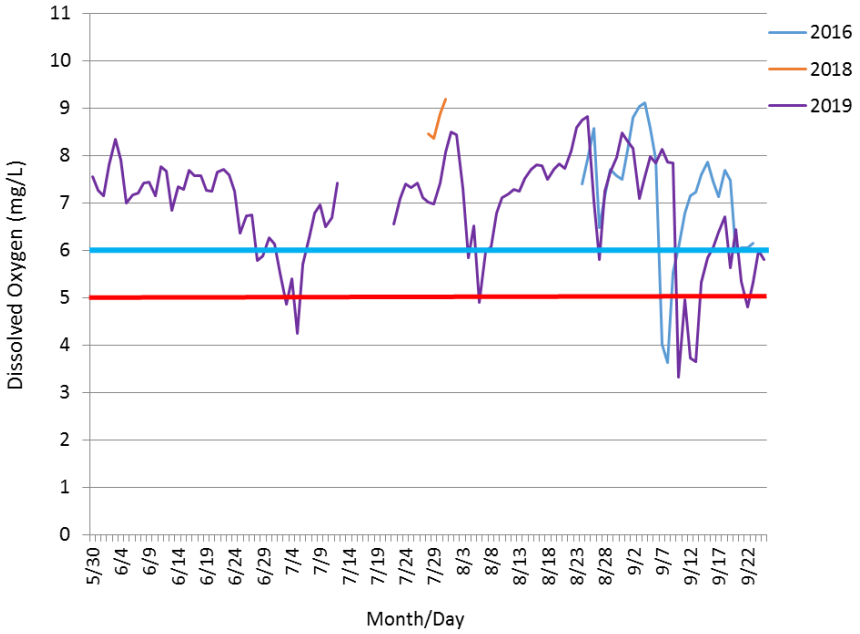
b.) pH

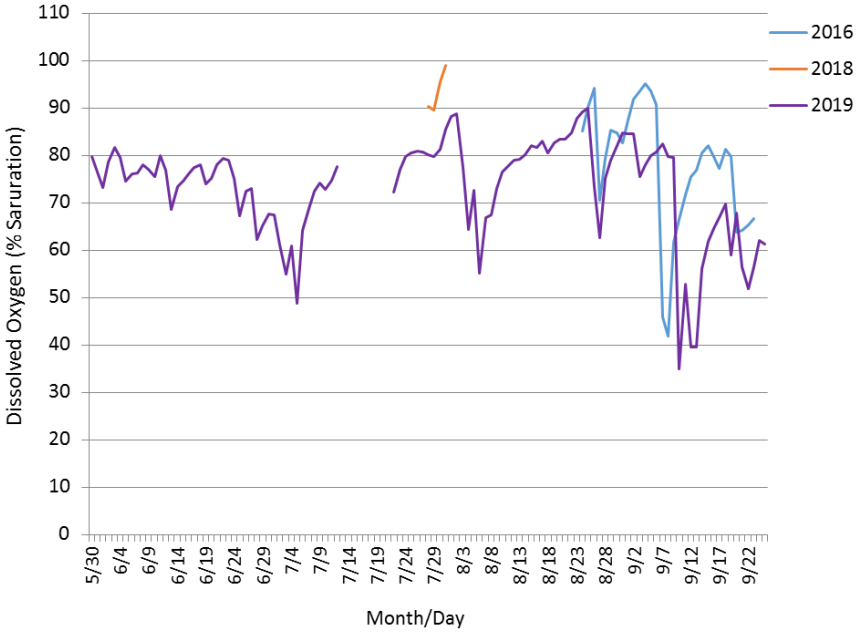


c.) Specific conductivity (µs/cm)



d.) Dissolved oxygen concentration (mg/L) and percent saturation; for concentration (mg/L) the red line indicates the minimum dissolved oxygen concentration for classification as a Warm Water Sport Fisheries and the blue line indicates the minimum dissolved oxygen concentration for classification as a Cold Water Fisheries.



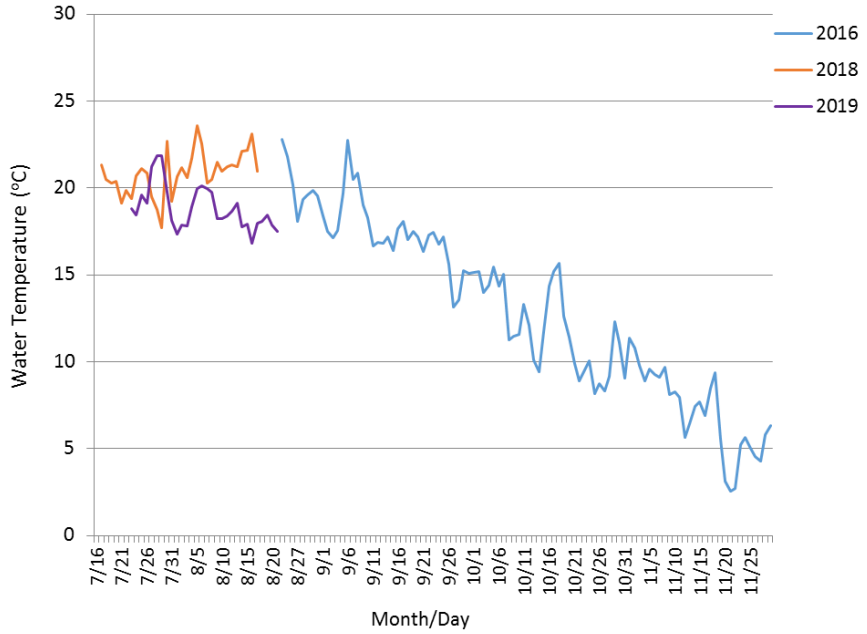


South of Hillcrest

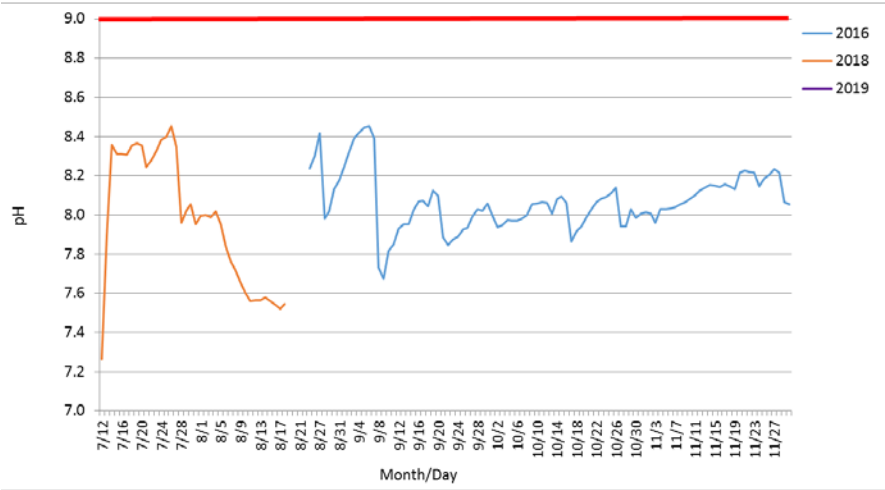
The continuous monitoring station located on Mole Creek south of Hillcrest Road is almost mid-way between the 6 established discrete water quality sampling locations. The pH probe malfunctioned in 2019, resulting in inaccurate data. TDS and salinity concentrations were only measured in 2016 (Figure 33).

Figure 33. Measure parameters from the Eureka continuous monitoring unit deployed on the Mole Creek sampling station located south of Hillcrest Road in Ozaukee County, WI.

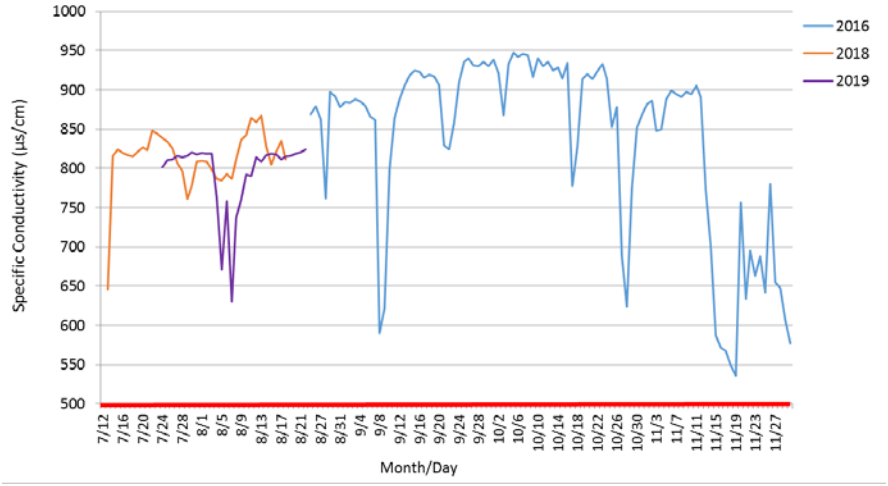
a.) Temperature (°C)



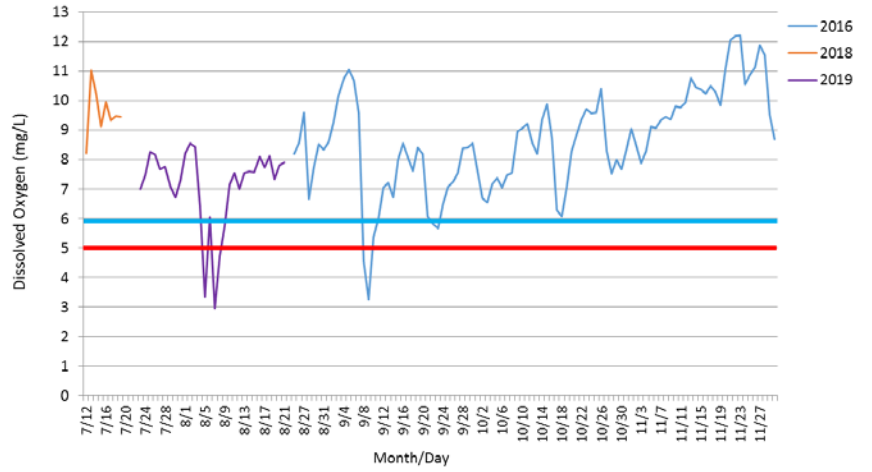
b.) pH

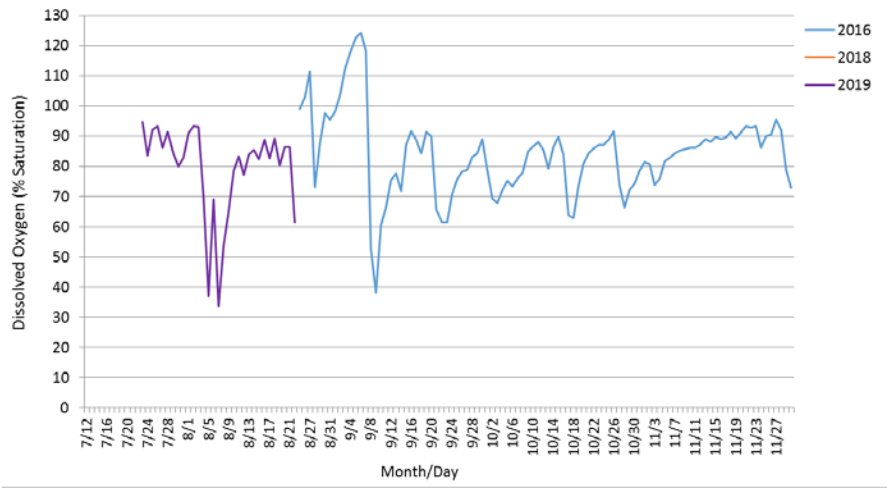


c.) Specific conductivity (µs/cm)

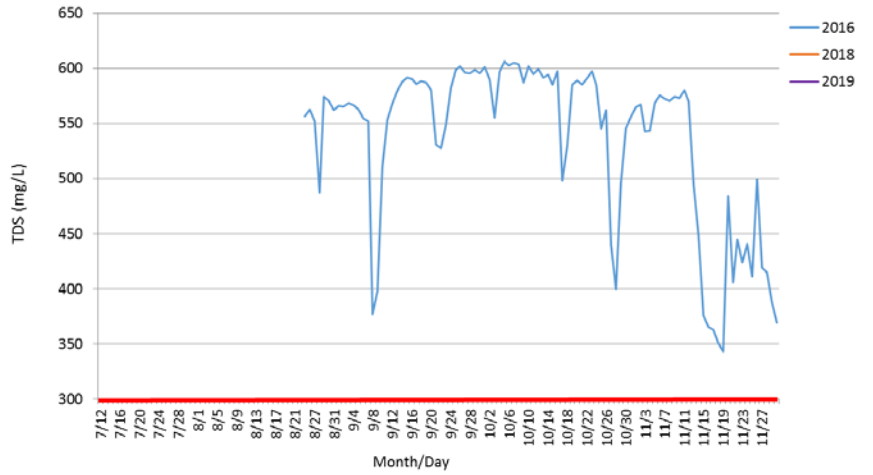


d.) Dissolved oxygen concentration (mg/L) and percent saturation; the red line indicates the minimum dissolved oxygen concentration for classification as a Warm Water Sport Fisheries and the blue line indicates the minimum dissolved oxygen concentration for classification as a Cold Water Fisheries.

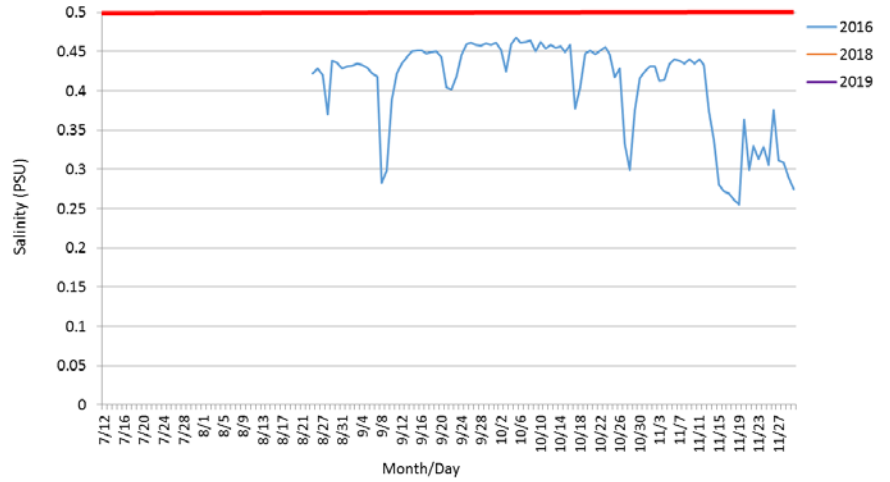




e.) TDS (mg/L)



f.) Salinity (PSU)

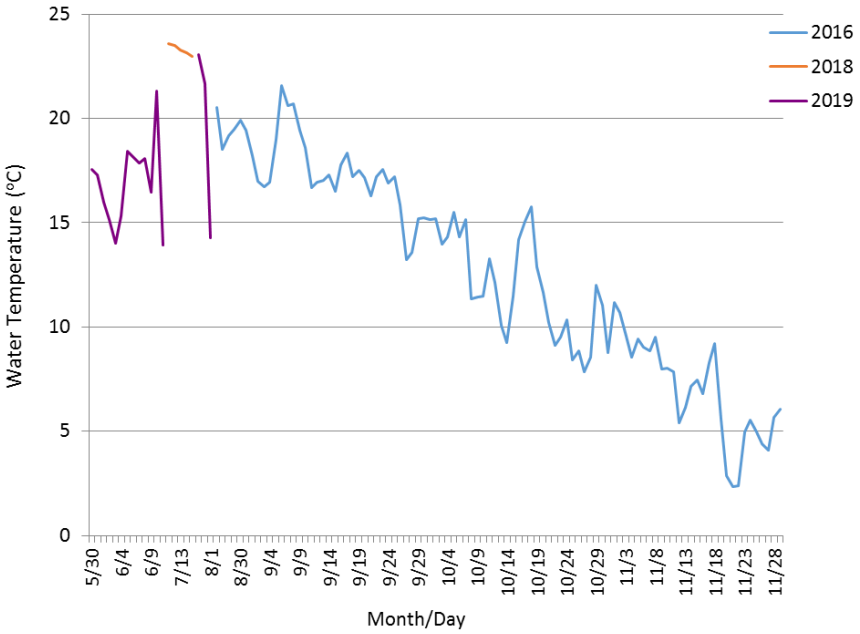


Downstream of Cedar Sauk Road

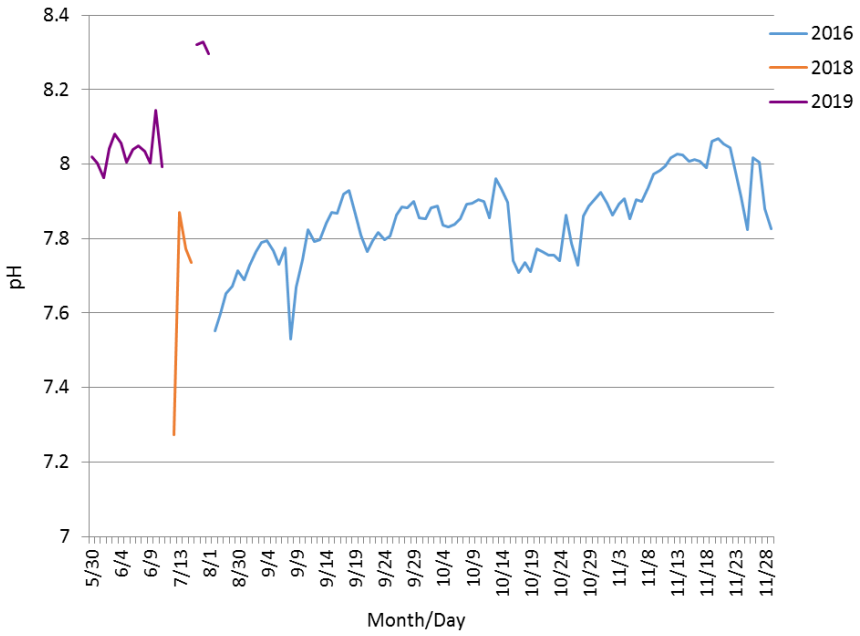
The continuous monitoring station located furthest downstream on Mole Creek was located near Cedar Sauk Road. In 2018, the monitoring unit malfunctioned, resulting in little and incomplete data (Figure 34).

Figure 34. Measure parameters from the Eureka continuous monitoring unit deployed on the Mole Creek sampling station located downstream of Cedar Sauk Road in Ozaukee County, WI.

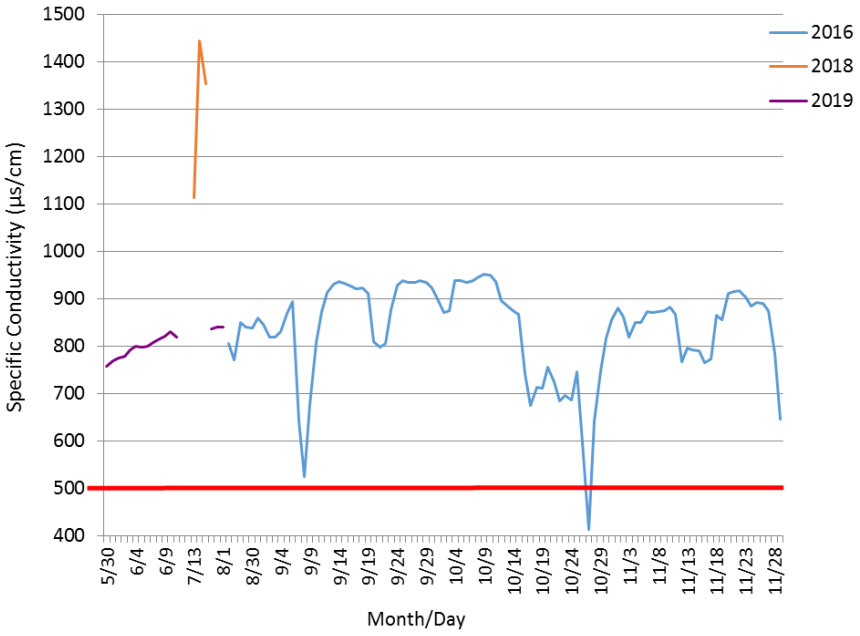
a.) Temperature (^{o}C)



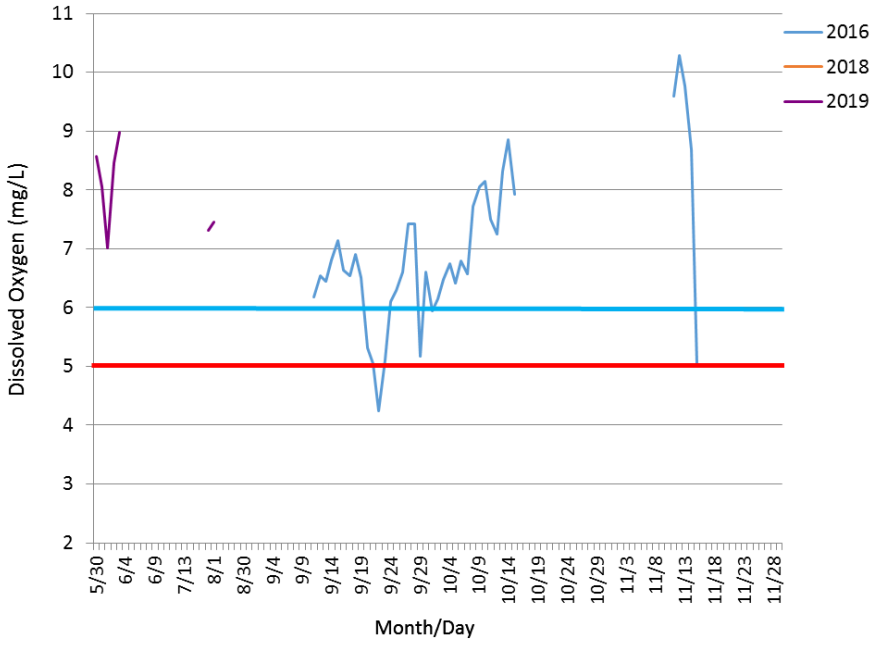
b.) pH

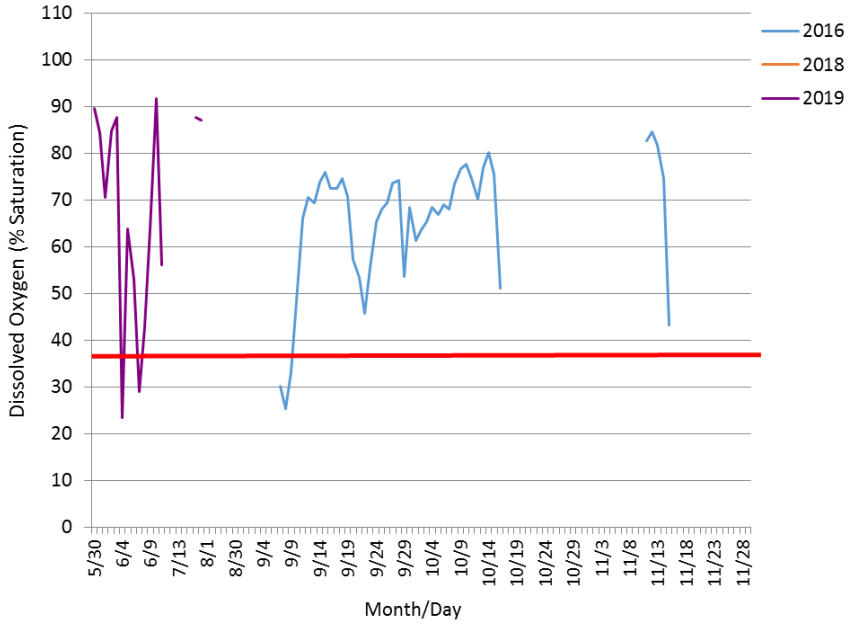


c.) Specific conductivity (µs/cm)



d.) Dissolved oxygen concentration (mg/L) and percent saturation; the red line indicates the minimum dissolved oxygen concentration for classification as a Warm Water Sport Fisheries and the blue line indicates the minimum dissolved oxygen concentration for classification as a Cold Water Fisheries.





E. coli Analysis

Enteric bacteria, such as *E. coli*, is a useful metric when assessing the potential for enteric pathogens in streams. A bacterium belonging to the Enterobacteriaceae family, *E. coli* resides in the intestines of humans and other warm blooded animals. In general, E. coli counts are significantly higher when streams are sampled immediately following a significant (0.5") rain event than during base flow events, indicating fecal contamination is entering the system through storm water runoff. The state of Wisconsin has not yet adopted a standard for *E. coli*; instead it has criteria for fecal coliform as an indicator of fecal contamination (WDNR & MMSD 2018). The USEPA has established recommended minimum criteria for *E. coli* that suggest that the geometric mean of all samples should not exceed 126 colony forming units (CFU) per 100 mL and not more than 10 percent of samples to exceed 400 CFU/100 mL (USEPA 1986a).

Two stations (below the confluence south of Hwy 33 and upstream of Cedar Sauk) had *E. coli* counts slightly above the 400 CFU/100 mL target in 2016 (Table 31 and 32, Figure 24). *E. coli* counts were consistently high, with geometric means above 400 CFU/100 mL in 2017 across all sampling stations; these high values are due to the very high counts occurring at all sites in the September water samples (Table 32). No geometric means above 400 CFU/100 mL were detected among the 2018 and 2019 samples. The current data does not suggest any obvious point source of *E. coli* in the Mole Creek watershed.

Table 31. *E. coli* geometric mean (100 CFU/100 mL) of all discrete water quality sampling stations on Mole Creek from 2016-2019. Values in red indicate results higher than the criterion set by WDNR and MMSD (2018) and USEPA. Stations are listed from furthest upstream to furthest downstream.

Site	Location	Year	Geometric Mean
10047105	Headwaters	2016	389.6
		2017	844.8
		2018	286.9
		2019	362.9
10046984	Below Confluence S of HWY 33	2016	449.2
		2017	623.5
		2018	171.2
		2019	307.6
10046985	South of Hillcrest	2016	394.9
		2017	784.9
		2018	307.1
		2019	322.9
10016375	Upstream of Cedar Sauk	2016	400.3
		2017	860.8
		2018	264.1
		2019	385.6
10008815	Pleasant Valley Rd	2016	207.9
		2017	538.0
		2018	143.9
		2019	158.6
1000816	Co. Hwy O	2016	173.4
		2017	437.7
		2018	145.3
		2019	163.5

Examining geometric mean *E. coli* counts per month within each year suggests a potential correlation between *E. coli* growth and water temperature (Table 32). Mean values at each station and across the stream were highest when the monthly average water temperature of the Creek was above 18^{o}C, with the exception of October 2017. Precipitation occurring within the Mole Creek watershed prior to both of the October 2017 sampling dates may have influenced *E. coli* counts in the collected water samples: COCORAHS (2020) recorded 0.5" of rain on October 15 and 0.44" on October 23, 2017. This precipitation may have led to increased rates of runoff, although other abiotic factors such as wind velocity, water velocity, robustness of the riparian zone, and surrounding land use can all affect *E. coli* counts.

Table 32. *E. coli* levels (CFU/100 mL) per sampling location per year as measured by SLOH versus monthly average water temperature (°C) for the discrete water quality sampling stations Mole Creek. Values in red indicate a result above 400 CFU/100 mL suggested by WDNR and MMSD (2018) and USEPA.

	2016			
Location	September		November	
	E. coli	Water Temp	*E. coli*	Water Temp
Headwaters	1250.2	16.9	126.3	8.8
S of HWY 33	1141.2	17.5	176.8	8.4
South of Hillcrest	868.2	19.0	179.6	9.2
Upstream of Cedar Sauk	818.3	19.0	195.9	9.8
Pleasant Valley Rd	284.6	18.2	151.8	10.1
Co. Hwy O	290.7	18.6	103.4	10.8
Geomean/Average	**661.6**	**18.2**	**152.0**	**9.5**

	2017									
Location	April		June		August		September		October	
	E. coli	Water Temp	*E. coli*	Water Temp	*E. coli*	Water Temp	*E. coli*	Water Temp	*E. coli*	Water Temp
Headwaters	365.0	9.2	365.0	14.4	517.0	16.3	18,600.0	17.4	532.6	11.8
S of HWY 33	272.0	9.5	219.0	15.3	488.0	17.0	11,120.0	17.9	426.3	11.9
South of Hillcrest	387.0	9.8	326.0	18.1	219.0	18.7	23,590.0	18.5	599.0	12.7
Upstream of Cedar Sauk	308.0	10.0	411.0	20.8	365.0	18.9	34,480.0	18.8	505.3	13.0
Pleasant Valley Rd	105.0	10.5	291.0	16.6	204.0	19.0	12,590.0	18.6	555.9	12.3
Co. Hwy O	150.0	10.8	115.0	17.7	201.0	20.6	26,130.0	20.0	278.6	12.8
Geomean/Average	**239.0**	**10.0**	**266.5**	**17.1**	**306.4**	**18.4**	**19,521.5**	**18.5**	**469.0**	**12.4**

	2018							
Location	July		August		September		October	
	E. coli	Water Temp	*E. coli*	Water Temp	*E. coli*	Water Temp	*E. coli*	Water Temp
Headwaters	1120.0	17.5	613.0	17.2	411.0	12.2	24.0	8.3
S of HWY 33	109.0	18.5	411.0	17.5	548.0	12.2	35.0	8.2
South of Hillcrest	1203.0	18.9	548.0	18.8	435.0	12.9	31.0	8.4
Upstream of Cedar Sauk	1553.0	22.4	365.0	18.5	260.0	13.3	33.0	8.5
Pleasant Valley Rd	192.0	20.5	231.0	18.4	276.0	13.4	35.0	8.5
Co. Hwy O	100.0	21.9	488.0	20.2	326.0	14.3	28.0	9.1
Geomean/Average	**404.5**	**19.9**	**422.4**	**18.4**	**363.1**	**13.1**	**30.7**	**8.5**

	2019							
Location	May		July		September		October	
	E. coli	Water Temp	*E. coli*	Water Temp	*E. coli*	Water Temp	*E. coli*	Water Temp
Headwaters	387.0	14.0	248.0	20.0	1986.0	17.0	91.0	9.2
S of HWY 33	179.0	14.9	219.0	20.5	1986.0	17.5	115.0	9.1
South of Hillcrest	179.0	16.4	365.0	22.0	1733.0	19.0	96.0	9.2
Upstream of Cedar Sauk	161.0	17.7	411.0	22.4	2420.0	20.1	138.0	9.4
Pleasant Valley Rd	58.0	17.2	248.0	21.9	411.0	19.1	107.0	9.3
Co. Hwy O	70.0	15.3	326.0	22.5	326.0	20.4	96.0	9.5
Geomean/Average	**141.7**	**15.9**	**295.0**	**21.6**	**1141.8**	**18.9**	**106.1**	**9.3**

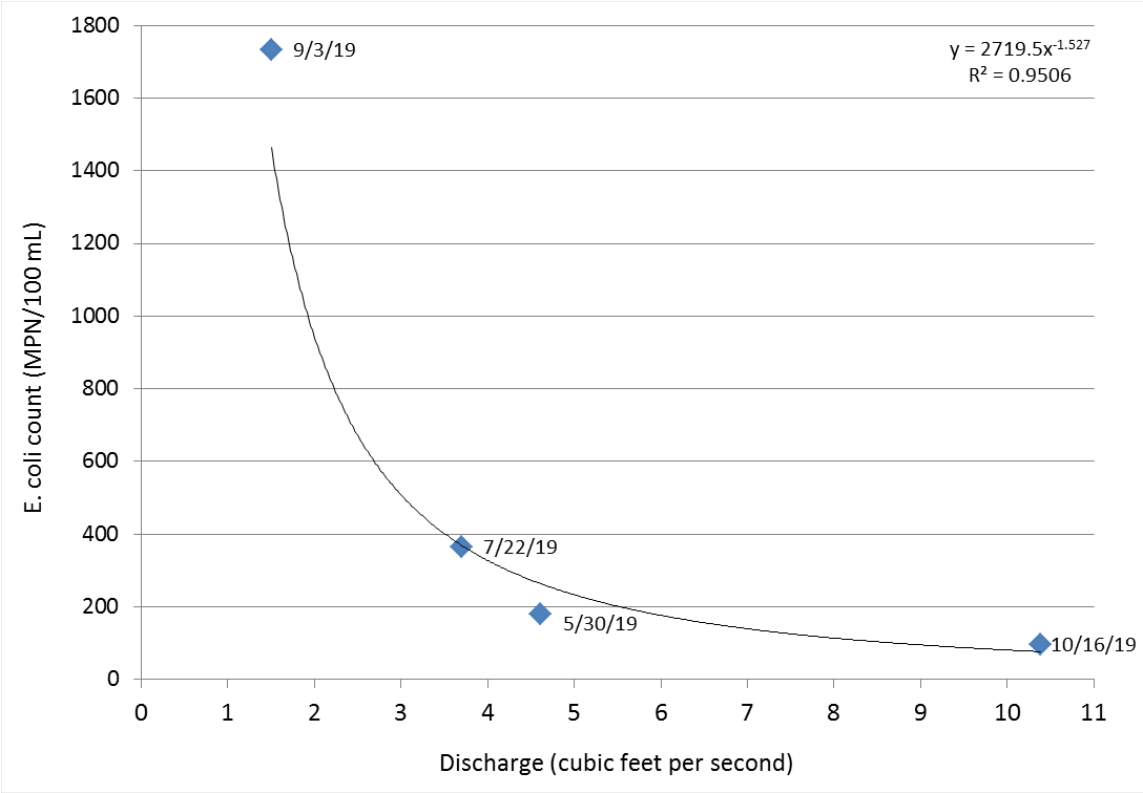
Daily discharge was calculated using stream flow data measured during water sampling events on Mole Creek at the south of Hillcrest station in 2019. Flow data was collected using a velocity meter that measures ft/sec to the thousandths. Prior to 2019, a less sensitive meter was utilized during velocity measurements. Therefore, only the 2019 relationship between *E. coli* counts and discharge is presented.

E. coli exhibit an exponential growth rate, with fastest growth occurring between 25° and 30°C. Additionally, bacterial growth is directly proportional to algal growth in freshwater environments (Byappanahalli et al. 2003, Nyguyen 2006). At the south of Hillcrest sampling station, *E. coli* counts decreased exponentially with increasing discharge (Table 33, Figure 35). Fitting a power trend line using regression analysis to the data results in an R^2 value of 0.95; however, a larger dataset is needed to accurately determine a line of best fit and establish an adequate baseline.

Table 33. Daily discharge calculations taken from flow data measured at the south of Hillcrest station along with *E. coli* and measured water temperature at the time of water collection on Mole Creek in 2019.

Sampling Event Date	Discharge (cfs)	*E. coli* count (CFU/100 mL)	Water Temp (°C)
5/30/2019	4.61	179	16.4
7/22/2019	3.70	365	22.0
9/3/2019	1.50	1733	19.0
10/16/2019	10.39	96	9.2

Figure 35. Comparison of *E. coli* results and discharge in 2019 at the Mole Creek South of Hillcrest water quality sampling station.



Section 3: Ulao Creek Results

Measured values from the discrete sampling events occurring from September 2016 to October 2019 in the Ulao Creek Watershed were summarized for each location and parameter. A total of 18 sampling events occurred at each of the 9 stations in the Ulao Creek Watershed: 4 in 2016, 6 in 2017, 4 in 2018, and 4 in 2019 (Figure 4, Tables 1-2). Of the 9 sampling stations, 2 were located on Kaul Creek, a small tributary to Ulao Creek. Twenty-two parameters were assessed during each sampling event at every station, 5 of which were analyzed by the SLOH. The SLOH has a limit of detection and limit of quantitation the parameters analyzed in the laboratory (Table 4). Results that were reported as "ND" (none detected) indicated the concentration of a specific parameter was below the limit of detection. For results that are below the limit of quantitation, there is a lower degree of confidence in the precision of the reported result.

The mean, median, maximum, minimum, interquartile range (IQR, or the difference between the 75^{th} and 25^{th} percentiles), number of samples (n), and standard deviation were calculated for the focus parameters: chloride concentration, orthophosphate, total phosphorus, total suspended solids, *E. coli* dissolved oxygen concentration, pH, conductivity, salinity, TDS, turbidity, and water temperature.

Chloride

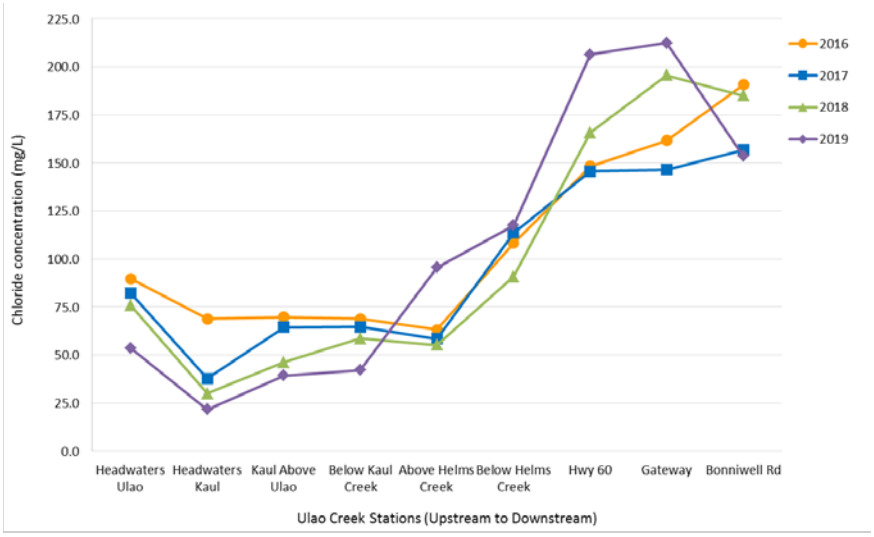
The WDNR (2019) has set the target concentration of chloride in Wisconsin's aquatic systems as less than 395 mg/L for chronic exposure and 757 mg/L for acute exposure (Table 17).

All water samples taken at the 9 Ulao and Kaul Creek stations from 2016 to 2019 had average chloride concentrations below 395 mg/L (Table 34, Figure 36). Measured mean chloride concentration values increased between the stations located above Helms Creek (a tributary to Ulao Creek) and downstream to Bonniwell Road in 2016 and 2017, with a decrease in mean concentration from the Bonniwell Road water samples in 2018 and 2019. Amount of precipitation received during the sampling period is correlated with amount of runoff and additional investigation regarding the rate and amount of precipitation received during the 4 sampling seasons is needed to clarify probable causes pertaining to the decrease of the 2018 and 2019 Bonniwell Road mean chloride concentration values.

Table 34. Chloride concentration (mg/L) summary from discrete samples analyzed by SLOH from the 9 water quality sampling stations in the Ulao Creek Watershed in Ozaukee County, WI.

Station	Location	Year	Median	Mean	Min	Max	IQR	n	Std Dev
10046975	Ulao Headwaters	2016	90.1	89.7	79.8	98.8	9.0	4	8.1
		2017	80.3	82.3	72.6	94.9	11.8	6	8.7
		2018	75.2	76.0	69.9	83.7	9.3	4	6.0
		2019	65.9	66.5	53.8	80.5	11.7	4	11.3
10047103	Kaul Headwaters	2016	70.3	68.9	43.2	91.9	39.8	4	25.0
		2017	38.5	37.7	16.3	58.8	18.3	6	15.3
		2018	29.9	30.0	27.1	32.9	3.3	4	2.1
		2019	26.3	26.9	11.2	43.6	8.6	4	13.2
10047104	Kaul Above Ulao	2016	68.5	69.8	67.6	74.6	2.8	4	3.3
		2017	63.4	64.4	58.7	73.1	8.5	6	5.8
		2018	51.6	46.3	26.4	55.7	15.1	4	11.6
		2019	45.0	39.3	19.0	53.9	17.5	4*	18.1
10046976	Below Kaul Creek	2016	68.2	68.9	63.7	75.5	3.8	4	4.9
		2017	63.5	64.6	58.8	73.6	9.1	6	6.1
		2018	58.4	58.7	51.2	66.7	14.5	4	7.3
		2019	50.1	51.8	44.2	62.6	12.3	4	8.8
10046981	Above Helms Creek	2016	62.2	63.2	55.9	72.5	7.7	4	7.1
		2017	59.9	58.5	46.6	65.5	8.9	6	7.3
		2018	55.1	55.3	47.5	63.4	15.2	4	7.6
		2019	47.3	95.7	34.1	254.0	64.5	4	105.9
10046982	Below Helms Creek	2016	106.4	108.4	84.8	136.0	33.3	4	23.8
		2017	111.0	113.6	66.7	170.0	75.4	6	45.2
		2018	83.6	90.8	74.1	122.0	30.2	4	18.9
		2019	68.9	117.5	57.4	275.0	66.3	4	105.3
10028775	Hwy 60	2016	128.0	148.3	103.0	234.0	40.3	4	58.5
		2017	140.0	145.7	101.0	189.0	64.5	6	38.5
		2018	136.0	165.8	109.0	282.0	102.5	4	69.0
		2019	100.5	206.5	58.8	566.0	141.1	4	240.6
10046983	Gateway	2016	133.0	161.8	114.0	267.0	38.3	4	70.7
		2017	147.0	146.5	114.0	188.0	44.8	6	29.9
		2018	197.0	195.8	110.0	279.0	144.5	4	73.3
		2019	113.9	212.5	82.2	540.0	138.7	4	219.3
10028773	Bonniwell Rd	2016	165.0	190.8	124.0	309.0	62.8	4	81.6
		2017	150.5	156.8	120.0	206.0	44.8	6	33.3
		2018	174.5	185.0	124.0	267.0	103.0	4	64.9
		2019	126.5	153.6	92.2	269.0	67.5	4	79.7

Figure 36. Chloride concentration (mg/L) per year per Ulao and Kaul Creek water quality sampling stations in Ozaukee County, WI.



Total Phosphorus and Orthophosphate (Dissolved Reactive Phosphorus)

Phosphorus was analyzed in samples as total phosphorus and total reactive phosphorus, also called orthophosphate. Phosphorus concentrations can fluctuate annually due to the number and severity of rain events and soil-disturbing activities occurring both upstream and near a sampling station. The Wisconsin water quality standard, established under NR102 (2019), for desirable phosphorus concentration in a stream environment is less than 0.075 mg/L (Table 17).

The annual mean concentration of phosphorous measured from the collected water samples collected exceeded the 0.075 mg/L criteria at every station during each sampling year with the exception of 2018 at Kaul above Ulao sampling station There is a general trend of decreasing phosphorus concentrations as the river flows downstream, with mean values plateauing and remaining steady at the Above Helms Creek Station (Table 35a, Figure 37a).

As no Wisconsin state standard exists for orthophosphate, the WDNR utilizes the federal water quality standard of a maximum level of 0.1 mg/L (USEPA 1986) (Table 17). All average values per sampling location per year had concentrations of orthophosphate below the USEPA recommendation (Table 35b, Figure 37b). Mean orthophosphate values exceeded the suggested maximum at the 2 furthest upstream stations in 2016 (Headwaters Ulao and Headwaters Kaul) while the mean concentration continued to exceeded 0.1 mg/L at the Headwaters Ulao station in 2017, 2018, and 2019. Two other stations, one on Kaul Creek and the other immediately below the Kaul Creek confluence on Ulao, had mean values greater than 0.1 mg/L in 2018 while sampling station below Kaul Creek exceeded 0.1 mg/L again in 2019.

Table 34. Total phosphorus and orthophosphate concentrations (mg/L) summary from discrete samples analyzed by SLOH from the 9 water quality sampling stations in the Ulao Creek Watershed in Ozaukee County, WI. Values in red indicate a measure concentration above the desirable phosphorus concentration of 0.075 mg/L in Wisconsin streams.

a.) Total phosphorus

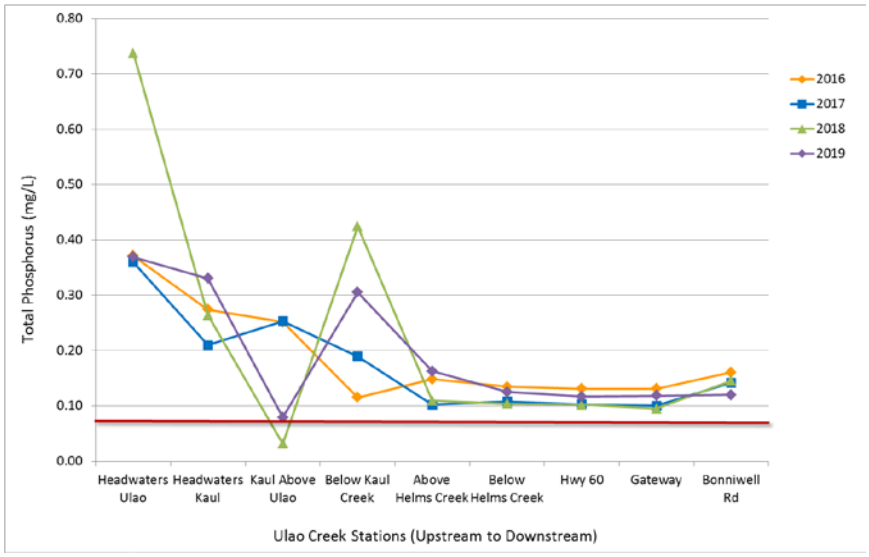
Station	Location	Year	Median	Mean	Min	Max	IQR	n	Std Dev
10046975	Ulao Headwaters	2016	0.170	0.371	0.077	1.070	0.345	4	0.471
		2017	0.326	0.360	0.051	0.661	0.460	6	0.271
		2018	0.757	0.737	0.115	1.320	1.096	4	0.551
		2019	0.217	0.369	0.072	0.970	0.373	4	0.414
10047103	Kaul Headwaters	2016	0.265	0.274	0.155	0.411	0.204	4	0.130
		2017	0.215	0.210	0.114	0.302	0.034	6	0.061
		2018	0.298	0.264	0.121	0.339	0.122	4	0.085
		2019	0.269	0.330	0.060	0.724	0.454	4	0.321
10047104	Kaul Above Ulao	2016	0.200	0.252	0.069	0.538	0.291	4	0.222
		2017	0.279	0.253	0.047	0.487	0.155	6	0.156
		2018	0.247	0.032	0.159	0.612	0.279	4	0.178
		2019	0.365	0.441	0.079	0.954	0.629	4	0.430
10046976	Below Kaul Creek	2016	0.107	0.115	0.070	0.178	0.071	4	0.051
		2017	0.159	0.189	0.049	0.443	0.125	6	0.142
		2018	0.458	0.425	0.138	0.645	0.349	4	0.194
		2019	0.304	0.305	0.085	0.528	0.427	4	0.250
10046981	Above Helms Creek	2016	0.111	0.148	0.070	0.302	0.060	4	0.104
		2017	0.095	0.102	0.071	0.148	0.045	6	0.031
		2018	0.120	0.110	0.054	0.145	0.068	4	0.037
		2019	0.155	0.163	0.066	0.276	0.167	4	0.106
10046982	Below Helms Creek	2016	0.122	0.134	0.069	0.226	0.048	4	0.066
		2017	0.108	0.108	0.063	0.154	0.043	6	0.034
		2018	0.115	0.104	0.052	0.135	0.062	4	0.034
		2019	0.092	0.126	0.071	0.248	0.072	4	0.084
10028775	Hwy 60	2016	0.113	0.131	0.068	0.230	0.041	4	0.069
		2017	0.101	0.103	0.066	0.148	0.034	6	0.030
		2018	0.098	0.103	0.055	0.159	0.063	4	0.038
		2019	0.085	0.117	0.072	0.225	0.051	4	0.073
10046983	Gateway	2016	0.112	0.131	0.069	0.233	0.045	4	0.071
		2017	0.094	0.100	0.077	0.137	0.033	6	0.239
		2018	0.100	0.095	0.054	0.125	0.046	4	0.027
		2019	0.097	0.118	0.071	0.208	0.072	4	0.064
10028773	Bonniwell Rd	2016	0.167	0.161	0.105	0.204	0.068	4	0.047
		2017	0.142	0.140	0.090	0.192	0.033	6	0.035
		2018	0.139	0.145	0.071	0.233	0.102	4	0.060
		2019	0.114	0.120	0.071	0.183	0.066	4	0.051

b.) Orthophosphate

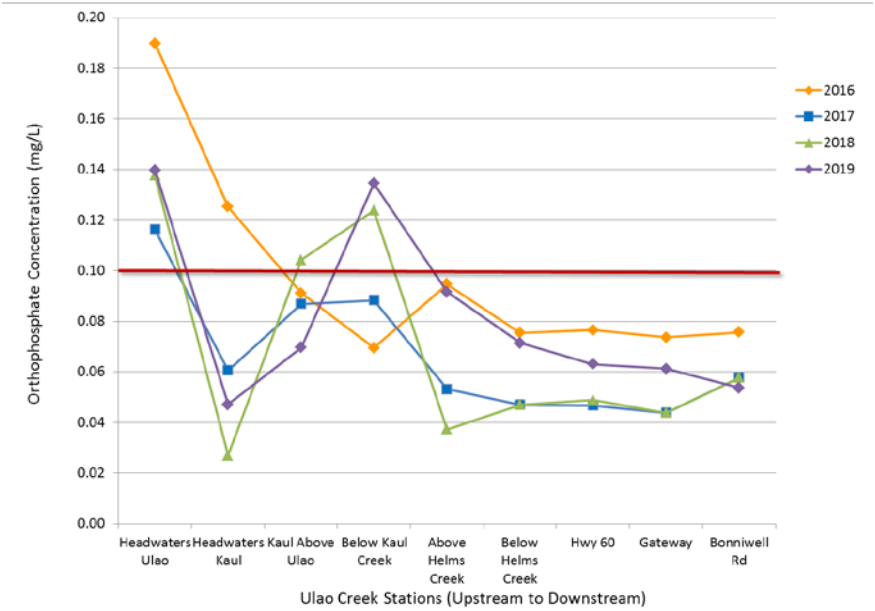
Station	Location	Year	Median	Mean	Min	Max	IQR	n	Std Dev
10046975	Ulao Headwaters	2016	0.081	0.190	0.038	0.560	0.181	4	0.249
		2017	0.102	0.116	0.027	0.286	0.048	6	0.090
		2018	0.135	0.138	0.047	0.234	0.118	4	0.068
		2019	0.148	0.140	0.049	0.214	0.136	4	0.085
10047103	Kaul Headwaters	2016	0.126	0.125	0.078	0.172	0.060	4	0.043
		2017	0.051	0.061	0.042	0.094	0.034	6	0.023
		2018	0.029	0.027	0.006	0.043	0.028	4	0.015
		2019	0.035	0.047	0.027	0.093	0.027	4	0.031
10047104	Kaul Above Ulao	2016	0.092	0.091	0.037	0.144	0.085	4	0.054
		2017	0.078	0.087	0.026	0.171	0.055	6	0.052
		2018	0.080	0.104	0.047	0.210	0.084	4	0.063
		2019	0.062	0.070	0.055	0.100	0.022	4	0.021
10046976	Below Kaul Creek	2016	0.069	0.069	0.034	0.106	0.047	4	0.033
		2017	0.082	0.088	0.026	0.164	0.061	6	0.051
		2018	0.129	0.124	0.000	0.238	0.161	4*	0.089
		2019	0.079	0.134	0.058	0.321	0.081	4	0.125
10046981	Above Helms Creek	2016	0.064	0.095	0.035	0.216	0.058	4	0.082
		2017	0.052	0.053	0.037	0.075	0.026	6	0.016
		2018	0.037	0.037	0.002	0.074	0.049	4	0.027
		2019	0.086	0.092	0.047	0.147	0.073	4	0.049
10046982	Below Helms Creek	2016	0.060	0.075	0.034	0.148	0.039	4	0.050
		2017	0.051	0.050	0.028	0.071	0.014	6	0.015
		2018	0.048	0.047	0.022	0.071	0.032	4	0.018
		2019	0.053	0.071	0.045	0.136	0.031	4	0.043
10028775	Hwy 60	2016	0.064	0.077	0.033	0.146	0.036	4	0.049
		2017	0.045	0.048	0.028	0.075	0.013	6	0.016
		2018	0.052	0.049	0.022	0.069	0.032	4	0.018
		2019	0.046	0.063	0.038	0.122	0.025	4	0.039
10046983	Gateway	2016	0.060	0.074	0.033	0.142	0.040	4	0.048
		2017	0.045	0.046	0.026	0.071	0.013	6	0.015
		2018	0.047	0.044	0.021	0.060	0.025	4	0.015
		2019	0.045	0.061	0.041	0.114	0.021	4	0.035
10028773	Bonniwell Rd	2016	0.078	0.076	0.029	0.117	0.032	4	0.036
		2017	0.057	0.056	0.038	0.070	0.012	6	0.011
		2018	0.062	0.058	0.021	0.085	0.050	4	0.026
		2019	0.044	0.054	0.039	0.089	0.017	4	0.024

Figure 37. Total phosphorus and orthophosphate concentration (mg/L) per year per water quality sampling station on Ulao and Kaul Creek in Ozaukee County, WI. The red line is set at the established Wisconsin desirable total phosphorus concentration of 0.075 mg/L and orthophosphate concentration of .1 mg/L.

a.) Total phosphorus



b.) Orthophosphate



Total Suspended Solids

Currently, there are no set water quality criteria for total suspended solids (TSS) by either the State of Wisconsin or Federal government; however, the WDNR in conjunction with MMSD (2018) implement the regional Total Maximum Daily Load (TMDL) value of 12 mg/L as the allowable load and target concentration (Table 17). High concentrations of total suspended solids increase turbidity of the water, negatively impacting biological, chemical, and physical properties of a stream. While the TMDL allows

for an adequate establishment of a baseline in a waterbody, the chronic level and target number need further examination through additional studies.

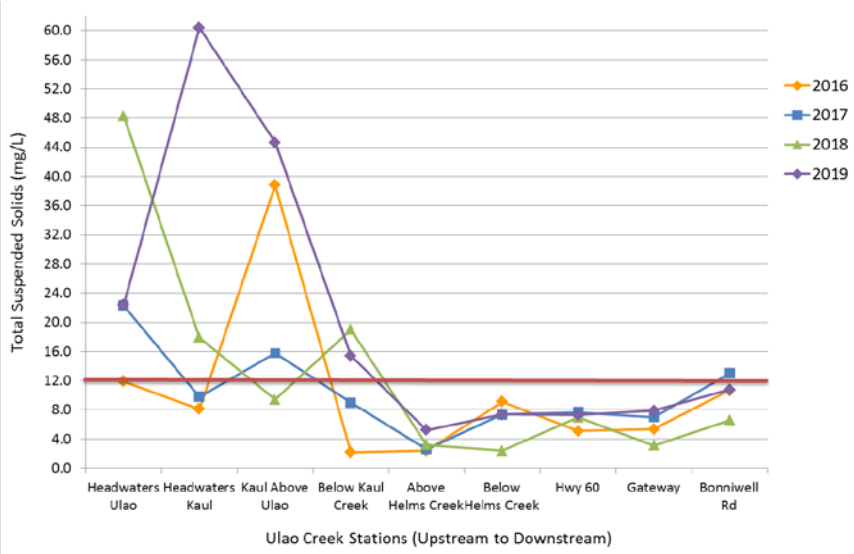
Annual mean TSS concentrations exceeded the 12 mg/L target concentration at several upstream locations over the 4 year study period and only one downstream station. Mean concentration values were above 12 mg/L at the Kaul Creek above Ulao station in 2016, 2017, and 2019. The furthest upstream station, the Headwaters of Ulao Creek, had mean concentrations exceeding the target in both 2017 and 2018 while the headwaters of Kaul Creek had TSS averages above 12 mg/L in 2018 and 2019. The station immediately below Kaul Creek also had high mean concentrations in 2018 and 2019. The furthest downstream sampling location, at Bonniwell Road, only exceeded the target criteria in 2017 (Table 35, Figure 38). However, many samples had TSS concentrations below the SLOH's level of detection over the course of the 4 year sampling period.

Table 35. TSS concentration (mg/L) summary from discrete samples analyzed by SLOH from the 9 water quality sampling stations in the Ulao Creek Watershed in Ozaukee County, WI. Values in red represent an average concentration above the recommended 12 mg/L regional TMDL.

Station	Location	Year	Median	Mean	Min	Max	IQR	n	Std Dev
10046975	Ulao Headwaters	2016	13.0	11.9	8.8	14.0	2.6	4*	2.8
		2017	25.5	22.3	7.0	45.5	23.0	6*	17.4
		2018	21.9	48.3	3.2	146.0	62.9	4	67.4
		2019	5.0	22.4	4.3	58.0	26.8	4*	30.8
10047103	Kaul Headwaters	2016	8.1	8.1	6.3	10.0	1.9	4*	2.7
		2017	7.6	9.8	4.3	24.0	3.9	6	7.3
		2018	19.3	17.9	7.2	26.0	10.8	4	8.5
		2019	60.4	60.4	10.8	110.0	49.6	4*	70.1
10047104	Kaul Above Ulao	2016	38.8	38.8	13.5	64.0	25.3	4*	35.7
		2017	9.3	15.8	4.8	28.7	23.5	6*	13.0
		2018	7.5	9.4	3.0	19.6	4.9	4	7.1
		2019	44.7	44.7	26.3	63.0	18.4	4*	26.0
10046976	Below Kaul Creek	2016	2.2	2.2	2.2	2.2	0.0	4*	N/A
		2017	5.8	9.0	3.0	18.3	7.7	6*	8.2
		2018	5.0	19.0	4.0	48.0	22.0	4*	25.1
		2019	5.0	15.4	2.8	38.5	17.9	4*	20.0
10046981	Above Helms Creek	2016	2.4	2.4	2.4	2.4	0.0	4*	N/A
		2017	2.4	2.6	2.0	3.5	0.8	6*	0.8
		2018	3.2	3.2	3.2	3.2	0.0	4*	N/A
		2019	4.0	5.3	3.8	8.0	2.1	4*	2.4
10046982	Below Helms Creek	2016	8.2	9.1	8.2	13.8	4.3	4*	4.4
		2017	7.5	7.4	3.4	13.5	5.1	6	3.8
		2018	2.4	2.4	2.0	2.8	2.2	4*	0.6
		2019	7.5	7.4	2.2	12.4	5.9	4	4.6
10028775	Hwy 60	2016	4.1	5.1	2.6	9.6	3.7	4	3.3
		2017	8.7	7.7	4.0	10.4	3.3	6	2.6
		2018	6.6	7.0	2.0	12.3	5.2	4*	5.2
		2019	7.3	7.3	5.2	9.3	2.1	4	1.8
10046983	Gateway	2016	3.8	5.4	2.4	11.4	3.5	4	4.1
		2017	5.5	7.0	3.3	12.3	6.2	6	3.9
		2018	3.0	3.1	2.8	3.6	0.4	4*	0.4
		2019	7.3	7.9	3.6	13.4	3.2	4	4.1
10028773	Bonniwell Rd	2016	10.2	10.7	8.0	14.4	1.8	4	2.7
		2017	9.9	13.0	7.0	21.8	8.9	6	6.5
		2018	6.5	6.6	2.8	10.5	7.5	4	4.4
		2019	11.8	10.8	5.2	14.3	3.9	4	4.0

*one or more samples were below level of detection

Figure 38. TSS concentration (mg/L) per year per water quality sampling station on Ulao and Kaul Creek in Ozaukee County, WI. The red line indicates the TMDL target concentration of 12 mg/L.



E. coli

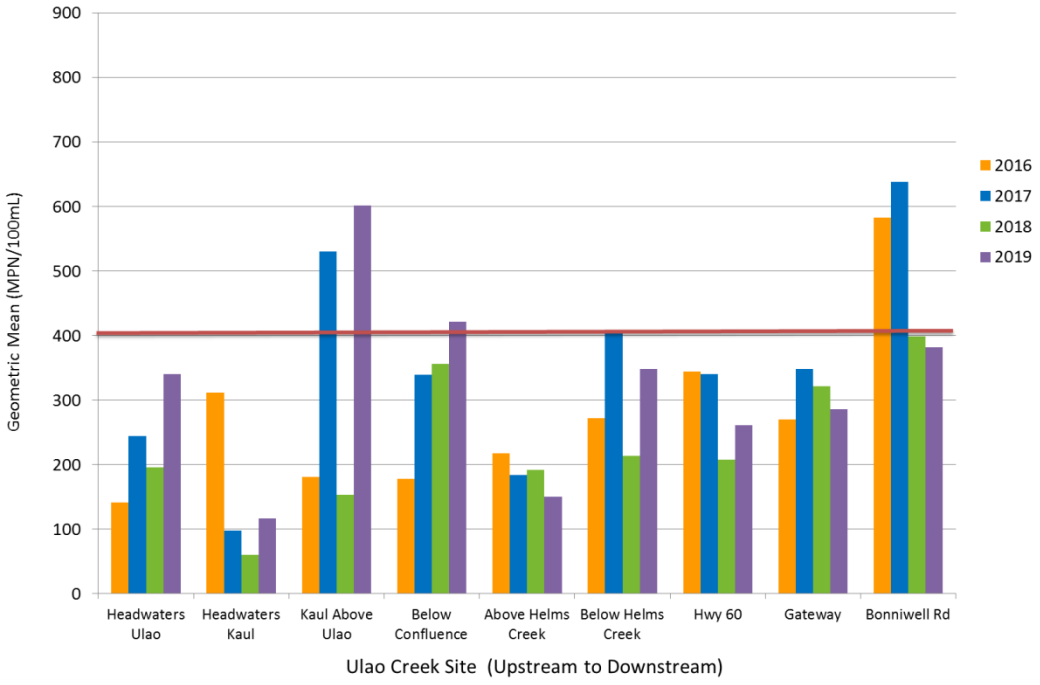
High bacteria concentrations can have a negative effect on streams as well as human health. Wisconsin State Recreational Use Standards state that fecal coliform levels are "not to exceed 400 CFU/100 mL" (colony forming units/100 milliliter sample; WDNR 1973, WDNR & MMSD 2018). WDNR recommended retesting for sites with results higher than 400 CFU/100 mL; retesting was not done for individual samples in this study. The USEPA has established recommended minimum criteria for *E. coli* that suggest that the geometric mean of all samples should not exceed 126 colony forming units (CFU) per 100 mL and not more than 10 percent of samples to exceed 400 CFU/100 mL (USEPA 1986a) (Table 17).

The geometric mean was used when summarizing the *E. coli* data as the bacteria naturally exhibits exponential growth. Means at 8 of 9 sampling locations were below 400 CFU/100 mL in 2016 (Bonniwell Road had a geometric mean of 582.6 CFU/100 mL). Geometric means exceeded 400 CFU/100 mL at Bonniwell Road again in 2017 and at the Kaul above Ulao station in both 2017 and 2019. The sampling station located below Helms Creek exceeded the criteria in 2017, and the station located below the Kaul Creek confluence had a geometric mean of 421.7 CFU/100 mL in 2019 (Table 36, Figure 39).

Table 36. *E. coli* concentration (CFU/100 mL) summary from discrete samples analyzed by SLOH from the 6 water quality sampling stations in the Ulao Creek Watershed in Ozaukee County, WI. Values in red represent a geometric mean above 400 CFU/100 mL.

Station	Location	Year	Median	Mean	Min	Max	IQR	n	Std Dev(P)
10046975	Ulao Headwaters	2016	156.0	141.8	93.0	185.0	66.5	4	39.4
		2017	179.5	244.2	71.0	3640.0	99.8	6	1300.0
		2018	385.0	195.9	23.0	816.0	594.3	4	337.3
		2019	600.5	340.2	61.0	2420.0	1369.0	4	965.9
10047103	Kaul Headwaters	2016	487.5	311.4	30.0	1986.0	912.8	4	765.4
		2017	60.5	97.6	13.0	1203.0	536.0	6	458.1
		2018	112.5	60.1	2.0	727.0	272.0	4	288.8
		2019	145.5	117.1	40.0	276.0	155.8	4	95.3
10047104	Kaul Above Ulao	2016	225.5	180.6	44.0	770.0	390.8	4	289.6
		2017	638.5	530.9	61.0	2590.0	412.0	6	813.7
		2018	215.5	153.1	32.0	579.0	331.0	4	218.7
		2019	1414.0	601.3	99.0	1553.0	727.0	4*	655.1
10046976	Below Kaul Creek	2016	244.5	178.1	50.0	510.0	328.8	4	192.1
		2017	461.0	339.2	68.0	1710.0	355.0	6*	588.5
		2018	601.5	356.7	49.0	1046.0	571.0	4	384.7
		2019	561.0	421.7	86.0	1986.0	1015.0	4	756.6
10046981	Above Helms Creek	2016	291.0	218.0	66.0	613.0	391.8	4	229.0
		2017	205.0	184.0	40.0	1120.0	168.0	6	344.7
		2018	262.0	191.8	40.0	548.0	251.5	4	189.6
		2019	115.0	150.1	77.0	517.0	143.0	4	180.9
10046982	Below Helms Creek	2016	351.5	272.2	83.0	921.0	550.8	4	345.4
		2017	216.0	408.3	93.0	9880.0	451.0	6	3583.3
		2018	328.5	213.7	47.0	613.0	424.3	4	240.4
		2019	363.5	348.4	96.0	1414.0	559.8	4	517.0
10028775	Hwy 60	2016	536.5	343.9	102.0	980.0	796.3	4	412.7
		2017	260.0	340.1	69.0	5120.0	172.9	6	1825.3
		2018	200.0	208.0	144.0	345.0	122.3	4	81.8
		2019	286.5	261.1	86.0	1046.0	501.8	4	387.2
10046983	Gateway	2016	318.0	269.7	89.0	727.0	368.0	4	250.1
		2017	204.0	348.8	99.0	6050.0	233.0	6	2173.8
		2018	378.0	321.4	173.0	435.0	115.0	4	102.4
		2019	237.5	285.9	108.0	1203.0	379.5	4	442.8
10028773	Bonniwell Rd	2016	732.5	582.6	172.0	1733.0	971.5	4	625.9
		2017	328.5	638.0	260.0	5760.0	979.0	6	1995.9
		2018	580.5	399.1	82.0	921.0	258.5	4	300.1
		2019	437.0	381.8	127.0	1046.0	493.8	4	355.9

Figure 39. *E. coli* concentration (CFU/100 mL) per year per water quality sampling station on Ulao and Kaul Creek in Ozaukee County, WI. The red line indicates the Wisconsin State Recreational Use Standards adapted for *E. coli* at 400 CFU/100 mL.



Dissolved Oxygen

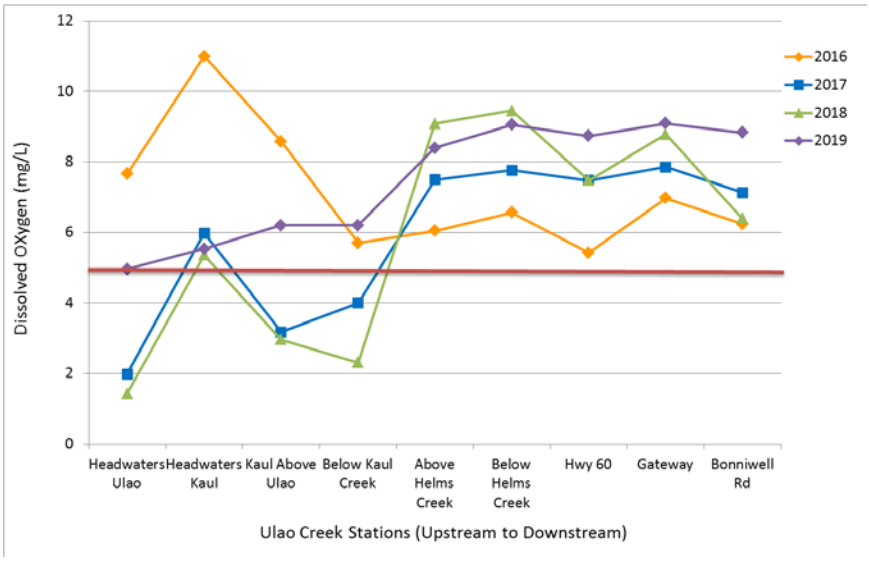
Dissolved oxygen concentration varies greatly with time of day and photosynthetic activity. Although Mole Creek is a cool-cold water stream, it is not officially categorized as a cold water (e.g., "trout") stream. WDNR Administrative Rule 102.04 (4a) states: "the dissolved oxygen content in many surface waters (including waters designated as a Warm Water Sport Fishery) may not be lowered to less than 5 mg/L at any time (WDNR 1973)" (Table 17).

Dissolved oxygen was measured using a held-hand multiparameter water quality instrument. Mean dissolved oxygen concentrations were below 5 mg/L at the Ulao Headwaters, Kaul Creek above Ulao, and the below Kaul Creek stations in 2017 and 2018 (Table 37, Figure 40).

Table 37. Dissolved oxygen concentration (mg/L) summary, measured using a handheld instrument, from the 9 water quality sampling stations in the Ulao Creek Watershed in Ozaukee County, WI.

Station	Location	Year	Median	Mean	Min	Max	IQR	n	Std Dev
10046975	Ulao Headwaters	2016	7.7	7.7	7.7	7.7	0.0	4	N/A
		2017	1.6	2.0	0.9	4.6	0.8	6	1.3
		2018	1.6	1.4	0.7	1.9	0.6	4	0.4
		2019	5.6	5.0	2.7	6.0	1.2	4	1.5
10047103	Kaul Headwaters	2016	11.0	11.0	11.0	11.0	0.0	4	N/A
		2017	6.1	6.0	4.9	7.4	1.2	6	1.0
		2018	5.9	5.4	1.1	8.6	4.3	4	2.7
		2019	5.9	5.5	2.6	7.7	1.6	4	2.2
10047104	Kaul Above Ulao	2016	8.6	8.6	8.6	8.6	0.0	4	N/A
		2017	2.5	3.2	0.8	7.0	2.2	6	2.2
		2018	2.7	3.0	0.9	5.6	3.8	4	2.0
		2019	6.1	6.2	4.8	7.8	2.7	4	1.6
10046976	Below Kaul Creek	2016	5.7	5.7	4.0	7.4	1.7	2	2.1
		2017	3.7	4.0	1.5	7.5	2.4	6	2.2
		2018	2.3	2.3	0.5	4.3	2.2	4	1.4
		2019	6.1	6.3	3.9	9.1	1.4	4	2.1
10046981	Above Helms Creek	2016	6.1	6.1	6.1	6.1	0.0	1	N/A
		2017	7.8	7.5	4.6	8.9	0.8	6	1.5
		2018	9.1	9.1	7.7	10.3	1.9	4	1.0
		2019	8.8	8.4	4.8	11.2	5.2	4	3.3
10046982	Below Helms Creek	2016	6.6	6.6	6.4	6.8	0.2	2	0.3
		2017	8.0	7.8	5.1	9.5	0.9	6	1.5
		2018	9.4	9.5	8.5	10.5	1.4	4	0.8
		2019	8.7	9.1	6.3	12.5	4.5	4	3.0
10028775	Hwy 60	2016	5.4	5.4	5.4	5.4	0.0	1	N/A
		2017	7.9	7.5	5.2	8.5	0.8	6	1.2
		2018	7.5	7.5	6.6	8.4	1.6	4	0.8
		2019	8.4	8.7	6.5	11.6	3.6	4	2.5
10046983	Gateway	2016	7.0	7.0	5.3	8.6	1.7	2	2.3
		2017	8.1	7.9	5.9	8.8	0.8	6	1.1
		2018	8.6	8.8	7.6	10.4	1.6	4	1.0
		2019	8.9	9.1	6.5	12.2	3.7	4	2.6
10028773	Bonniwell Rd	2016	6.2	6.2	6.2	6.2	0.0	1	N/A
		2017	7.1	7.1	6.6	7.5	0.4	6	0.3
		2018	6.3	6.4	5.3	7.7	2.1	4	1.0
		2019	8.8	8.8	5.7	12.0	1.7	4	2.6

Figure 40. Dissolved oxygen concentration (mg/L) per year per water quality sampling station on Ulao and Kaul Creek in Ozaukee County, WI. The red line indicates the minimum dissolved oxygen concentration for classification as a Warm Water Sport Fisheries.



Conductivity

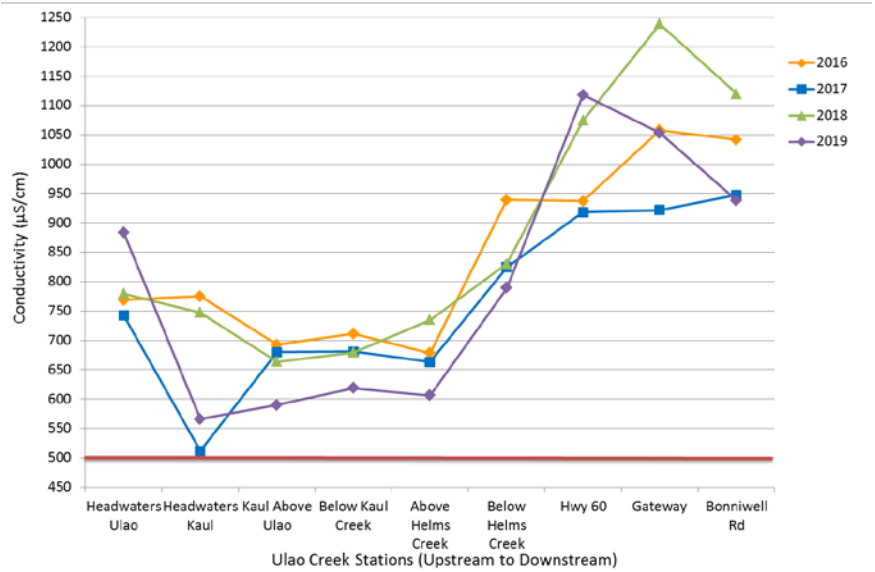
Conductivity in streams is naturally affected by geology that is influenced by the bedrock, soils, and ground water passing through. It can also be affected by discharges to streams such as chlorides, heavy metals, sewage, and nutrients (phosphates and nitrates). A conductivity reading of 150-500 µS/cm can provide for a healthy aquatic ecosystem and conductivity outside of this range could indicate the waterbody is not suitable for certain aquatic species (USEPA 2012) (Table 17).

In all 4 study years, the average daily maximum and mean conductivity values were significantly above the maximum recommended by USEPA (2012). All but 3 of the mean minimum values, 2 were measured at the Kaul Headwaters in 2017 and 2019 and 1 at Kaul above Ulao location in 2019, were below 500 µS/cm (Table 38, Figure 41). These high measurements require additional investigation, but may indicate high levels of nutrients or other pollutants entering the waterbody (Appendix B).

Table 38. Conductivity (µS/cm) summary, measured using a handheld instrument, from the 9 water quality sampling stations in the Ulao Creek Watershed in Ozaukee County, WI. Values in red indicate means above 500 µS/cm.

Station	Location	Year	Median	Mean	Min	Max	IQR	n	Std Dev
10046975	Ulao Headwaters	2016	771.5	768.8	680.0	852.0	46.8	4	70.3
		2017	766.0	742.5	618.0	832.0	61.3	12	66.1
		2018	777.0	780.0	720.0	846.0	67.0	4	44.7
		2019	664.5	884.0	557.0	2030.0	154.8	6	567.1
10047103	Kaul Headwaters	2016	769.0	775.0	594.0	968.0	353.0	4	208.1
		2017	492.0	511.3	283.0	648.0	166.5	12	111.2
		2018	585.0	747.5	516.0	1304.0	417.0	4	322.9
		2019	542.7	566.1	450.0	782.0	98.0	5	130.7
10047104	Kaul Above Ulao	2016	667.0	692.5	666.0	770.0	27.5	4	51.7
		2017	681.0	679.8	629.0	723.0	46.0	11	29.5
		2018	624.0	663.5	570.0	836.0	159.0	4	103.6
		2019	614.7	589.7	476.0	672.0	106.0	5	80.6
10046976	Below Kaul Creek	2016	706.0	711.1	668.5	764.0	37.4	4	40.1
		2017	684.0	681.2	634.0	722.0	50.5	12	28.6
		2018	679.0	679.5	584.0	776.0	129.0	4	71.8
		2019	623.0	618.5	501.0	649.0	33.5	5	74.3
10046981	Above Helms Creek	2016	661.5	678.3	644.0	746.0	26.3	4	45.9
		2017	659.5	663.0	603.0	708.0	37.3	12	31.1
		2018	749.5	734.8	645.0	795.0	88.5	4	55.9
		2019	601.0	606.4	504.0	700.0	41.0	5	71.1
10046982	Below Helms Creek	2016	873.8	939.5	785.5	1225.0	198.0	4	200.6
		2017	787.0	824.9	645.0	1069.0	174.5	12	131.9
		2018	856.5	830.5	574.0	1035.0	307.0	4	173.7
		2019	686.7	789.3	531.0	1351.0	22.0	5	321.4
10028775	Hwy 60	2016	820.0	937.3	812.0	1180.0	184.0	3	210.2
		2017	885.5	918.4	781.0	1250.0	121.8	12	127.6
		2018	1012.5	1074.5	876.0	1397.0	369.0	4	209.0
		2019	904.0	1118.3	778.0	1029.0	178.6	5	517.8
10046983	Gateway	2016	1030.0	1058.0	857.0	1355.0	258.0	4	203.1
		2017	916.0	922.2	811.0	1093.0	114.5	12	85.7
		2018	1283.0	1238.6	893.0	1773.0	448.0	37	258.4
		2019	1070.0	1053.2	671.0	1967.0	179.0	31	215.0
10028773	Bonniwell Rd	2016	945.5	1042.0	833.0	1444.0	233.0	4	276.7
		2017	939.5	947.6	842.0	1118.0	97.0	14	78.3
		2018	1116.5	1120.0	982.0	1265.0	217.0	4	113.5
		2019	889.0	938.2	748.0	1290.0	96.0	5	208.1

Figure 41. Conductivity (µS/cm) per year per water quality sampling station on Ulao and Kaul Creek in Ozaukee County, WI. The red line indicates the maximum recommended conductivity per the USEPA.



pH

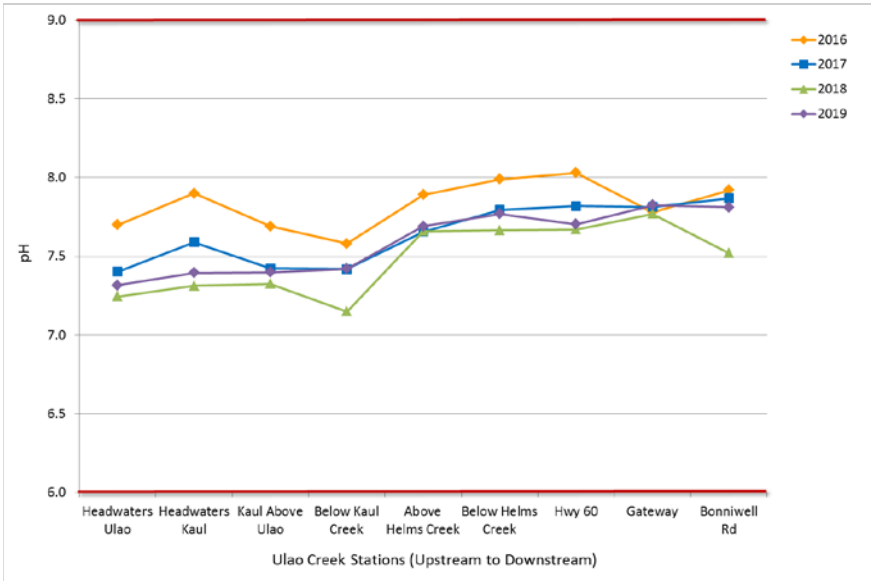
Most streams have a neutral to slightly basic pH, which is dependent upon abiotic factors such as the composition of the stream bed, water temperature, dissolved oxygen concentration, time of day, and weather activities. Wisconsin Administrative Rule 102.04(4) states that the pH shall be within the range 6.0 to 9.0, with no change greater than 0.5 units outside the estimated natural seasonal maximum and minimum (Table 17). A pH of 7.5 is considered ideal and values are generally higher during the summer months, when primary production is greatest.

All measured values were within the Wisconsin state criteria (6.0 - 9.0) set for maintaining aquatic life in a stream (Table 38, Figure 42).

Table 39. pH summary, measured using a handheld instrument, from the 9 water quality sampling stations in the Ulao Creek Watershed in Ozaukee County, WI.

Station	Location	Year	Median	Mean	Min	Max	IQR	n	Std Dev
10046975	Ulao Headwaters	2016	7.57	7.70	7.32	7.65	0.18	4	0.46
		2017	7.41	7.40	7.08	7.79	0.35	6	0.27
		2018	7.31	7.25	6.93	7.44	0.33	4	0.20
		2019	7.27	7.32	6.81	7.85	0.65	6	0.42
10047103	Kaul Headwaters	2016	7.77	7.90	7.59	8.49	0.31	4	0.40
		2017	7.53	7.59	7.37	7.93	0.24	6	0.21
		2018	7.39	7.31	7.00	7.48	0.33	4	0.19
		2019	7.44	7.40	6.96	7.72	0.06	5	0.27
10047104	Kaul Above Ulao	2016	7.69	7.69	7.58	7.81	0.07	4	0.09
		2017	7.31	7.42	7.23	7.79	0.24	6	0.22
		2018	7.34	7.33	7.13	7.50	0.22	4	0.13
		2019	7.42	7.40	6.95	7.83	0.27	5	0.33
10046976	Below Kaul Creek	2016	7.59	7.58	7.49	7.66	0.13	4	0.09
		2017	7.33	7.42	7.25	7.92	0.13	6	0.25
		2018	7.09	7.15	7.08	7.34	0.14	4	0.11
		2019	7.44	7.42	7.00	7.75	0.25	5	0.28
10046981	Above Helms Creek	2016	7.75	7.89	7.65	8.40	0.32	4	0.35
		2017	7.59	7.66	7.47	7.98	0.19	6	0.19
		2018	7.66	7.66	7.34	7.98	0.38	4	0.23
		2019	7.59	7.69	7.22	8.42	0.26	5	0.45
10046982	Below Helms Creek	2016	7.90	7.99	7.74	8.43	0.32	4	0.31
		2017	7.76	7.80	7.53	8.15	0.29	6	0.23
		2018	7.58	7.67	7.40	8.11	0.38	4	0.27
		2019	7.66	7.77	7.33	8.48	0.26	5	0.43
10028775	Hwy 60	2016	7.97	8.03	7.79	8.32	0.27	3	0.27
		2017	7.82	7.82	7.59	8.10	0.19	6	0.18
		2018	7.65	7.67	7.48	7.91	0.31	4	0.17
		2019	7.72	7.70	7.40	7.91	0.21	5	0.20
10046983	Gateway	2016	7.97	7.98	7.78	8.18	0.28	4	0.19
		2017	7.80	7.81	7.59	8.07	0.16	6	0.16
		2018	7.78	7.77	7.48	8.26	0.14	37	0.15
		2019	7.81	7.82	7.46	8.10	0.15	31	0.12
10028773	Bonniwell Rd	2016	7.93	7.92	7.79	8.01	0.10	4	0.09
		2017	7.83	7.87	7.78	8.07	0.05	6	0.10
		2018	7.50	7.52	7.46	7.62	0.12	4	0.07
		2019	7.80	7.81	7.47	8.05	0.14	5	0.22

Figure 42. pH values per year per water quality sampling station on Ulao and Kaul Creek in Ozaukee County, WI. Red lines indicated the minimum and maximum set State criteria for pH values.



Salinity

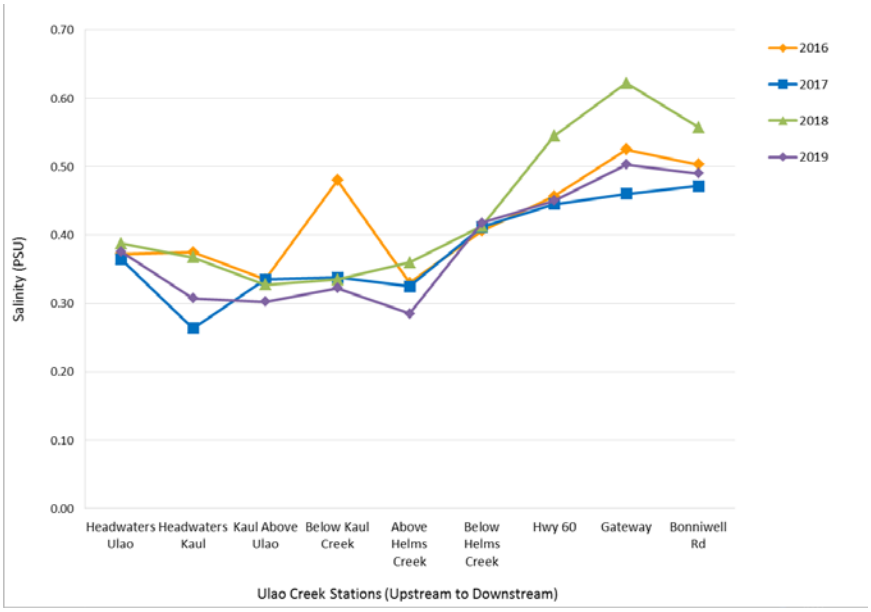
Salinity, the measure of ionic concentrations of soluble salts, fluctuates seasonally due to distribution of deicing road salt and precipitation. There are no Wisconsin-specific set criteria for ideal salinity concentration; however, USEPA states the average salinity of freshwater is 0.5 PSU, with 0-1 PSU the acceptable range for freshwater (Ohrel and Register 2006, USEPA 2020).

Mean salinity concentration appears consistent across the Ulao Creek Watesrhed study locations, with a gradual increase in means at the Above Helms Creek location and continuing downstream (Table 40, Figure 42). The height average salinity readings occurred at the Highway 60, Gateway and Bonniwell Road stations in 2018.

Table 40. Salinity concentration (PSU) summary, measured using a handheld instrument, from the 9 water quality sampling stations in the Ulao Creek Watershed in Ozaukee County, WI.

Station	Location	Year	Median	Mean	Min	Max	IQR	n	Std Dev
10046975	Ulao Headwaters	2016	0.37	0.37	0.33	0.41	0.03	4	0.03
		2017	0.38	0.37	0.31	0.41	0.04	6	0.04
		2018	0.39	0.39	0.36	0.42	0.04	4	0.02
		2019	0.36	0.36	0.31	0.40	0.05	4	0.04
10047103	Kaul Headwaters	2016	0.37	0.37	0.28	0.47	0.17	4	0.10
		2017	0.27	0.26	0.21	0.32	0.07	6	0.05
		2018	0.29	0.37	0.25	0.65	0.22	4	0.16
		2019	0.31	0.31	0.22	0.40	0.16	4	0.10
10047104	Kaul Above Ulao	2016	0.33	0.33	0.31	0.37	0.02	4	0.03
		2017	0.33	0.34	0.32	0.35	0.02	6	0.01
		2018	0.31	0.33	0.28	0.42	0.09	4	0.06
		2019	0.29	0.30	0.23	0.40	0.10	4	0.08
10046976	Below Kaul Creek	2016	0.38	0.48	0.33	0.84	0.13	4	0.24
		2017	0.34	0.34	0.32	0.35	0.02	6	0.01
		2018	0.34	0.34	0.29	0.38	0.06	4	0.03
		2019	0.33	0.32	0.24	0.40	0.06	4	0.07
10046981	Above Helms Creek	2016	0.32	0.33	0.31	0.37	0.03	4	0.03
		2017	0.32	0.32	0.29	0.34	0.02	6	0.02
		2018	0.37	0.36	0.32	0.39	0.04	4	0.03
		2019	0.27	0.29	0.20	0.40	0.08	4	0.09
10046982	Below Helms Creek	2016	0.41	0.41	0.34	0.46	0.06	4	0.05
		2017	0.42	0.41	0.34	0.47	0.07	6	0.05
		2018	0.43	0.41	0.28	0.52	0.15	4	0.09
		2019	0.37	0.42	0.26	0.67	0.15	4	0.18
10028775	Hwy 60	2016	0.40	0.46	0.38	0.59	0.10	3	0.11
		2017	0.44	0.45	0.40	0.52	0.05	6	0.04
		2018	0.53	0.55	0.43	0.70	0.21	4	0.11
		2019	0.45	0.45	0.39	0.51	0.06	2	0.08
10046983	Gateway	2016	0.51	0.52	0.42	0.66	0.17	4	0.12
		2017	0.46	0.46	0.40	0.55	0.04	6	0.05
		2018	0.64	0.62	0.44	0.90	0.23	37	0.14
		2019	0.50	0.50	0.33	1.01	0.05	29	0.12
10028773	Bonniwell Rd	2016	0.46	0.50	0.41	0.69	0.12	4	0.13
		2017	0.46	0.47	0.43	0.52	0.06	6	0.04
		2018	0.56	0.56	0.49	0.63	0.11	4	0.06
		2019	0.46	0.49	0.37	0.64	0.14	3	0.14

Figure 42. Salinity concentration (PSU) per year per water quality sampling station on Ulao and Kaul Creek in Ozaukee County, WI.



Total Dissolved Solids

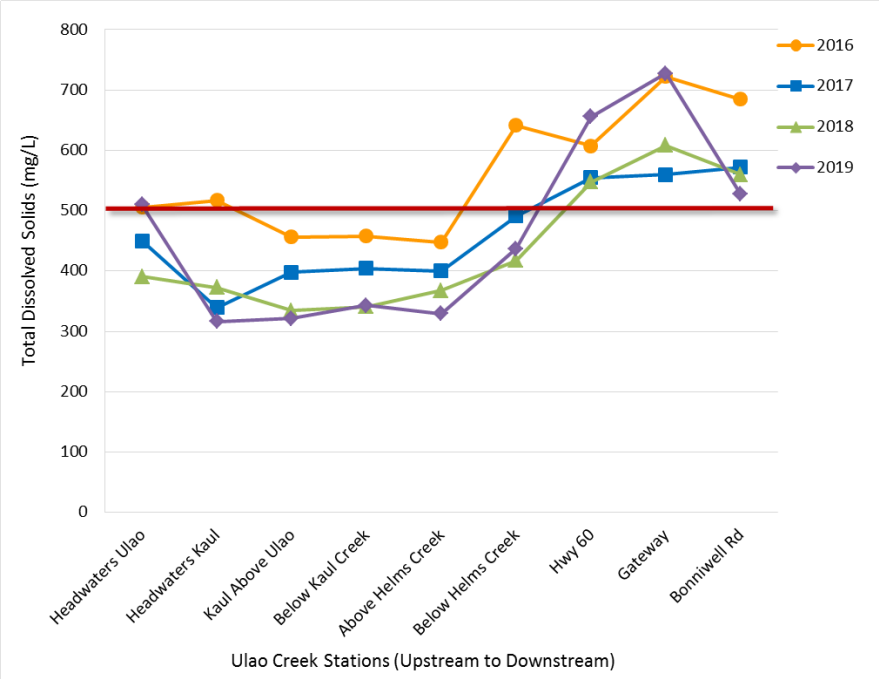
There is no State or Federal set standard for TDS concentration, but the National Secondary Drinking Water Regulations are a maximum value of 500 mg/L for aesthetic reasons (e.g. corrosion of plumbing, bad taste) (Table 17). Studies have found variable results on the effects of TDS on aquatic organisms, indicating that various combinations of ions are more toxic than others and organisms may be more sensitive at one life stage than another (Brix et al. 2010, Sorensen et al. 1977, Timpano et al. 2010).

Mean TDS concentrations increased at all stations beginning at the location located above Helms Creek, where average values were less than 500 mg/L, and increased at every station thereafter during all 4 sampling years (Table 41, Figure 42). Stream bed composition, precipitation, runoff, water velocity, and stream gradient can all potentially influence TDS values and additional investigation of the aforementioned abiotic parameters is needed to determine potential correlations.

Table 41. Total dissolved solids concentration (mg/L), measured using a handheld instrument, from the 9 water quality sampling stations in the Ulao Creek Watershed in Ozaukee County, WI. Values in red are above the 500 mg/L maximum set by the National Secondary Drinking Water Regulations.

Station	Location	Year	Median	Mean	Min	Max	IQR	n	Std Dev
10046975	Ulao Headwaters	2016	517.0	505.8	385.0	604.0	107.3	4	94.8
		2017	433.0	449.9	312.0	563.0	147.5	12	90.5
		2018	390.0	390.8	361.0	422.0	33.5	4	21.7
		2019	391.0	510.2	317.0	1077.0	70.0	5	319.2
10047103	Kaul Headwaters	2016	543.5	516.8	297.0	683.0	277.3	4	188.3
		2017	310.0	339.3	221.0	598.0	81.5	12	108.9
		2018	292.5	372.5	252.0	653.0	212.0	4	163.0
		2019	315.5	316.5	225.0	410.0	159.5	4	97.5
10047104	Kaul Above Ulao	2016	474.0	456.5	333.0	545.0	53.0	4	88.9
		2017	359.5	397.8	320.0	502.0	141.8	12	76.9
		2018	312.0	334.0	285.0	427.0	84.0	4	55.6
		2019	294.5	321.3	238.0	458.0	118.8	4	101.1
10046976	Below Kaul Creek	2016	449.8	457.9	382.0	550.0	109.9	4	78.5
		2017	388.5	404.4	301.0	503.0	128.3	14	75.0
		2018	341.5	340.8	292.0	388.0	66.5	4	36.4
		2019	332.0	343.3	250.0	459.0	82.3	4	87.8
10046981	Above Helms Creek	2016	463.5	448.0	331.0	534.0	60.5	5	85.0
		2017	388.0	400.3	316.0	502.0	123.5	12	73.1
		2018	375.0	367.5	322.0	398.0	43.0	4	28.1
		2019	307.0	329.3	252.0	451.0	64.8	4	85.6
10046982	Below Helms Creek	2016	575.0	641.6	535.0	868.0	98.0	5	135.3
		2017	479.5	491.0	353.0	664.0	116.5	12	95.7
		2018	428.5	417.8	286.0	528.0	153.5	4	89.2
		2019	406.0	437.3	263.0	674.0	213.8	4	182.0
10028775	Hwy 60	2016	575.0	607.7	410.0	838.0	214.0	3	215.9
		2017	534.0	554.6	404.0	868.0	176.5	12	137.1
		2018	526.5	547.5	438.0	699.0	208.0	4	109.4
		2019	576.5	655.5	392.0	1077.0	266.5	4	298.7
10046983	Gateway	2016	676.0	722.3	577.0	960.0	161.8	4	169.1
		2017	560.0	559.9	422.0	720.0	176.5	12	157.7
		2018	641.0	608.4	46.0	887.0	224.0	37	111.0
		2019	759.0	727.0	337.0	985.0	118.5	30	123.2
10028773	Bonniwell Rd	2016	670.0	684.8	415.0	984.0	197.8	4	234.9
		2017	559.5	572.1	435.0	790.0	179.5	14	111.5
		2018	557.5	559.8	491.0	633.0	108.5	4	56.8
		2019	545.5	527.5	374.0	645.0	188.5	4	130.4

Figure 43. Total dissolved solids concentration (mg/L) per year per water quality sampling station on Ulao and Kaul Creek in Ozaukee County, WI. Values in red are above the 500 mg/L maximum set by the National Secondary Drinking Water Regulations.



Turbidity

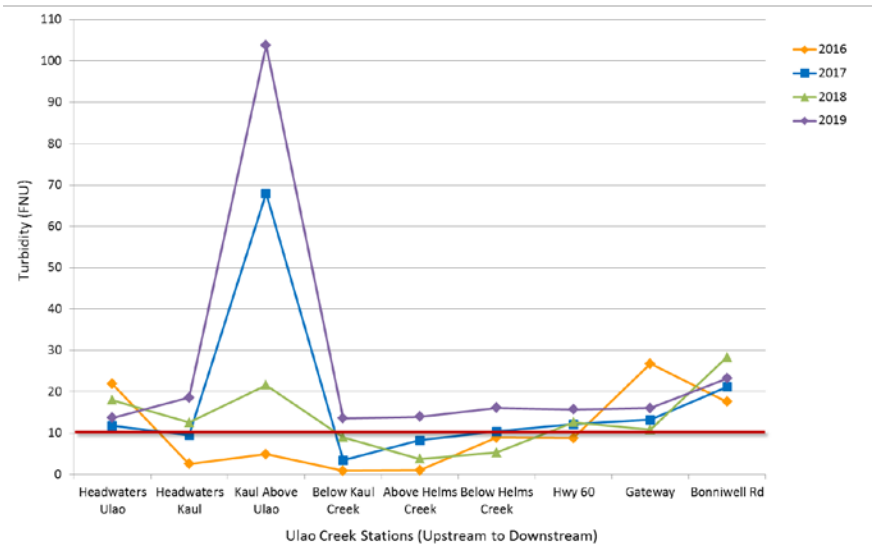
Per Milwaukee Riverkeeper (2016), the ideal turbidity readings for the Milwaukee River drainage basin is 10 FNU and below (Table 29). In 2016, the annual mean turbidity values at the Ulao headwaters and the 2 most downstream sampling locations (Gateway and Bonniwell Road) surpassed 10 FNU. Turbidity values exceeded the ideal reading at 6 of the 9 sampling stations in both 2017 and 2018, with the stations on Ulao Creek located below Kaul Creek and above Helms Creek having an annual mean below 10 FNU both years. All sampling stations in the Ulao Creek Watershed exceeded 10 FNU in 2019 (Table 42, Figure 44)

Per Göransson et al. (2013), a complex relationship exists between turbidity, precipitation, discharge, and size of the watershed. It was concluded high turbidity values are associated with heavy rainfall and high discharge while periods of dry weather results lower levels of turbidity in a regulated river system. In the Ulao Creek Watershed, approximately 44% of the land use is categorized as agricultural (Figure 3). Additional sampling and analysis is needed to correlate the conditions measured during a sampling and precipitation.

Table 42. Turbidity (FNU) summary, measured at the time of discrete water sampling using a handheld instrument, from the 6 water quality sampling stations in the Ulao Creek Watershed in Ozaukee County, WI. Values in red indicate means above the maximum recommended turbidity value (10 FNU) for the study region.

Station	Location	Year	Median	Mean	Min	Max	IQR	n	Std Dev
10046975	Ulao Headwaters	2016	21.9	21.9	21.9	21.9	0.0	1	N/A
		2017	3.7	11.8	1.1	35.4	16.8	6	14.5
		2018	13.5	18.0	0.0	44.9	34.0	4	18.4
		2019	10.5	13.7	3.5	30.4	14.6	4	12.4
10047103	Kaul Headwaters	2016	2.6	2.6	2.6	2.6	0.0	1	N/A
		2017	8.8	9.5	2.9	18.3	2.8	6	5.1
		2018	10.4	12.6	5.3	24.2	13.1	4	7.5
		2019	16.2	18.6	7.7	31.9	12.1	3	12.3
10047104	Kaul Above Ulao	2016	4.9	4.9	4.9	4.9	0.0	1	N/A
		2017	82.5	68.0	6.9	121.0	71.9	6	47.6
		2018	21.2	21.6	3.2	40.8	21.0	4	13.4
		2019	39.8	103.8	21.5	250.0	114.3	3	127.0
10046976	Below Kaul Creek	2016	0.9	0.9	0.9	0.9	0.0	2	N/A
		2017	3.6	3.5	1.4	4.8	1.2	7	1.2
		2018	8.4	9.0	2.3	17.0	8.4	4	5.3
		2019	9.7	13.6	7.3	23.7	8.2	3	8.9
10046981	Above Helms Creek	2016	1.0	1.0	1.0	1.0	0.0	1	N/A
		2017	2.0	8.3	0.7	29.9	9.4	6	11.6
		2018	3.7	3.8	3.1	4.5	1.3	4	0.7
		2019	6.7	14.0	3.1	32.1	14.5	3	15.8
10046982	Below Helms Creek	2016	9.0	9.0	3.9	14.0	5.1	2	7.1
		2017	8.6	10.4	5.7	21.6	4.2	6	5.9
		2018	5.9	5.3	2.9	6.6	2.3	4	1.5
		2019	11.4	16.1	6.2	30.8	12.3	3	13.0
10028775	Hwy 60	2016	8.8	8.8	8.8	8.8	0.0	1	N/A
		2017	9.9	12.2	6.9	21.1	8.6	6	6.0
		2018	10.7	12.6	5.3	23.8	11.6	4	7.0
		2019	15.7	15.7	10.3	21.1	5.4	3	5.4
10046983	Gateway	2016	26.8	26.8	16.2	37.4	10.6	2	2.0
		2017	9.6	13.2	7.3	32.7	4.3	6	9.8
		2018	10.3	10.8	6.8	14.8	5.8	5	2.8
		2019	14.2	16.1	10.0	24.0	7.0	3	7.2
10028773	Bonniwell Rd	2016	17.6	17.6	17.6	17.6	0.0	1	N/A
		2017	18.2	21.2	13.1	37.5	11.5	7	9.2
		2018	19.5	28.4	5.7	69.0	35.9	4	24.3
		2019	24.4	23.2	20.6	24.7	2.1	3	2.3

Figure 44. Turbidity (FNU) measurements per year per water quality sampling station on Ulao and Kaul Creek in Ozaukee County, WI. The red line indicates the maximum recommended turbidity value (10 FNU) for the study region.



Water Temperature

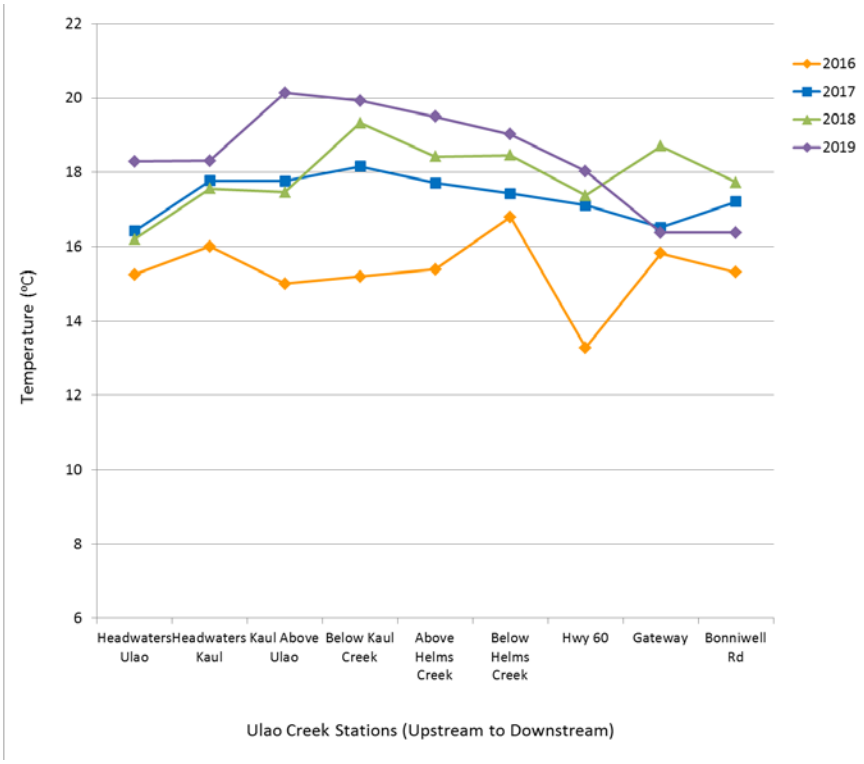
The WDNR Chapter NR102 Water Quality Standards for Wisconsin Surface Waters (WDNR 1973) sets a water temperature maximum for a Warm Water Sport Fishery (Milwaukee River) of 31.7°C (Table 17). Daily maximums were measured against this standard.

Water temperature was recorded using a handheld instrument and was variable with season, water depth, riparian vegetation cover, and time of day. In 2016, mean temperatures ranged from 13.3 at the station located at Hwy 60 to 16.8 at the station immediately upstream below Helms Creek; additionally, mean temperatures were lowest at all stations in 2016. Temperatures were relatively consistent throughout the stream system in 2017. Mean temperature values at 7 of 9 stations were highest in 2019 (Table 43, Figure 45). All average maximum values were below the criteria for a Warm Water Sport Fishery. Time of year, time of day, shading, weather, and precipitation all contribute to the variations seen within the temperature data.

Table 43. Water temperature (°C) summary, measured at the time of discrete water sampling using a handheld instrument, discrete samples analyzed by SLOH from the 6 water quality sampling stations on Ulao and Kaul Creek in Ozaukee County, WI.

Location	Year	Median	Mean	Min	Max	IQR	n	Std Dev
Ulao Headwaters	2016	15.1	15.3	11.1	19.8	7.7	4	4.6
	2017	16.4	16.4	12.2	22.1	7.2	14	3.9
	2018	17.4	16.2	9.2	20.8	8.7	4	4.7
	2019	19.7	18.3	9.0	21.2	1.8	6	4.6
Kaul Headwaters	2016	15.7	16.0	10.7	22.0	10.1	4	6.1
	2017	15.1	17.8	12.7	24.2	8.8	13	4.8
	2018	18.4	17.6	9.5	23.9	10.6	4	5.7
	2019	19.8	18.3	8.7	23.0	2.6	5	5.6
Kaul Above Ulao	2016	14.5	15.0	10.7	20.4	8.1	4	5.0
	2017	17.6	17.8	12.1	24.4	7.8	12	4.8
	2018	18.6	17.5	9.3	23.3	9.3	4	5.3
	2019	21.4	20.1	9.6	25.0	2.7	5	6.1
Below Kaul Creek	2016	14.7	15.2	10.6	20.8	8.1	4	3.0
	2017	21.1	18.2	12.3	23.6	8.4	15	4.6
	2018	19.5	19.3	14.3	23.9	8.2	4	4.2
	2019	20.8	19.9	9.5	25.0	3.0	5	6.1
Above Helms Creek	2016	14.7	15.4	10.7	21.6	8.5	4	5.5
	2017	13.7	17.7	12.2	23.6	9.7	13	5.1
	2018	19.0	18.4	9.9	25.7	12.2	4	6.4
	2019	19.9	19.5	9.0	24.9	4.1	5	6.3
Below Helms Creek	2016	17.4	16.8	10.9	21.5	4.3	4	4.5
	2017	13.6	17.4	12.3	23.3	8.6	13	4.9
	2018	19.3	18.5	9.8	25.4	12.1	4	6.3
	2019	19.6	19.0	9.1	23.4	3.9	5	5.9
Hwy 60	2016	10.9	13.3	10.7	20.7	2.6	4	5.0
	2017	13.9	17.1	12.7	22.6	9.4	13	4.6
	2018	18.4	17.4	10.0	22.6	9.4	4	5.1
	2019	19.1	18.0	9.7	21.3	2.4	5	4.8
Gateway	2016	15.8	15.8	11.7	20.0	6.4	5	4.1
	2017	16.8	16.5	9.0	23.0	7.7	45	4.1
	2018	18.9	18.7	8.4	51.3	5.5	38	6.9
	2019	16.2	16.4	9.3	21.8	4.5	31	3.2
Bonniwell Rd	2016	14.7	15.3	10.7	21.1	8.4	4	5.3
	2017	19.3	17.2	11.5	22.6	8.9	15	4.6
	2018	18.3	17.7	10.7	23.5	9.2	4	5.0
	2019	18.4	16.4	9.3	21.8	2.9	5	5.1

Figure 45. Water temperature (°C) measurements per year per water quality sampling stations on Ulao and Kaul Creek in Ozaukee County, WI.



Continuous Data

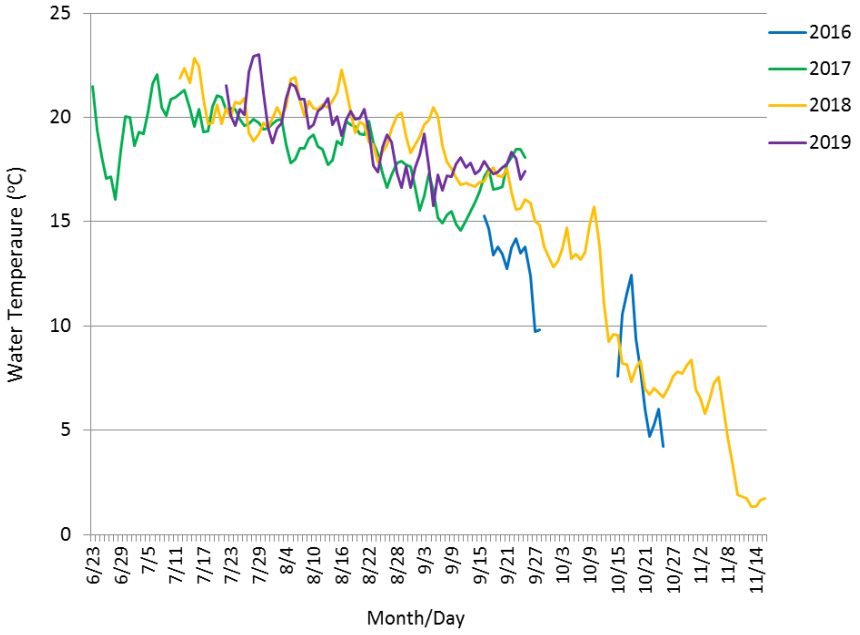
Global Water and Eureka brand continuous water quality monitoring units were deployed, maintained, and collected data at 4 rotating water quality sampling locations (below the confluence with Kaul Creek, below Helms Creek, Gateway, and downstream of the railroad crossing central to the restoration site) between the months of May and August in 2015, July and December in 2016, June and November in 2017, July and December in 2018, and July and September 2019. Monitoring units were not deployed at all 4 stations each year (Table 3). The continuous monitoring unit located at Gateway was relocated in 2015 to the "downstream of railroad tracks station" due to stream channel and adjacent floodplain restoration. Due to seasonal and weather-related variations in water level and velocity (i.e., very low and/or slow moving water), battery power, and tampering by aquatic animals such as crayfish, continuously recorded data may not have accurately represented stream conditions.

Below Kaul Creek Confluence

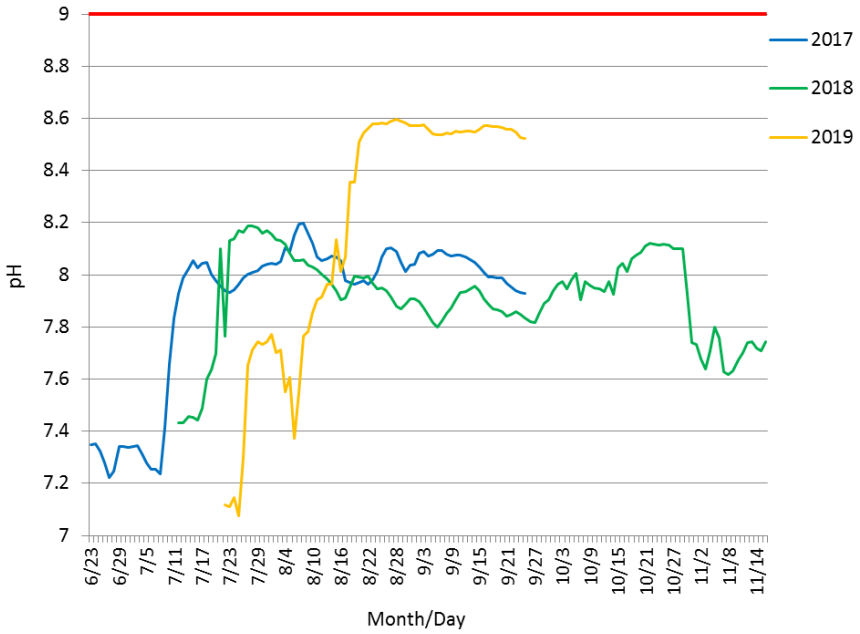
Continuous temperature, pH, and specific conductivity data was recorded from 2016-2019 at this station located immediately below the confluence with Kaul Creek (Figure 46). No data was collected for pH during the 2016 deployment period, nor was any accurate data collected for dissolved oxygen, chloride, and nitrate due to faulty probes.

Figure 46. Measure parameters from the Eureka continuous monitoring unit deployed at the Ulao Creek sampling station located below the confluence with Kaul Creek in Ozaukee County, WI. Red lines indicate maximum water quality criteria set by the State of Wisconsin, WDNR, Milwaukee Riverkeeper, or USEPA.

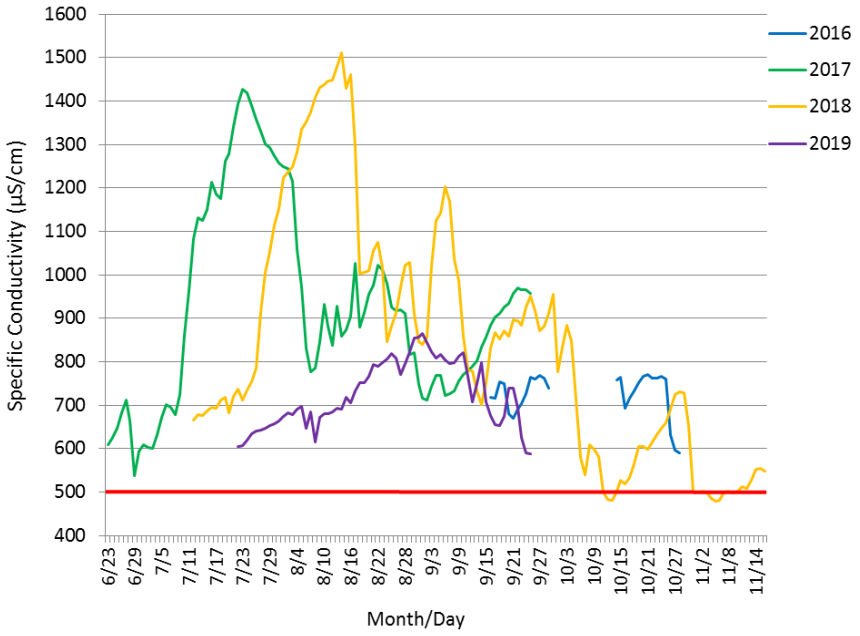
a.) Temperature (^{o}C)



b.) pH



c.) Specific conductivity (µs/cm)

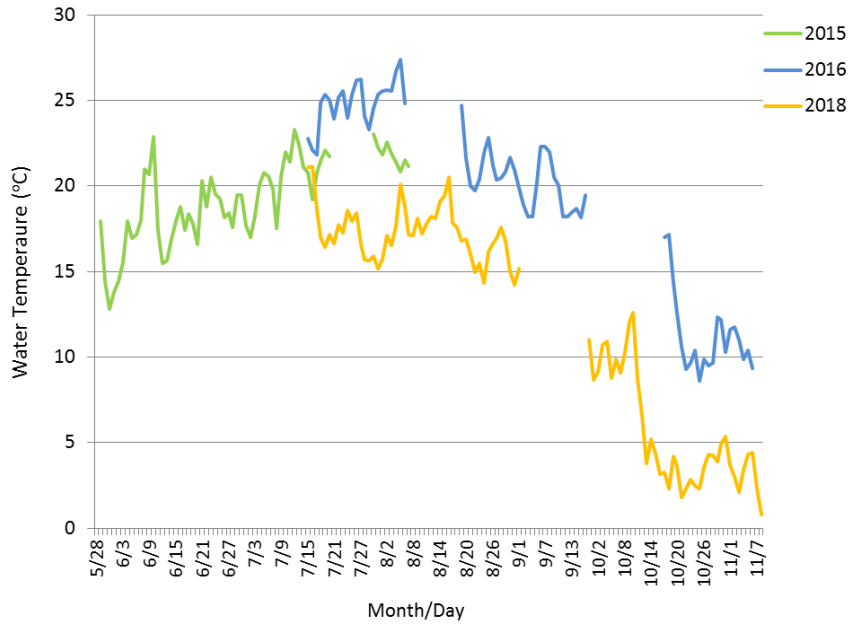


Below Helms Creek Confluence

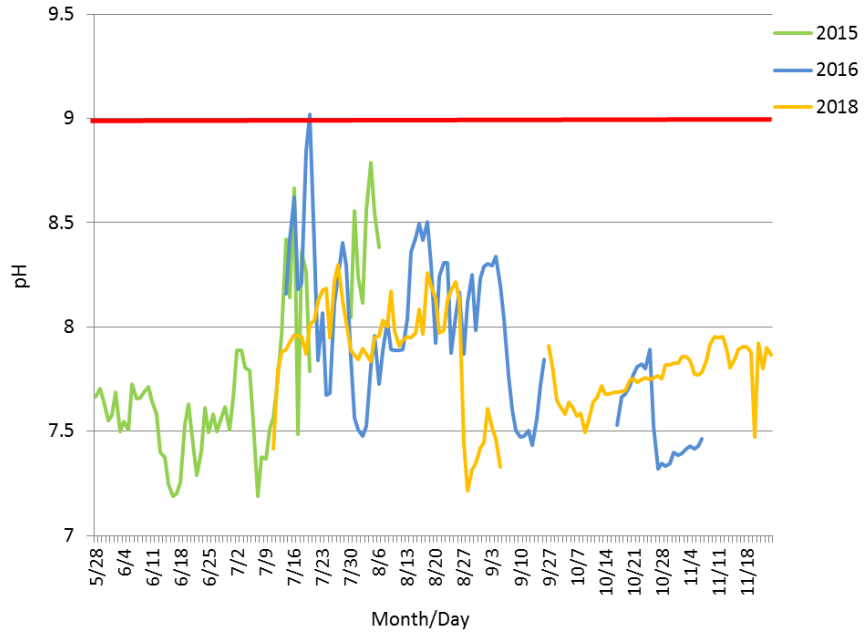
Continuous data was collected at this station on Ulao Creek in 2015, 2016, and 2018 (Figure 47). Dissolved oxygen data is only available for a few days in July 2018 due to a faulty probe (Figure 47d).

Figure 47. Measure parameters from the Global Water continuous monitoring unit deployed at the Ulao Creek sampling station located below the confluence with Helms Creek in Ozaukee County, WI. Red lines indicate maximum water quality criteria set by the State of Wisconsin, WDNR, Milwaukee Riverkeeper, or USEPA.

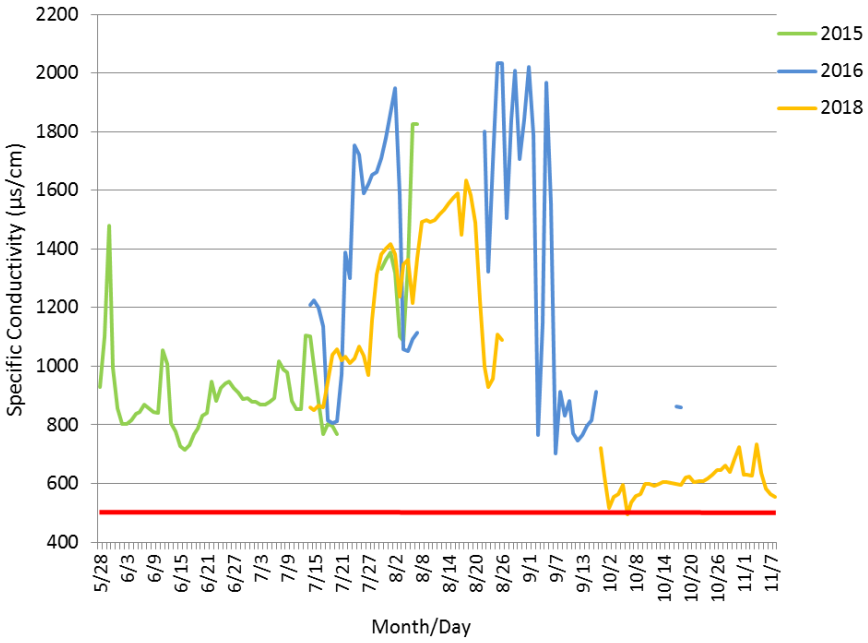
a.) Temperature (°C)



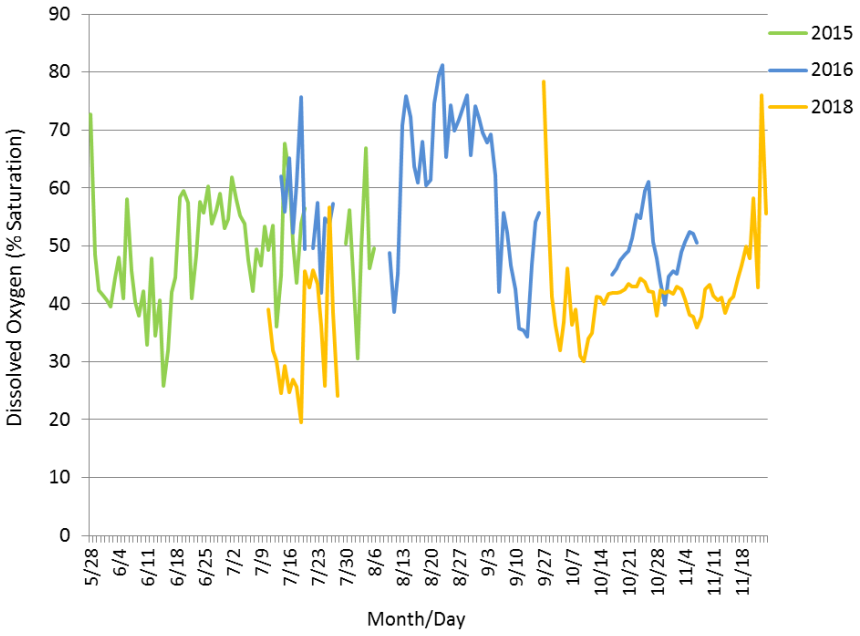
b.) pH



c.) Specific conductivity (µs/cm)



d.) Dissolved oxygen (percent saturation)

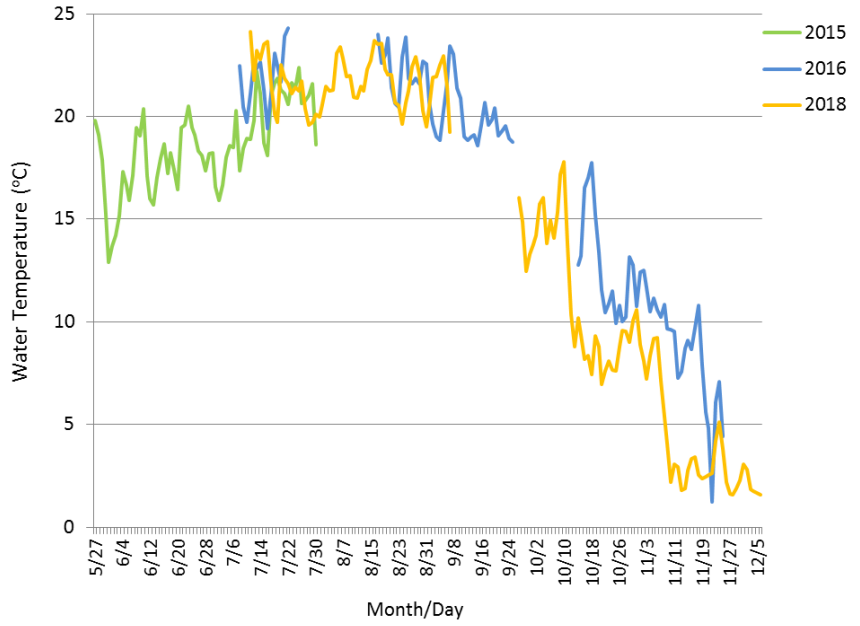


Gateway

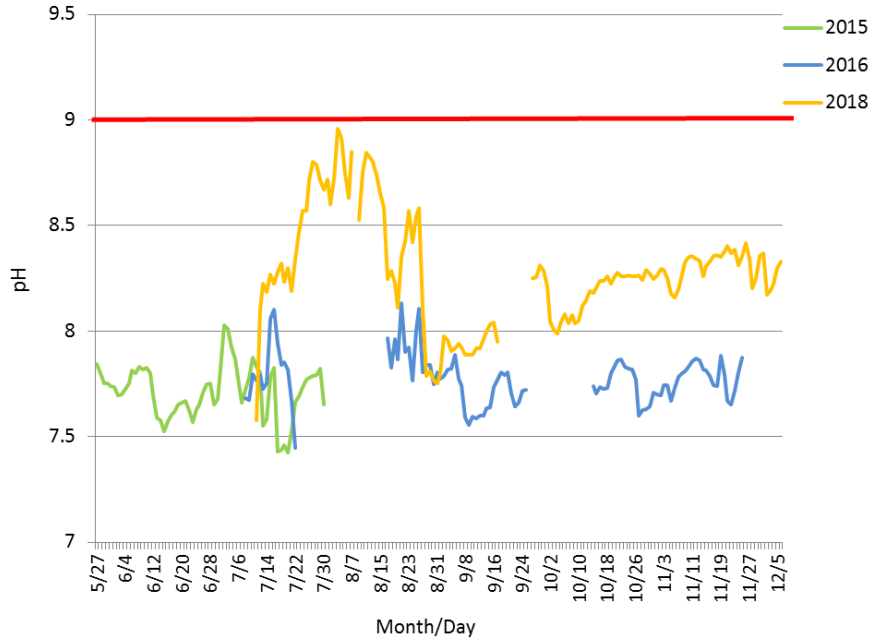
Continuous monitoring units located on Ulao Creek at the Gateway station recorded continuous data in 2015, 2016, and 2018 (Figure 48).

Figure 48. Measure parameters from the Global Water continuous monitoring unit at the Ulao Creek sampling station located at the Gateway site in Ozaukee County, WI. Red lines indicate maximum water quality criteria set by the State of Wisconsin, WDNR, Milwaukee Riverkeeper, or USEPA.

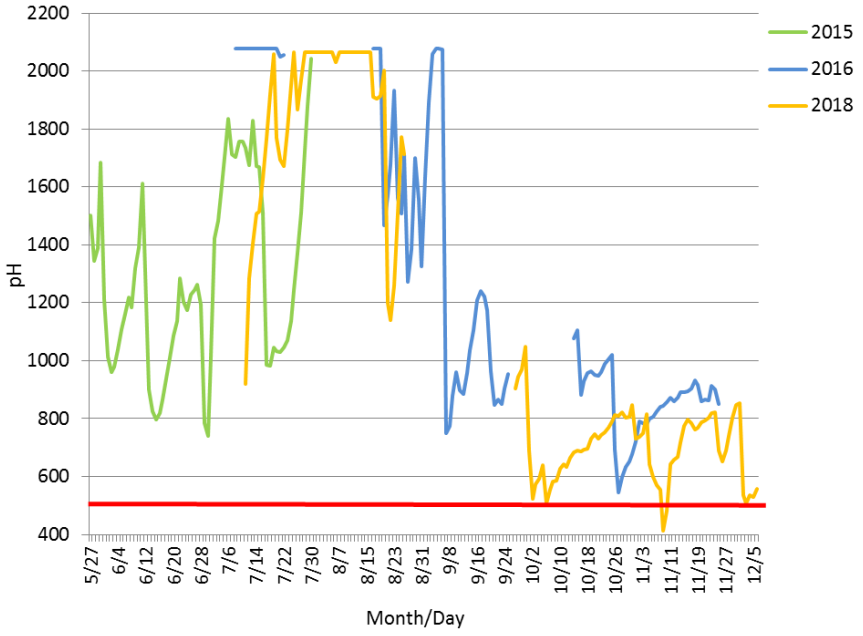
a.) Temperature (^{o}C)



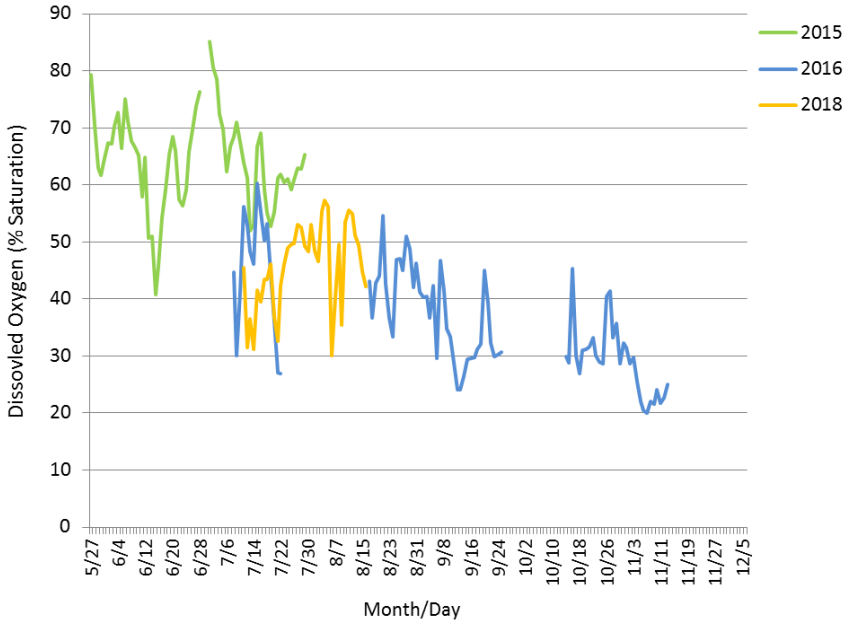
b.) pH



c.) Specific conductivity (µs/cm)



d.) Dissolved oxygen concentration (percent saturation)

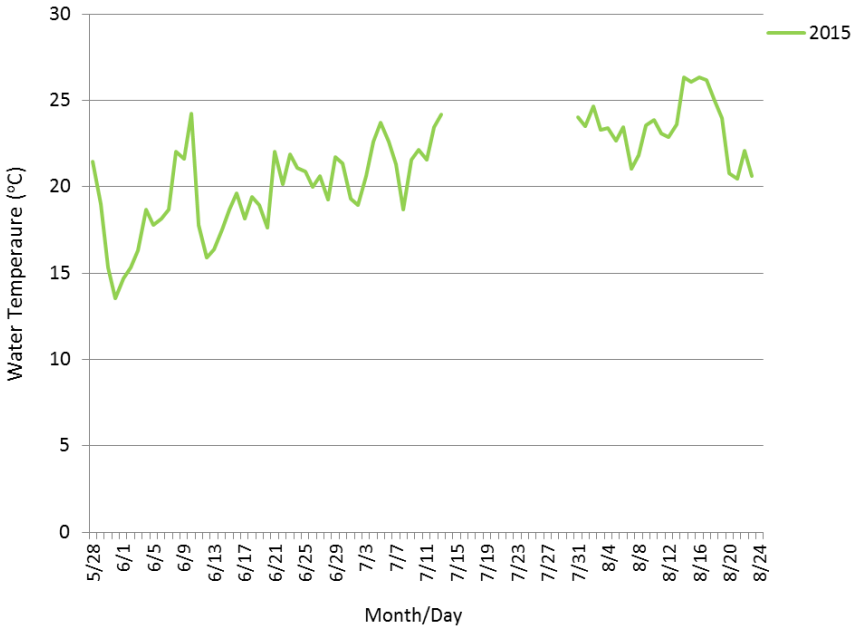


Downstream of the Railroad Tracks (Central to the Restoration Site) in Gateway

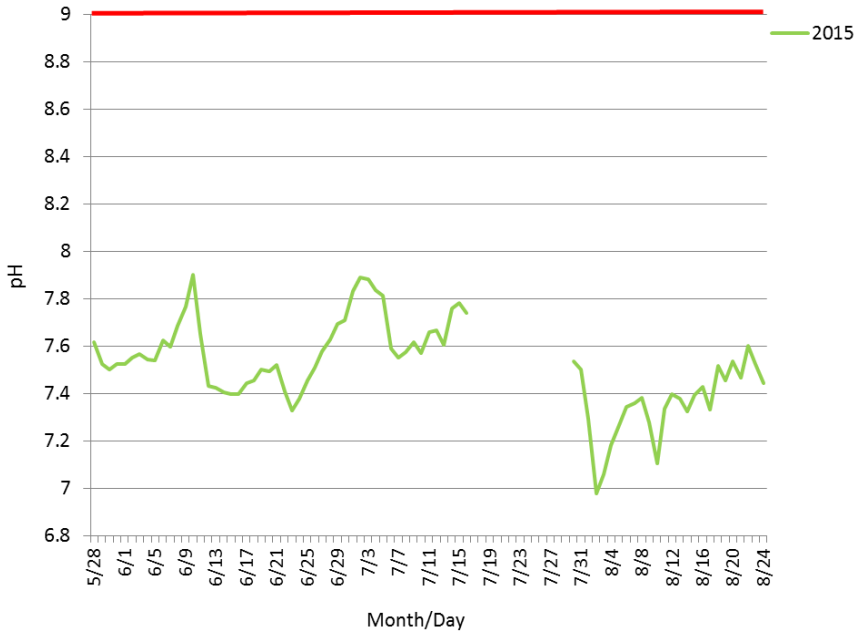
The continuous monitoring station located at downstream of the railroad tracks (central to the restoration site)only recorded data in 2015 from the end of May through August (Figure 49) as it was removed to avoid damage during 2015 construction activities. Dissolved oxygen percent saturation readings may be inaccurate due to the construction activity or a malfunctioning probe (Figure 49d).

Figure 49. Measure parameters from the Global Water continuous monitoring unit deployed on the Ulao Creek sampling station located downstream of the railroad tracks (central to the restoration site)in Ozaukee County, WI. Red lines indicate maximum water quality criteria set by the State of Wisconsin, WDNR, Milwaukee Riverkeeper, or USEPA.

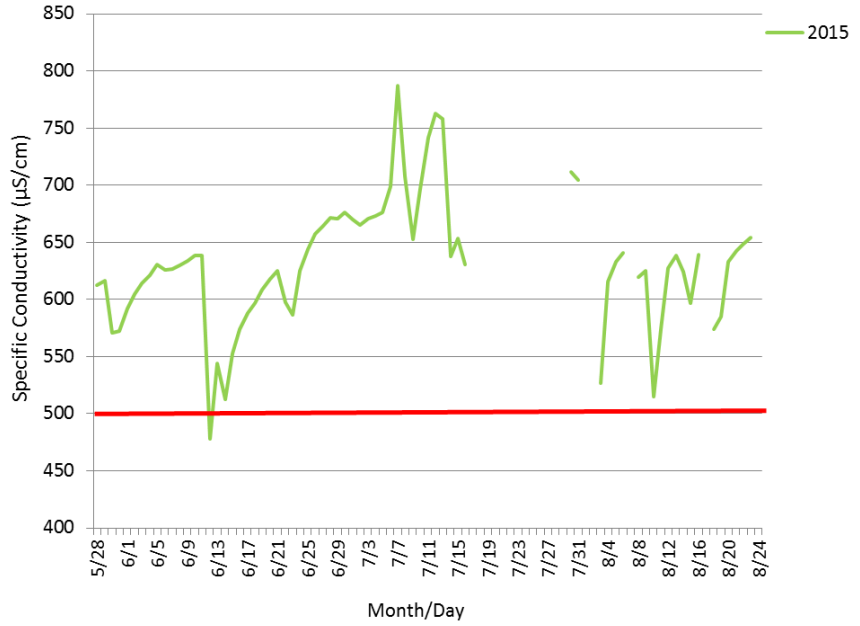
a.) Temperature (^{o}C)



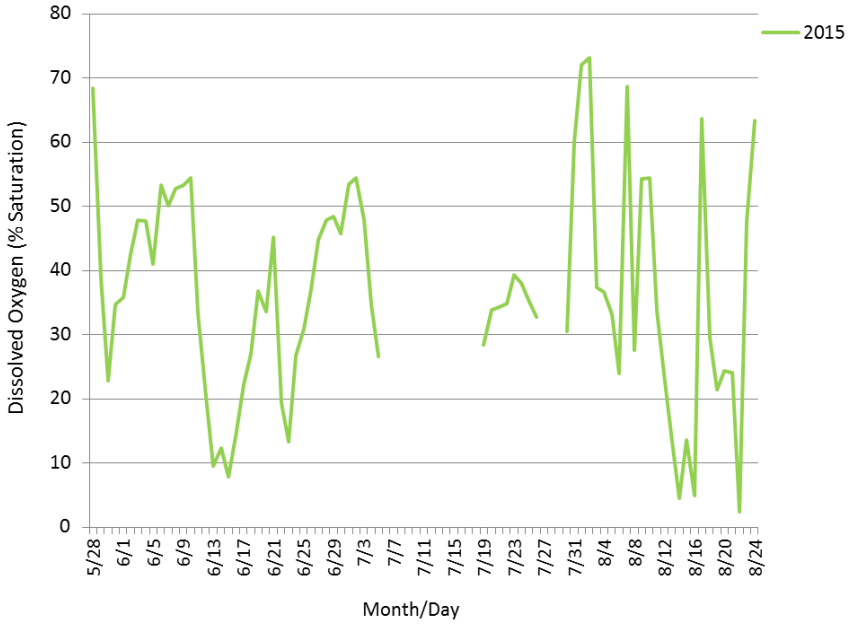
b.) pH



c.) Specific conductivity (µs/cm)



d.) Dissolved oxygen (percent saturation)



E. coli Analysis

Enteric bacteria, such as *E. coli*, is a useful metric when assessing the potential for enteric pathogens in streams. A bacterium belonging to the Enterobacteriaceae family, *E. coli* resides in the intestines of humans and other warm blooded animals. In general, E. coli counts are significantly higher when streams are sampled immediately following a significant (0.5") rain event than during base flow events, indicating fecal contamination is entering the system through storm water runoff. The state of Wisconsin has not yet adopted a standard for *E. coli*; instead it has criteria for fecal coliform as an indicator of fecal contamination (WDNR & MMSD 2018). The USEPA has established recommended minimum criteria for *E. coli* that suggest that the geometric mean of all samples should not exceed 126 colony forming units (CFU) per 100 mL and not more than 10 percent of samples to exceed 400 CFU/100 mL (USEPA 1986a).

Examining annual geometric means from each water quality sampling station on Ulao and Kaul Creek show *E. coli* counts only exceeded 400 CFU/100 mL at Bonniwell location in 2016. Three of the 9 sampling stations had annual geometric mean values greater than 400 CFU/100 mL in 2017. None of the sampling stations exceed the target maximum in 2018, and only 2 stations had values above the target maximum in 2019 (Kaul Creek above Ulao and Ulao Creek below the Kaul Creek confluence) (Table 44).

Table 44. *E. coli* geometric mean (100 CFU/100 mL) of all discrete water quality sampling stations on Ulao and Kaul Creek from 2016-2019. Values in red indicate results higher than the criterion set by WDNR and MMSD (2018) and USEPA. Stations are listed from furthest upstream to furthest downstream.

Site	Location	Year	Geometric Mean
10046975	Headwaters Ulao	2016	141.8
		2017	244.2
		2018	195.9
		2019	340.2
10047103	Headwaters Kaul	2016	311.4
		2017	97.6
		2018	60.1
		2019	117.1
10047104	Kaul Above Ulao	2016	180.6
		2017	530.9
		2018	153.1
		2019	601.3
10046976	Below Kaul Confluence	2016	178.1
		2017	339.2
		2018	356.7
		2019	421.7
10046981	Above Helms Creek	2016	218.0
		2017	184.0
		2018	191.8
		2019	150.1
10046982	Below Helms Creek	2016	272.2
		2017	408.3
		2018	213.7
		2019	348.4
10028775	Hwy 60	2016	343.9
		2017	340.1
		2018	208.0
		2019	261.1
10046983	Gateway	2016	269.7
		2017	348.8
		2018	321.4
		2019	285.9
10028773	Bonniwell Rd	2016	582.6
		2017	638.0
		2018	399.1
		2019	381.8

Investigating *E. coli* values per sampling location per month during each sampling year reveals the highest values generally occur during the warm summer months from July to August (Table 45). Values were highest at all 9 locations in September 2017. Average water temperature per station was similar for measurements taken in August 2017, August 2018, and July and September 2019. Additional examination of other collected abiotic parameters and recorded weather events is necessary to hypothesize a possible cause that resulted in these values. Stations located on Kaul Creek above Ulao Creek and Ulao Creek at Bonniwell exceeded 400 CFU/100 mL most frequently (7 of the 15 months over the 4 sampling years).

Table 45. *E. coli* levels (CFU/100 mL) per sampling location per year as measured by the SLOH versus monthly average water temperature (°C) for the discrete water quality sampling stations on Ulao and Kaul Creek. Values in red indicate a result above 400 CFU/100 mL suggested by WDNR and MMSD (2018) and USEPA. "N/D" indicates counts were below the level of detection.

	2016			
Location	September		November	
	E. coli	Water Temp	*E. coli*	Water Temp
Headwaters Ulao	131.2	19.3	153.3	11.3
Headwaters Kaul	1236.6	21.3	78.4	10.8
Kaul Above Ulao	530.1	19.3	61.5	10.7
Below Kaul Confluence	440.3	19.6	71.4	11.0
Above Helms Creek	531.6	20.1	89.4	10.7
Below Helms Creek	444.3	19.6	71.4	10.5
Hwy 60	791.4	20.7	124.5	10.8
Gateway	576.4	19.4	126.2	10.4
Bonniwell Rd	621.6	19.9	546.0	10.8
Geomean/Average	**514.7**	**19.9**	**112.5**	**10.8**

	2017									
Location	April		June		August		September		October	
	E. coli	Water Temp	*E. coli*	Water Temp	*E. coli*	Water Temp	*E. coli*	Water Temp	*E. coli*	Water Temp
Headwaters Ulao	71.0	12.4	108.0	18.3	236.0	20.3	3640.0	22.1	179.3	13.3
Headwaters Kaul	13.0	13.2	75.0	21.6	727.0	24.1	1203.0	22.2	31.8	13.9
Kaul Above Ulao	61.0	13.5	435.0	21.0	866.0	24.3	2590.0	21.4	613.3	13.2
Below Kaul Confluence	68.0	13.7	N/D	21.8	461.0	23.6	1710.0	21.3	289.4	13.3
Above Helms Creek	40.0	13.6	62.0	22.3	205.0	23.3	1120.0	23.5	190.7	12.9
Below Helms Creek	93.0	13.4	155.0	22.0	172.0	23.3	9880.0	22.1	434.8	13.0
Hwy 60	69.0	9.1	326.0	20.7	186.0	22.6	5120.0	22.3	434.8	12.8
Gateway	99.0	12.7	194.0	20.4	214.0	22.5	6050.0	22.1	269.0	13.3
Bonniwell Rd	260.0	11.7	365.0	19.4	292.0	21.8	5760.0	21.5	649.9	13.2
Geomean/Average	**66.5**	**12.6**	**172.4**	**20.8**	**312.1**	**22.8**	**3230.2**	**22.1**	**264.7**	**13.2**

	2018							
Location	July		August		September		October	
	E. coli	Water Temp	*E. coli*	Water Temp	*E. coli*	Water Temp	*E. coli*	Water Temp
Headwaters Ulao	649.0	20.3	816.0	20.8	121.0	14.5	23.0	9.2
Headwaters Kaul	173.0	21.8	727.0	23.9	52.0	15.0	2.0	9.5
Kaul Above Ulao	86.0	23.3	579.0	20.9	345.0	16.3	21.0	9.3
Below Kaul Confluence	816.0	22.9	1046.0	23.9	387.0	16.1	49.0	9.5
Above Helms Creek	345.0	25.7	548.0	23.3	179.0	14.7	40.0	9.9
Below Helms Creek	517.0	27.4	613.0	23.6	140.0	15.1	47.0	9.8
Hwy 60	152.0	22.6	345.0	21.5	248.0	15.4	144.0	10.0
Gateway	435.0	22.9	345.0	21.7	411.0	16.8	173.0	9.8
Bonniwell Rd	921.0	23.5	548.0	21.1	613.0	15.6	82.0	10.7
Geomean/Average	**353.2**	**23.4**	**583.8**	**22.3**	**222.1**	**15.5**	**38.4**	**9.8**

Location	2019							
	May		July		September		October	
	E. coli	Water Temp	*E. coli*	Water Temp	*E. coli*	Water Temp	*E. coli*	Water Temp
Headwaters Ulao	61.0	19.1	1120.0	21.1	2420.0	20.7	81.0	9.0
Headwaters Kaul	81.0	19.0	210.0	23.0	276.0	21.3	40.0	8.7
Kaul Above Ulao	N/D	21.2	1414.0	23.7	1553.0	25.0	99.0	9.6
Below Kaul Confluence	201.0	20.7	921.0	25.0	1986.0	23.7	86.0	9.5
Above Helms Creek	77.0	19.8	517.0	23.9	93.0	24.9	137.0	9.0
Below Helms Creek	201.0	20.7	921.0	25.0	1986.0	23.7	86.0	9.5
Hwy 60	112.0	19.0	461.0	21.3	1046.0	21.3	86.0	9.7
Gateway	108.0	19.2	308.0	20.8	1203.0	21.6	167.0	9.3
Bonniwell Rd	127.0	18.3	613.0	21.2	1046.0	22.7	261.0	9.5
Geomean/Average	**111.3**	**19.7**	**615.6**	**22.8**	**926.0**	**22.8**	**102.2**	**9.3**

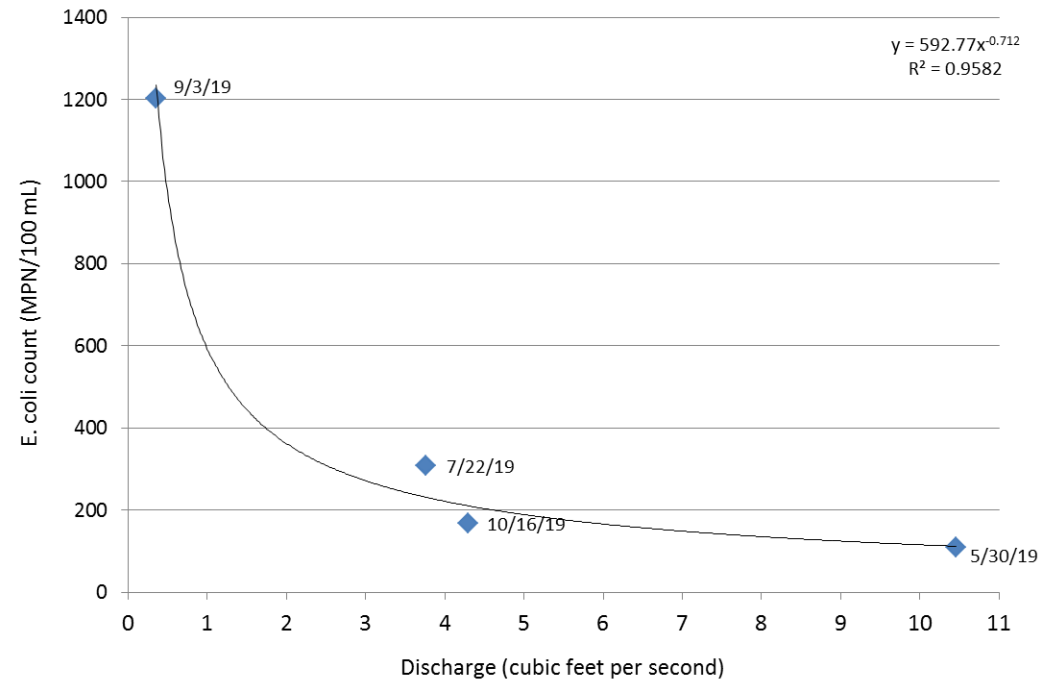
Daily discharge was calculated using stream flow data measured during water sampling events on Ulao Creek at the Gateway station in 2019. Flow data was collected using a velocity meter that measures ft/sec to the thousandths. Prior to 2019, a less sensitive meter was utilized during velocity measurements. Therefore, only the 2019 relationship between *E. coli* counts and discharge is presented.

E. coli exhibit an exponential growth rate, with fastest growth occurring between 25° and 30°C. Additionally, bacterial growth is directly proportional to algal growth in freshwater environments (Byappanahalli et al. 2003, Nyguyen 2006). Daily discharge was calculated using flow data collected simultaneously with water samples at the Gateway location. Similar to the relationship seen at the LMR Mequon 3 and Mole Creek south of Hillcrest Station, *E. coli* CFUs decreased with increasing discharge (Table 46, Figure 51). Fitting a power trend line using regression analysis to the data results in an R^2 value of 0.96; however, a larger dataset is needed to accurately determine a line of best fit and establish an adequate baseline.

Table 46. Daily discharge calculations taken from measured flow, *E. coli,* and measured water temperature at the time of sampling at the Gateway Ulao Creek station in 2019.

Sampling Event Date	Discharge	*E. coli* count (CFU/100 mL)	Water Temp (°C)
5/30/2019	10.46	108	18.3
7/22/2019	3.77	308	21.2
9/3/2019	0.36	1203	22.7
10/16/2019	4.29	167	9.5

Figure 51. Comparison of *E. coli* results and discharge in 2019 at the Ulao Creek Gateway water quality sampling station.

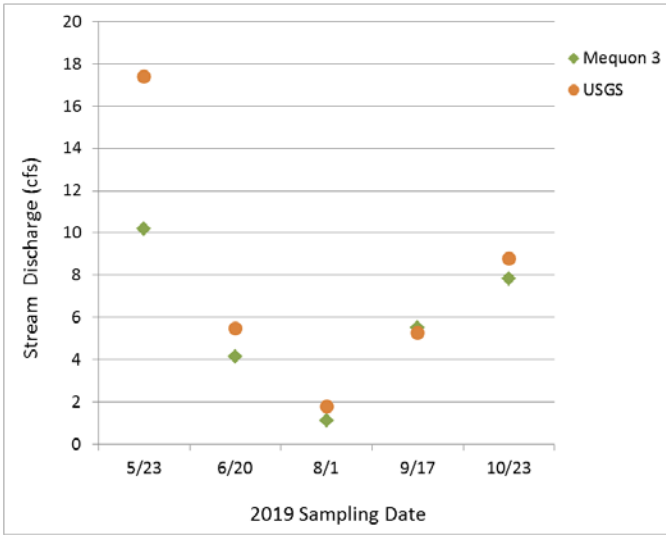


Section 4: 2019 Discharge and Loading Profiles

Daily discharge was calculated using stream flows measured at the time of discrete water sampling on the LMR, Mole, and Ulao Creek sampling locations during each sampling event in 2019. Interpolation methods were used to compute data for each point across a transect perpendicular to the stream channel, spaced 1 foot equidistant from each bank, between measurements taken with a velocity meter. Daily pollutant loads of chloride, total suspended solids, and total phosphorus were estimated using the calculated discharge (cubic feet per second) and SLOH reported concentrations from collected water samples.

The recorded daily discharge values (cfs) measured by the USGS gauge on LMR, stationed downstream of Donges Bay Road and adjacent to Lemke Park located in the City of Mequon, were compared to flow measurements (ft/sec) taken at the closest water quality sampling location upstream of Donges Bay Road (Mequon 3) to ensure relative accuracy (Figure 52). It is important to note that gradient, width of riparian buffer, stream bed composition, and width and depth of channel impact water velocity and subsequently discharge (Hauer and Lamberti 1996). At the USGS gauge location, the stream bead composition is primarily gravel and cobble while the substrate at the water quality sampling station Mequon 3 is comprised of smaller hard substrate and fines and has a deeper channel resulting in greater water depth (personal observation by Planning and Parks Department staff).

Figure 52. Mean daily discharge measured by a permanent USGS gauge stationed immediately downstream of Donges Bay Road, in Mequon, compared to calculated discharge values based on stream velocity measurements taken at the Mequon 3 water quality sampling location on LMR, Ozaukee County, WI.



The presented discharge and loading values for each parameter are based upon the postulation that flow and concentration remained consistent during the day in which the water sample was collected. Extrapolation of discharge and loading per week, month, and/or year requires additional data.

Upper Little Menomonee River System

Stream water velocity and discharge is heavily dependent upon precipitation and ground water input. The mean daily discharge values for the Little Menomonee River were the greatest during the 5/23/2019 sampling event (Table 46, Figure 53a). Loading values (lbs/day) of chloride were the highest, on average, on 10/23/2019; total phosphorus and TSS concentrations peaked on the 6/20/2019 sampling date (Table 47, Figure 52b-d).

Table 46. Discharge and loading values per LMR sampling station per collection date in 2019.

Date	Station	Discharge (cfs)	Load, lbs/day		
			Chloride	Total Phosphorus	TSS
5/23	Freistadt	3.07	612.7	0.92	102.7
	Mequon 2	1.55	357.0	0.28	N/D
	Green Seams 1	3.60	951.5	1.26	85.4
	Green Seams 2	2.82	780.3	1.01	143.0
	Mequon Road	3.68	1111.5	1.80	230.2
	LMC - North	5.57	1658.4	1.26	126.2
	Central	5.19	1567.6	2.09	112.0
	LMC - South	7.62	2268.7	1.82	189.1
	Green Seams 7	13.40	3975.2	3.73	318.0
	Mequon 3	10.20	2992.9	2.92	247.6
	County Line Road	17.24	5151.6	4.65	464.9
6/20	Freistadt	0.07	15.7	0.03	1.1
	Mequon 2	0.16	36.1	0.08	6.9
	Green Seams 1	0.06	17.2	0.03	1.9
	Green Seams 2	0.70	214.1	1.18	675.8
	Mequon Road	0.10	32.8	0.05	5.9
	LMC - North	2.09	671.9	1.34	329.2
	Central	2.17	764.3	1.88	214.2
	LMC - South	14.10	4532.7	9.05	2220.7
	Green Seams 7	4.05	1328.2	2.97	581.1
	Mequon 3	4.14	1324.2	2.72	388.5
	County Line Road	10.34	3279.4	6.47	847.7
8/1	Freistadt	0.02	5.3	0.01	0.3
	Mequon 2	0.22	58.0	0.12	8.3
	Green Seams 1	0.08	35.9	0.14	6.4
	Green Seams 2	0.07	27.0	0.10	17.9
	Mequon Road	1.22	471.2	1.16	157.9
	LMC - North	1.50	508.9	0.61	61.5
	Central	0.65	254.9	1.44	585.5
	LMC - South	7.80	2637.9	3.25	403.9
	Green Seams 7	0.62	218.7	0.39	42.8
	Mequon 3	1.14	384.3	0.62	58.4
	County Line Road	0.95	315.1	0.58	75.8
9/17	Freistadt	0.61	113.5	0.20	10.5
	Mequon 2	0.02	4.5	0.01	0.3
	Green Seams 1	1.58	431.2	0.88	42.6
	Green Seams 2	N/D	N/D	N/D	N/D
	Mequon Road	10.64	3030.2	5.73	596.9
	LMC - North	2.49	839.4	0.96	69.8
	Central	1.02	231.1	1.03	60.5
	LMC - South	1.45	462.2	0.55	37.5
	Green Seams 7	4.79	1291.8	3.23	242.9
	Mequon 3	5.51	1480.0	3.42	219.9
	County Line Road	3.82	1034.3	2.66	292.6
10/23	Freistadt	2.42	486.9	0.59	39.2
	Mequon 2	1.85	420.1	0.41	27.4
	Green Seams 1	3.83	1045.3	1.64	129.1
	Green Seams 2	3.69	1005.1	1.34	114.4
	Mequon Road	5.19	1634.8	1.69	168.0
	LMC - North	6.13	1904.5	2.09	935.7
	Central	12.97	3826.7	6.28	559.7
	LMC - South	4.48	1394.3	0.99	138.9
	Green Seams 7	13.20	3987.1	4.84	498.4
	Mequon 3	7.84	2342.7	2.44	232.6
	County Line Road	4.31	1290.2	1.33	122.0

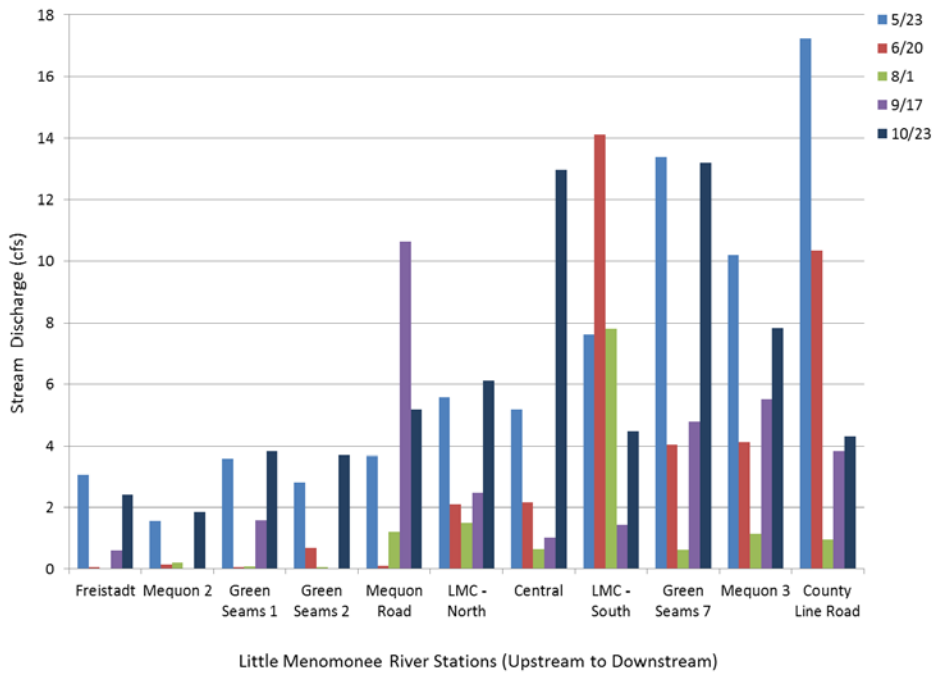
*N/D indicates measured parameter value below the threshold of detection or no water velocity data

Table 47. Average values for discharge and pollutant loading for each variable measured during the 2019 sampling period on the LMR.

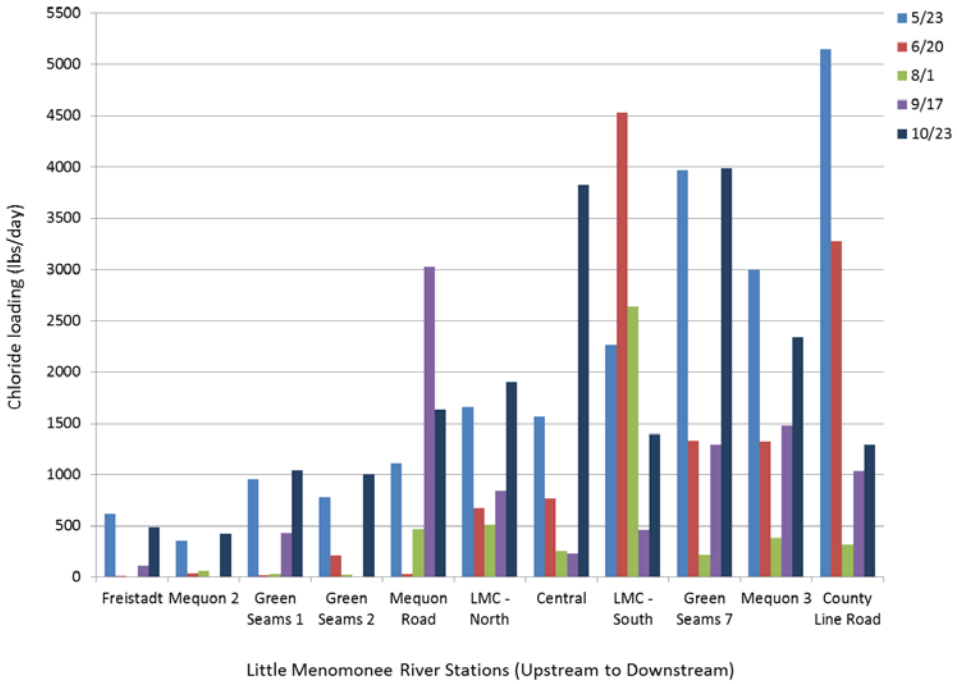
Date	Discharge (cfs)	Load (lbs/day)		
		Chloride	Total Phosphorus	TSS
5/23/2019	6.7	1947.9	2.0	201.9
6/20/2019	3.5	1110.6	2.3	479.4
8/1/2019	1.3	447.0	0.8	129.0
9/17/2019	3.2	891.8	1.9	157.4
10/23/2019	6.0	1758.0	2.1	269.6

Figure 53. Stream discharge calculations and loading values for parameters measured by the SLOH from collected water samples on the LMR during the 2019 sampling period.

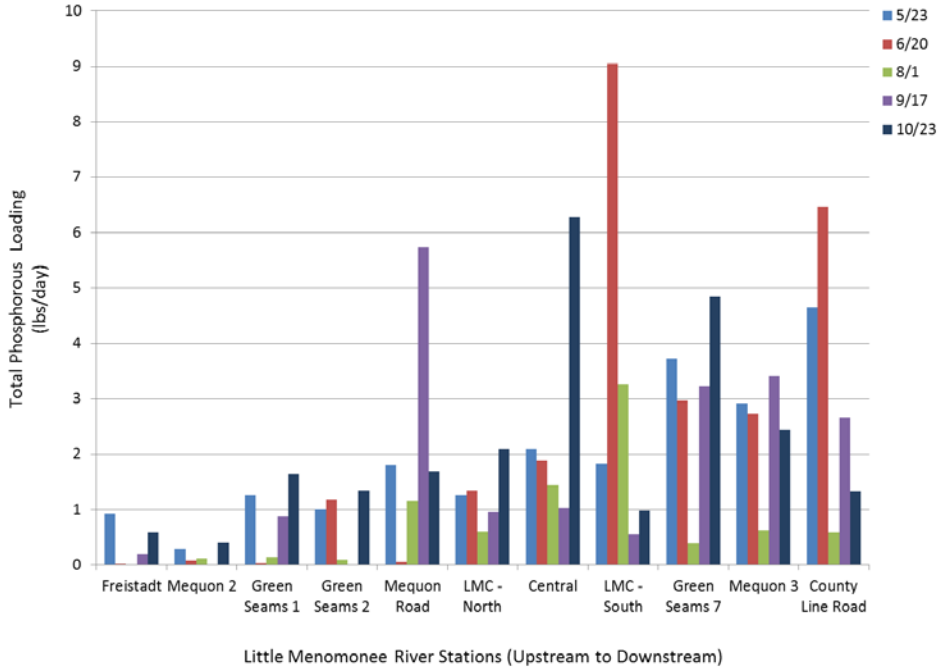
a.) Stream discharge (cfs)



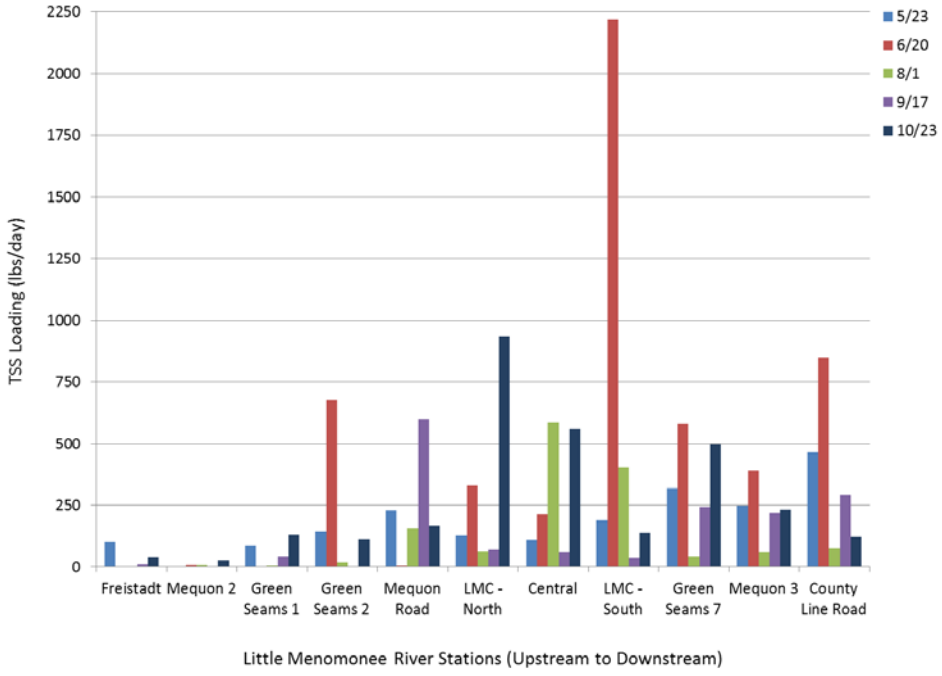
b.) Chloride loading per site per day (lbs/day)



c.) Total phosphorus per site per day (lbs/day)



d.) TSS per site per day (lbs/day)



Mole Creek

The mean daily discharge values for sampling location on Mole Creek were the greatest during the 10/16/2019 sampling event (Table 48, Figure 54a). Additionally, loading values (lbs/day) of chloride, phosphorus, and TSS were the highest, on average, on 10/23/2019 (Table 49, Figure 54b-d).

Table 48. Discharge and loading values per Mole Creek sampling station per collection date in 2019.

Date	Station	Discharge (cfs)	Load, lbs/day		
			Chloride	Total Phosphorus	TSS
5/30	Headwaters	3.94	926.6	0.89	261.4
	Below Confluence S. of HWY 33	4.90	1007.0	2.37	396.4
	South of Hillcrest	4.61	962.3	1.21	167.8
	Upstream of Cedar Sauk	5.20	1023.7	1.90	105.2
	Pleasant Valley Rd	10.81	2367.3	2.65	221.6
	Co. Hwy O	13.48	3235.5	3.48	436.2
7/22	Headwaters	1.64	386.6	0.55	138.9
	Below Confluence S. of HWY 33	0.89	192.0	0.38	64.8
	South of Hillcrest	3.71	820.4	1.31	50.0
	Upstream of Cedar Sauk	9.60	1858.9	5.18	N/D
	Pleasant Valley Rd	12.35	2424.7	7.13	288.4
	Co. Hwy O	9.87	2044.3	6.39	745.3
9/3	Headwaters	3.00	1064.7	1.05	254.0
	Below Confluence S. of HWY 33	2.30	750.5	1.02	161.3
	South of Hillcrest	1.50	439.3	0.66	56.6
	Upstream of Cedar Sauk	2.40	625.2	1.90	105.2
	Pleasant Valley Rd	1.15	315.1	1.15	44.0
	Co. Hwy O	3.80	1139.6	1.18	82.0
10/16	Headwaters	6.03	1366.0	1.53	445.6
	Below Confluence S. of HWY 33	9.19	1893.5	3.96	991.4
	South of Hillcrest	10.39	2196.8	3.51	434.3
	Upstream of Cedar Sauk	8.95	1815.1	3.10	337.9
	Pleasant Valley Rd	16.64	3715.7	4.51	269.3
	Co. Hwy O	22.85	5669.4	5.92	369.7

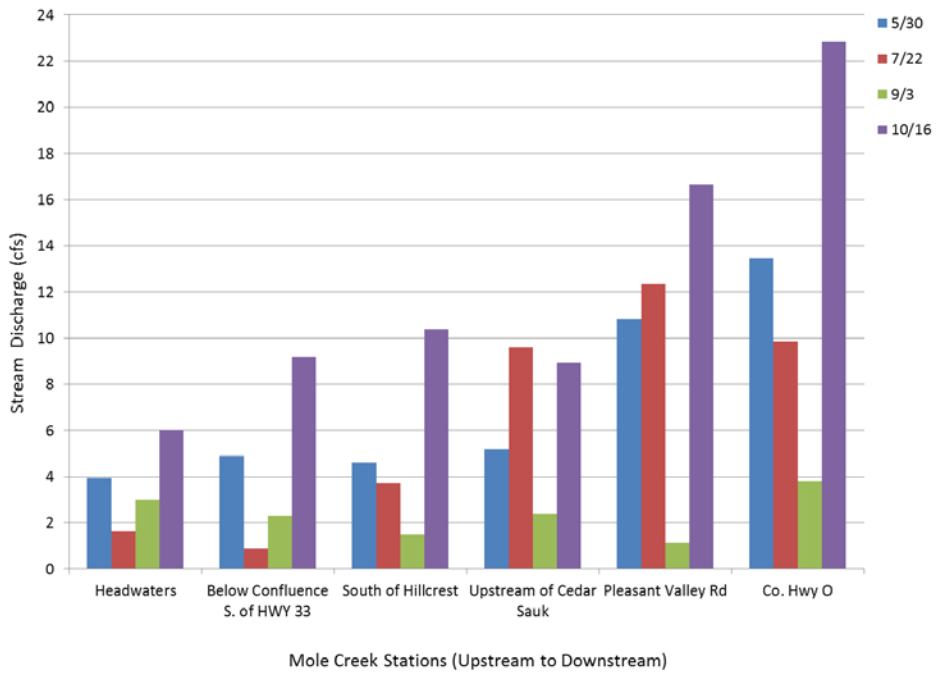
*N/D indicates measured parameter value below the threshold of detection

Table 49. Average values for discharge and pollutant loading for each variable measured during the 2019 sampling period on Mole Creek.

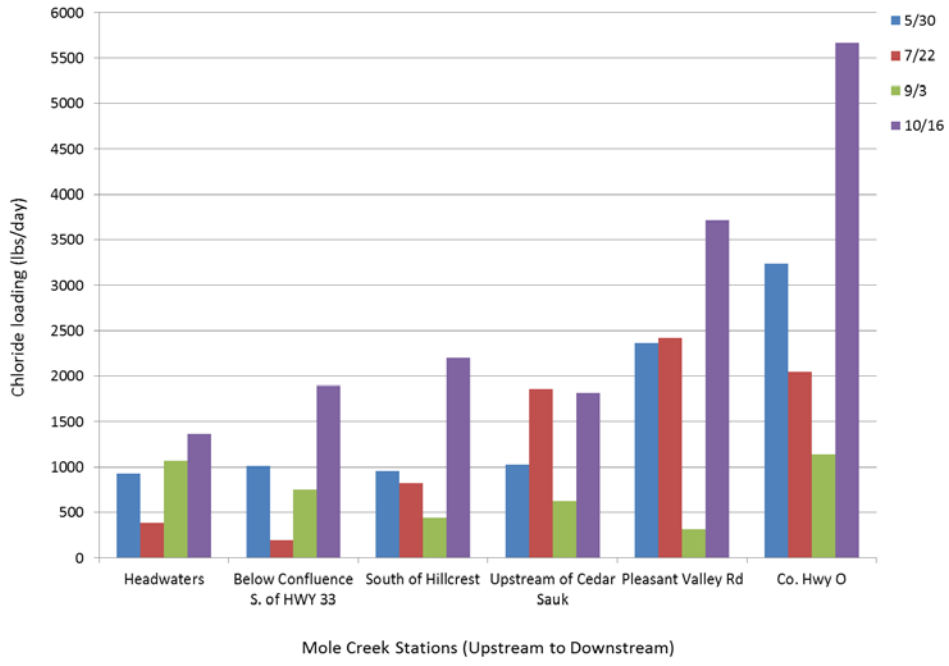
Date	Discharge (cfs)	Load (lbs/day)		
		Chloride (lbs/day)	Total Phosphorus (lbs/day)	TSS (lbs/day)
5/30/2019	7.2	1587.1	2.1	264.8
7/22/2019	6.3	1287.8	3.5	257.5
9/3/2019	2.4	722.4	1.2	117.2
10/16/2019	12.3	2776.1	3.8	474.7

Figure 54. Stream discharge calculations and loading values for parameters measured by the SLOH from collected water samples on Mole Creek during the 2019 sampling period.

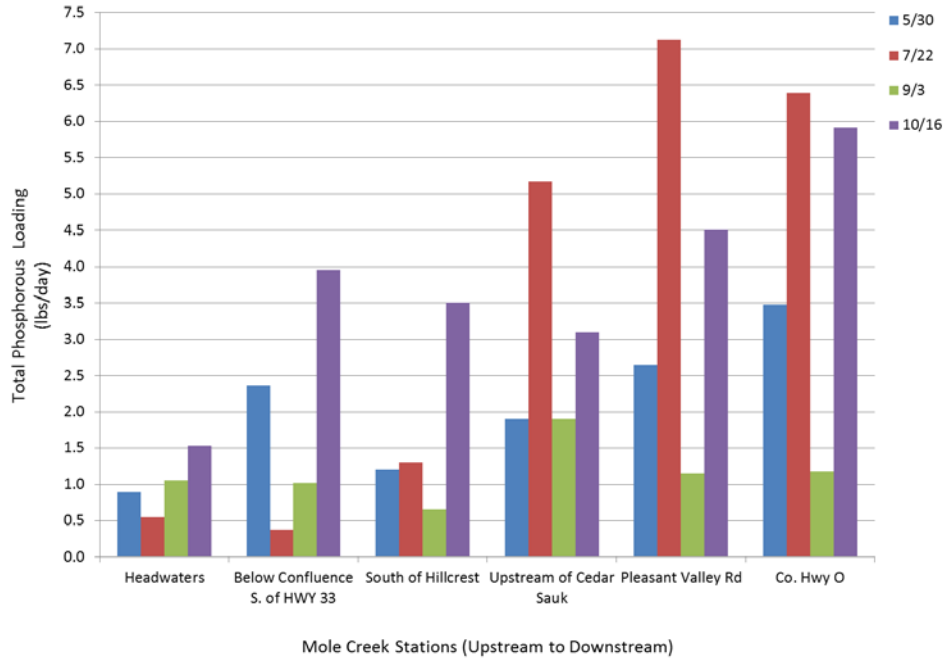
a.) Stream discharge (cfs)



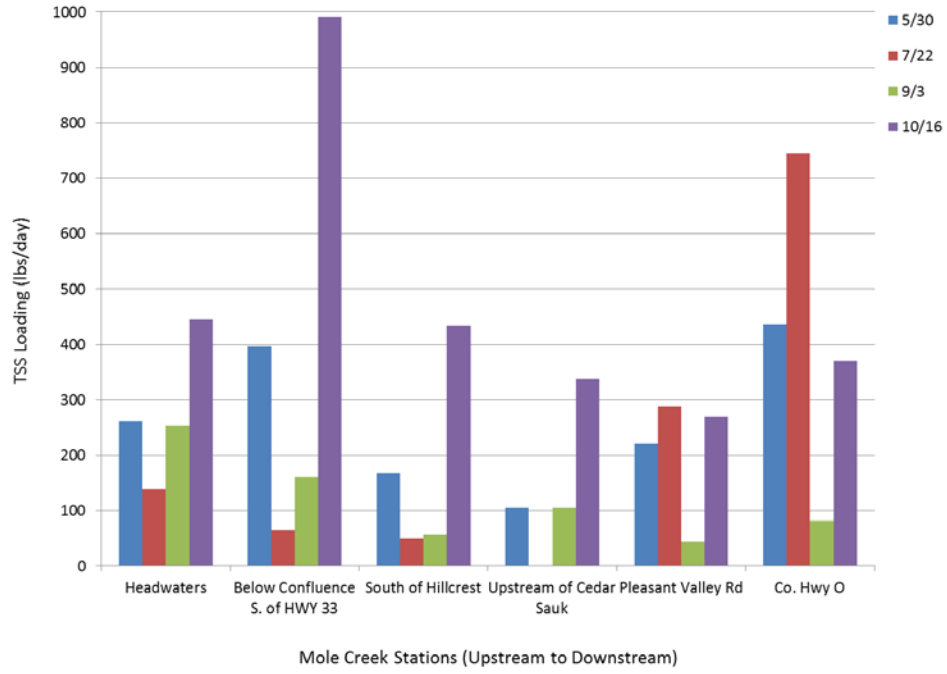
b.) Chloride loading per site per day (lbs/day)



c.) Total phosphorus per site per day (lbs/day)



d.) TSS per site per day (lbs/day)



Ulao and Kaul Creek System

The mean daily discharge was highest among the Ulao and Kaul Creek sampling locations during the 5/30/2019 sampling event (Table 50, Figure 55a). Loading values (lbs/day) of chloride, phosphorus, and TSS were the highest, on average, during the 7/22/2019 sampling event (Table 51, Figure 55b-d).

Table 50. Discharge and loading values per Ulao and Kaul Creek sampling station per collection date in 2019.

Date	Station	Discharge (cfs)	Load, lbs/day		
			Chloride	Total Phosphorus	TSS
5/30	Headwaters Ulao	0.43	124.8	0.27	N/D
	Headwaters Kaul	1.76	252.5	0.73	N/D
	Kaul Above Ulao	0.021	N/D	0.01	N/D
	Below Kaul Creek	3.6	1215.5	1.81	N/D
	Above Helms Creek	7.12	2058.4	3.01	N/D
	Below Helms Creek	9.76	4043.0	3.86	115.8
	Hwy 60	11.52	5654.4	4.75	323.1
	Gateway	10.46	1048.5	0.24	26.0
	Bonniwell Rd	5.24	3137.2	2.00	147.0
7/22	Headwaters Ulao	0.17	57.3	3.97	0.3
	Headwaters Kaul	0.5	30.2	1.24	29.1
	Kaul Above Ulao	4.14	424.3	14.27	587.3
	Below Kaul Creek	0.71	169.3	1.97	19.1
	Above Helms Creek	1.78	16.4	2.65	38.4
	Below Helms Creek	3.09	1015.0	4.13	87.5
	Hwy 60	2.89	1714.7	3.5	145.44
	Gateway	3.77	5512.1	4.03	203.1
	Bonniwell Rd	13.79	10562.0	13.6	795.87
9/3	Headwaters Ulao	N/D	N/D	N/D	N/D
	Headwaters Kaul	N/D	N/D	N/D	N/D
	Kaul Above Ulao	N/D	N/D	N/D	N/D
	Below Kaul Creek	N/D	N/D	N/D	N/D
	Above Helms Creek	0.012	16.4	0.01	0.5
	Below Helms Creek	0.086	127.6	0.05	5.8
	Hwy 60	N/D	N/D	N/D	N/D
	Gateway	0.36	1048.5	0.24	26.0
	Bonniwell Rd	N/D	N/D	N/D	N/D
10/16	Headwaters Ulao	0.87	324.7	0.34	23.5
	Headwaters Kaul	1.57	220.2	0.51	N/D
	Kaul Above Ulao	N/D	N/D	N/D	N/D
	Below Kaul Creek	7.13	1730.6	3.25	105.8
	Above Helms Creek	4.78	1054.5	1.69	96.7
	Below Helms Creek	4.14	1281.8	1.58	217.7
	Hwy 60	5.14	1630.2	2.00	221.8
	Gateway	4.29	1902.0	1.67	179.3
	Bonniwell Rd	N/D	N/D	N/D	N/D

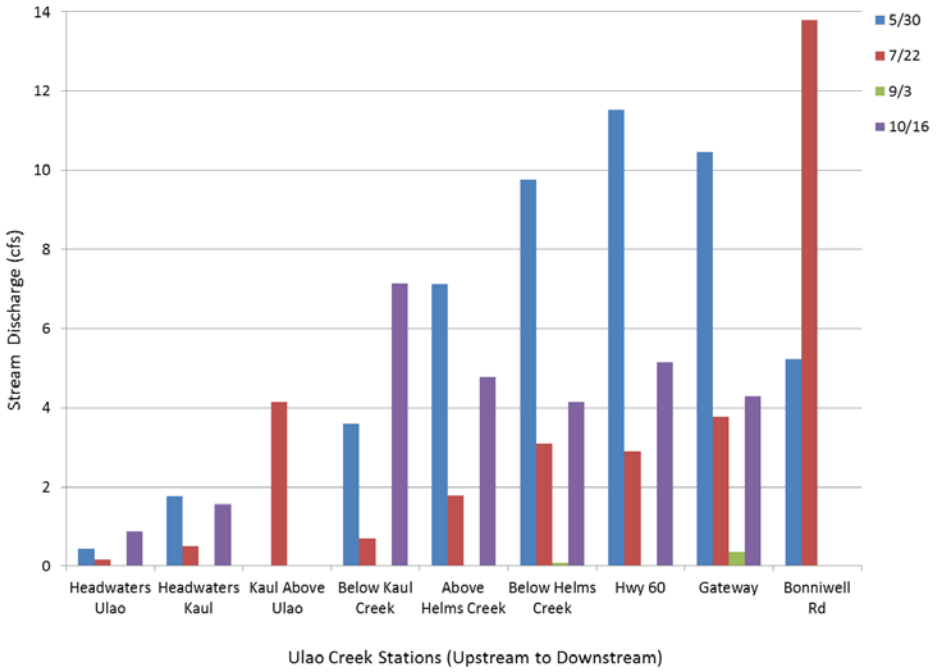
*N/D indicates measured parameter value below the threshold of detection or no water velocity data

Table 51. Average values for discharge and pollutant loading for each variable measured during the 2019 sampling period on Ulao and Kaul Creek.

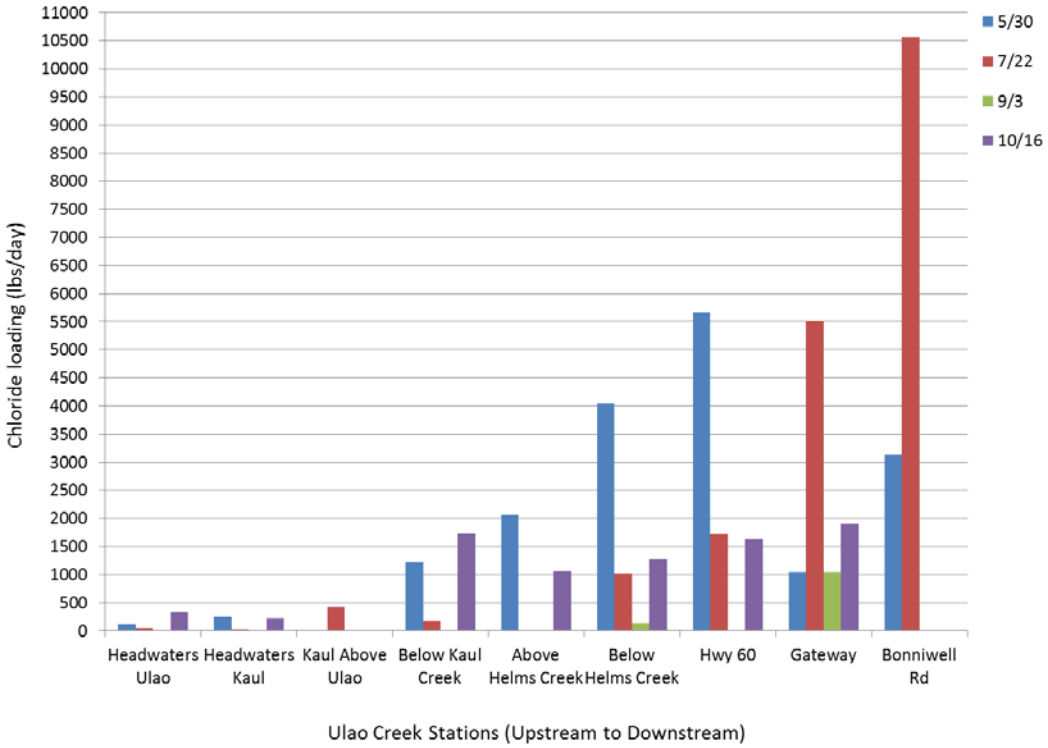
Date	Discharge (cfs)	Load (lbs/day)		
		Chlorine	Total Phosphorus	TSS
5/30/2019	5.5	2191.8	1.9	153.0
7/22/2019	3.4	2166.8	5.5	211.8
9/3/2019	0.2	397.5	0.1	10.8
10/16/2019	4.0	1163.4	1.6	140.8

Figure 55. Stream discharge calculations and loading values for parameters measured by the Wisconsin SLOH from collected water samples on Ulao and Kaul Creek during the 2019 sampling period.

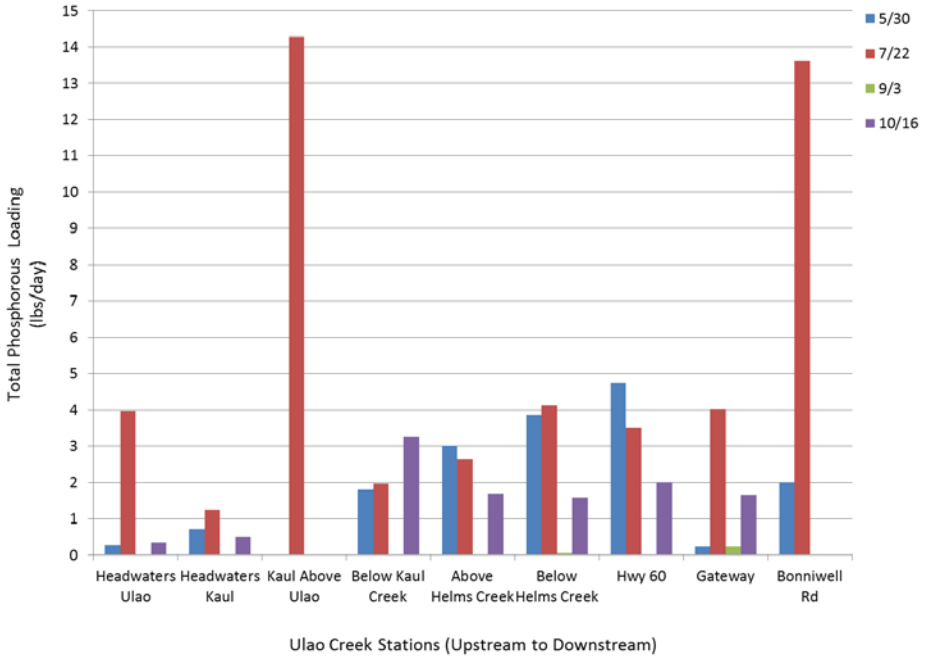
a.) Stream discharge (cfs)



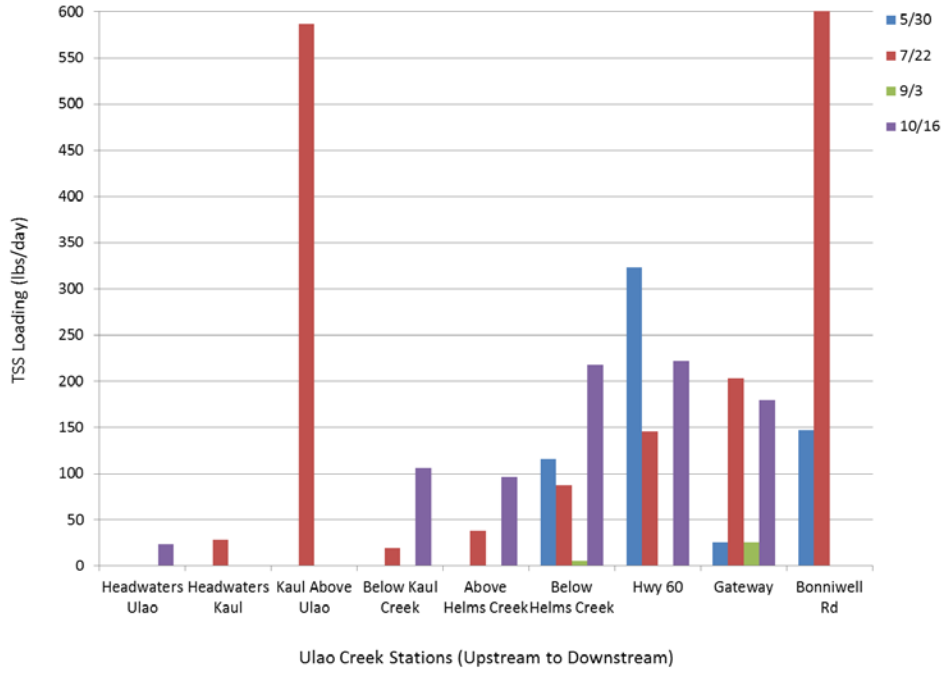
b.) Chloride loading per site per day (lbs/day)



c.) Total phosphorus per site per day (lbs/day)



d.) TSS per site per day (lbs/day)



Additional Observations

Conductivity and TDS

Conductivity readings at all discrete sampling locations and recorded by the 3 continuous monitoring stations from all years were consistently above the ideal range for a healthy fisheries of 150-500 µs/cm (USEPA 2012). Per the USEPA (2012), average conductivity of inland rivers in the United States ranges from 50-1500 µs/cm with low conductivity (0 to 200 µS/cm) indicating pristine conditions, mid-range (200 to 1000 µS/cm) serving as an average for major rivers, and high conductivity (1000 to 10,000 µS/cm) occurring in salt water environments and heavily polluted freshwater. Streams with consistent average measurements above 1000 µS/cm may lack fish and aquatic invertebrate biodiversity due to the presence of inorganic dissolved solid and chemical pollutants commonly associated with agricultural runoff and wastewater (e.g., chloride, nitrate, sulfate, phosphate, sodium, magnesium, calcium, iron, and aluminum). In general, conductivity readings increase with increasing water temperatures due to increased rates of evaporation (USEPA 2006). Additionally, streams or reaches of streams with high levels of inorganic dissolved solids will have high TDS readings (Scannell and Jacobs 2001).

The highest average readings from the discrete sampling events occurred at the Mequon Road station all 3 years, decreasing annually from 2017 to 2019 from 991.2 to 927.7 µs/cm (Table 10). The continuous monitoring units recorded measurements exceeding 1500 µs/cm at Mequon Road in 2017 and the Freistadt location in 2019, occurring during the months of July and August, when average daily water temperature was highest (Figures 16 and 17). TDS was also, on average, highest at the Mequon Road sampling location during both 2018 and 2019 (Table 13).

On average, the highest conductivity readings among the 6 Mole Creek water quality sampling locations were measured in 2016. Average values decreased annually between 2016 and 2019 with the lowest average concentrations measuring 824.2 µs/cm at the Headwaters location to 750.5 µs/cm at the Co. Hwy O station (Table 25, Figure 26). TDS followed a similar pattern, with highest average values measured during 2016; across the 6 stations, values were lowest in 2017 (Table 28, Figure 29).

In the Ulao Creek stream system, conductivity values were generally high at the Headwaters location and increased from the location above the confluence with Helms Creek toward the downstream sampling locations. The 2 Kaul Creek sampling stations demonstrated no particular relationship between upstream and downstream locations (Table 38, Figure 41). However, TDS values appeared to follow the same pattern as conductivity at all sampling locations (Table 35, Figure 43).

Additional data is needed to infer a consistent trend between conductivity, TDS, and water temperature on the studied stream systems in Ozaukee County.

Turbidity

High levels of turbidity can negatively influence water quality and degrade habitats for aquatic organisms through the reduction of light penetration, siltation, increased surface area for attachment of pollutants and bacteria, increased water temperature, and decreased or unstable levels of dissolved oxygen. A variety of factors, including but not limited to: stormwater runoff, soil composition, sinuosity, stream gradient, and quality and quantity of buffer and floodplain vegetation, influence stream turbidity (Miguel-Chinchilla et al. 2019). Measuring turbidity is beneficial in detecting landscape changes, erosion, and

monitoring pathogens as it is strongly correlated with sediment, pollutants such as pesticides, metals, and nutrients, and bacteria (Sadar 2017).

Turbidity readings during discrete water sampling events were consistently high across nearly all locations during all 3 study years. While the primary land use of the Little Menomonee Watershed is agriculture, the landscape surrounding the 2 upstream sampling stations is undisturbed (Figure 2). These 2 stations measured the lowest average turbidity during 2018 and 2019 and were the only 2 locations below the recommended 10 FNU criteria (Table 14). Stream channel, adjacent floodplain and native vegetation restoration occurring adjacent to the Mequon Road sampling location may assist in lessening average turbidity readings at sampling stations further downstream in the future.

Between the Mole Creek water quality sampling stations, average annual turbidity readings decreased, overall, as the stream flowed downstream (Table 29, Figure 30). The highest annual average value occurred in 2019, with an average concentration of 23.9 FNU at the Headwaters, while in 2016 the lowest average of 3.2 FNU occurring at the furthest downstream sampling location (Co. Highway O).

Average annual turbidity readings were relatively stable across the Ulao Creek sampling locations between years and across locations (Table 42, Figure 44). Measurements were lower at the headwaters of Kaul Creek than downstream station near the confluence with Ulao Creek. Highest turbidity averages occurred in 2018 (68.0 FNU) and 2019 (103.8 FNU) at the Kaul Creek above the Ulao Creek confluence locations.

Additional investigation into stream bed and hyporheic zone substrate composition is needed to properly correlate measured turbidity, TDS, and conductivity within all 3 studied stream systems and between stations and study years.

Applications

Studies demonstrate past land use has a greater impact on processes linked to sediment, such as turbidity and TDS, while recent land use is more closely linked to variables in water chemistry and water temperature particularly in regions where stream gradient and elevation is relatively low (Frissell et al. 1986, Harding et al. 1998, Meade et al. 1990, Scott et al. 2002, Wang et al. 1997). Additionally, community composition of biological organisms, such as fish and invertebrates, are influenced more by past land use with biological diversity recovering slowly overtime (Harding et al. 1998, Wang et al. 1997). This is primarily due to sedimentation processes, which are influenced by the size of the watershed, elevation, stream channel gradient, buffer vegetation along waterways, and land cover, and are correlated with water temperature, turbidity, and nutrient loading. Through a series of assessments and models, Scott et al. (2002) concluded that legacy change in land cover paired with stream gradient, elevation, and catchment size were significant predictors of ammonia and nitrate levels, turbidity, soluble reactive phosphorus, TDS, mean summer temperatures, and substrate coarseness. Water temperature was negatively related to elevation and positively related to the catchment area, with lower water temperatures associated with increased forested areas within a catchment and riparian buffer overtime. Additionally, lower nutrient concentrations, TDS, and turbidity were detected in regions with more vegetative cover in the riparian buffer.

In small, predominantly agricultural watersheds, like the ones found in Ozaukee County, restoration of intact riparian buffers along stream banks have been shown to reduce transport of sediment and nutrients and improve both water quality and instream habitat for fish and invertebrates (Lammert and Allan 1999, Schlosser and Karr 1981, Lowrance et al. 1984). Loss of natural vegetative cover in floodplains and buffer zones due to anthropogenic activity has resulted in erosion and subsequently increased turbidity, suspended solids, silt loading and channel sedimentation, nutrient levels due to stormwater runoff, and loss of instream habitat particularly in urbanizing regions (Lammert and Allan 1999, Schlosser and Karr 1981, Walters 1995, Wang et al. 1997). Degradation of water quality and aquatic habitat is the result of such cumulative impacts, hence riparian and instream rehabilitation efforts on only short stream reaches may be inadequate for aquatic species restoration efforts.

Comprehensive stream management practices focus on a holistic view of stream corridor and surrounding landscape. While the repair and maintenance of stream buffers improves the integrity and ecological quality of a stream system, additional efforts must be focused on the anthropogenic activities occurring throughout the watershed (Scott et al. 2002). Stream water quality can improve through best management practices and mitigation efforts.

The Department has had success in the construction and restoration of 2 nearby stream systems, Ulao and Mole Creek, which resulted in improved stream function, restoration of native plants and habitat for aquatic, semiaquatic, and migratory animals, improved aquatic connectivity, and population increase in the target native fish species through natural reproduction. Similar construction efforts are currently underway along reaches of the Little Menomonee River system, with the additional goal of delisting beneficial use impairments for the Menomonee River as part of the Milwaukee Estuary AOC.

Redesigning the stream channel, enhancing the instream and riparian habitat, and adjacent floodplain and wetlands along the Little Menomonee system will continue to improve aquatic connectivity and fish passage within the watershed. Final plans and ongoing construction activities include a combination of fish passage impediment removals or remediation, stream remeandering, restoration of hydrologically and ecologically functional floodplains, addition of in-channel (e.g., woody debris) and avian (e.g., nest boxes) habitat structures, wetland restorations, invasive vegetation management, and native vegetation (e.g., tree and shrub plantings, native prairie and wetland seeding) restoration activities. Impediment removal or remediation is prioritized to improve linear aquatic connectivity throughout the project area; whereas, connectivity to floodplain and adjacent wetlands (restored) improves lateral aquatic connectivity, as both are critical components of holistic habitat restoration and enhancement activities.

Continued water quality monitoring is necessary and will determine the effectiveness of stream remeandering, floodplain connection, and wetland restoration as a best management practice. Although the construction and restoration efforts are not intended to restore the landscape to pre-settlement conditions, the efforts will restore function and value for fish and other aquatic life within the stream corridor and wetland areas. This project may serve as a model for future cooperative habitat restoration projects in the Milwaukee River Watershed, the AOC, and the Great Lakes Basin.

Conclusions

This study has generated a robust source of water chemistry data from the Upper Little Menomonee River, Mole Creek, and Ulao/Kaul Creek Watershed systems that can be utilized as a baseline for these

watershed systems and compared to previous and on-going data collections to assist in identifying variations within and between watersheds. Continued water quality monitoring will strengthen this data set for further analysis and comparisons, particularly for post-restoration efforts. This analysis has not accounted for comprehensive temporal or spatial differences, somewhat limiting its applicability to all seasons and climate conditions. Additional, consistent continuous monitoring data may help better explain seasonal or daily variations by providing further insight into water quality conditions. The data presented here has also been shared with partnering organizations including the Milwaukee Riverkeeper and MMSD for review. The next steps in the Department's analysis is to compare the Ulao and Mole Creek data with the results of baseline water quality monitoring completed by MMSD (2020) and incorporate local rainfall data to determine the impact on water quality parameters per sampling date/year.

Further studies are needed to correlate land use and the various water quality parameters; however, agricultural runoff may be elevating total phosphorus, turbidity, and conductivity of the 3 studied lotic systems. Several locations, including the Mequon Road sampling location that is currently undergoing restoration and rehabilitation, may benefit from restoration of the riparian buffer, stream channel and instream habitat, and/or adjacent wetlands and floodplains. Additional data collection and further analysis will greatly assist in understanding water quality trends, sources of water quality problems, and management practices that improve water quality (e.g., pre- and post-restoration water quality monitoring). Continuous water quality monitoring can be utilized to better understand natural variations that may confound attempts to identify trends. Overall, variables such as TSS, conductivity, temperature, and turbidity are best understood when comparing from a baseline. The data presented here, while useful in comparison to historic data, may serve as a baseline for future research and water quality data collection as well as a guide for future management projects.

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Appendix A.

Photograph of a continuous water quality monitoring station.

Appendix B.

Mean values for each sampled parameter per year for all sampling locations within the Upper LMR Watershed.

Watershed	Parameter	Year	Mean	Std. Deviation
Upper Little Menomonee	Chloride (mg/L)	2017	54.331	10.818
		2018	55.116	8.470
		2019	54.742	9.492
	Orthophosphate (mg/L)	2017	0.050	0.018
		2018	0.045	0.023
		2019	0.044	0.028
	Total Phosphorus (mg/L)	2017	0.137	0.049
		2018	0.123	0.140
		2019	0.104	0.073
	Total Suspended Solids (mg/L)	2017	20.297	22.709
		2018	7.842	10.400
		2019	16.403	32.194
	E. coli (MPN/100 mL)	2017	443.843	433.272
		2018	196.553	166.116
		2019	196.529	226.375
	Dissolved Oxygen (mg/L)	2017	7.064	2.629
		2018	8.807	13.869
		2019	8.215	2.759
	pH	2017	7.944	0.337
		2018	7.631	0.274
		2019	7.797	0.298
	Salinity (PSU)	2017	0.418	0.058
		2018	0.433	0.036
		2019	0.433	0.053
	Conductivity (µS/cm)	2017	853.182	105.369
		2018	878.481	69.281
		2019	869.571	85.979
	Total Dissolved Solids (mg/L)	2017	423.909	56.395
		2018	433.036	50.861
		2019	16.403	124.381
	Turbidity (FNU)	2017	24.848	14.498
		2018	10.924	10.836
		2019	21.650	18.051
	Water Temperature (^{o}C)	2017	18.584	3.955
		2018	16.474	3.563
		2019	15.503	3.180

Mean values for each sampled parameter per year for all sampling locations within the Mole Creek Watershed.

Watershed	Parameter	Year	Mean	Std. Deviation
Mole	Chloride (mg/L)	2016	51.058	5.129
		2017	48.547	7.089
		2018	45.258	5.626
		2019	44.046	8.011
	Orthophosphate (mg/L)	2016	0.027	0.013
		2017	0.022	0.010
		2018	0.036	0.015
		2019	0.037	0.021
	Total Phosphorus (mg/L)	2016	0.059	0.021
		2017	0.073	0.026
		2018	0.077	0.026
		2019	0.069	0.021
	Total Suspended Solids (mg/L)	2016	4.365	2.642
		2017	9.517	7.507
		2018	4.862	5.489
		2019	8.606	5.424
	E. coli (MPN/100 mL)	2016	316.088	534.310
		2017	661.514	8495.113
		2018	395.873	395.519
		2019	266.7536	708.945
	Dissolved Oxygen (mg/L)	2016	10.084	1.608
		2017	8.016	2.074
		2018	8.800	1.833
		2019	9.943	26.726
	pH	2016	8.255	0.188
		2017	7.983	0.188
		2018	7.922	0.261
		2019	7.863	0.293
	Salinity (PSU)	2016	0.426	0.014
		2017	0.409	0.047
		2018	0.415	0.016
		2019	0.392	0.019
	Conductivity (µS/cm)	2016	857.444	27.163
		2017	812.227	142.386
		2018	837.958	30.235
		2019	777.560	43.625
	Total Dissolved Solids (mg/L)	2016	546.310	92.419
		2017	413.773	45.397
		2018	419.167	15.273
		2019	437.250	76.587
	Turbidity (FNU)	2016	10.811	12.547
		2017	14.580	10.845
		2018	6.988	5.423
		2019	14.002	9.073
	Water Temperature (^{o}C)	2016	13.740	4.798
		2017	13.846	4.888
		2018	14.983	4.766
		2019	16.379	4.438

Mean values for each sampled parameter per year for all sampling locations within the Ulao Creek Watershed.

Watershed	Parameter	Year	Mean	Std. Deviation
Ulao	Chloride (mg/L)	2016	107.733	59.084
		2017	97.369	48.548
		2018	100.386	73.136
		2019	101.274	126.180
	Orthophosphate (mg/L)	2016	0.097	0.092
		2017	0.068	0.044
		2018	0.072	0.061
		2019	0.081	0.062
	Total Phosphorus (mg/L)	2016	0.184	0.096
		2017	0.174	0.089
		2018	0.224	0.226
		2019	0.232	0.129
	Total Suspended Solids (mg/L)	2016	6.829	11.025
		2017	9.103	9.335
		2018	14.130	27.408
		2019	16.299	23.529
	E. coli (MPN/100 mL)	2016	254.968	469.063
		2017	301.308	1844.167
		2018	207.200	288.030
		2019	285.2082	621.150
	Dissolved Oxygen (mg/L)	2016	6.947	1.860
		2017	6.349	4.201
		2018	6.827	3.046
		2019	7.497	2.712
	pH	2016	7.833	0.270
		2017	7.775	0.335
		2018	7.618	0.267
		2019	7.675	0.316
	Salinity (PSU)	2016	0.359	0.045
		2017	0.378	0.072
		2018	0.430	0.102
		2019	0.473	0.256
	Conductivity (µS/cm)	2016	732.222	91.826
		2017	764.112	146.085
		2018	866.333	198.164
		2019	876.457	303.086
	Total Dissolved Solids (mg/L)	2016	546.025	166.046
		2017	464.161	125.142
		2018	518.071	169.282
		2019	568.098	218.765
	Turbidity (FNU)	2016	10.842	11.128
		2017	17.454	24.485
		2018	14.183	18.376
		2019	26.095	46.818
	Water Temperature (^{o}C)	2016	14.245	4.428
		2017	17.399	4.455
		2018	18.390	6.475
		2019	17.673	4.553