2021 Water Quality Report

U.S. Army Corps of Engineers
Saint Louis District

Carlyle Lake Water Quality Conditions: 1971-2021

March 2023

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Prepared for

United States Army Corps of Engineers
Saint Louis District
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EXECUTIVE SUMMARY

The United States Army Corps of Engineers (USACE) commitment to environmental compliance and protection of estuaries, rivers, lakes, and navigable waters arises from the national policy and directives expressed in Federal Statutes, Executive Orders, and internal regulations. These regulations were designed to minimize pollution, maximize recreation, protect aesthetics, preserve natural resources, and promote the comprehensive planning and use of water bodies to enhance the public interest rather than private gain. Therefore, USACE, in the design, construction, management, operation, and maintenance of its facilities, will exert leadership within existing authorities and appropriations in the nationwide effort to protect, enhance, and sustain the quality of the nation's resources. It is USACEs policy to comply with requirements of the Clean Water Act and not to degrade existing water quality conditions to the maximum extent that is practicable, consistent with project authorities, Federal legal and regulatory requirements, the public interest, and water control manuals.

The United States Army Corps of Engineers, Saint Louis District (CEMVS), implemented a water quality monitoring program during the 1970s to evaluate how its civil projects may be affecting water resources. Data collected from this effort serves as an invaluable tool for evaluating the significance of annual water quality measurements and tracking long-term trends. Water quality data is provided to the Missouri Department of Natural Resources and the Illinois Environmental Protection Agency to be used as a screening mechanism for the Missouri and Illinois Water Quality Report which is required every two years by the Clean Water Act Sections 303(d) and 305(b).

The National Water Quality Inventory Report to Congress (305(b) report) is the primary vehicle for informing law makers and the public about general water quality conditions in the United States. This document characterizes our water quality, identifies widespread water quality problems of national significance, and describes various programs implemented to restore and protect our waters. Currently the Illinois Environmental Protection Agency (IEPA, 2020) has listed Carlyle Lake as impaired for total phosphorous and mercury while the Kaskaskia River upstream from the Lake is impaired for fecal coliform, and mercury. In addition, the North Fork Kaskaskia River is impaired for phosphorus, Atrazine, and Terbufos. The lists of sources for these impairments are contaminated sediments, crop production, and unknown sources. The entire Kaskaskia watershed is impaired by the above parameters as well as many others.

Water quality sampling in 2021 revealed the following concerns at Carlyle Lake: bacteria, iron, dissolved oxygen, temperature, pesticides, and total phosphorus.

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INTRODUCTION

The Carlyle Lake watershed encompasses approximately 1,663 square miles and includes all or portions of Bond, Clinton, Effingham, Fayette, Marion, Shelby, and Montgomery counties. The watershed includes the Kaskaskia River between Carlyle Lake Dam and Lake Shelbyville Dam and major tributaries of the Kaskaskia River, including: Big, Richland, Robinson, Becks, Ramsey, Old Hickory, and Hurricane Creeks (respectively) and the East Fork Kaskaskia River. Agriculture is the predominant land use within the watershed. Currently, 82% of the land is used for agricultural purposes. Of that 82%, 63% is cropland and 19% grassland. Since 1978, the number of farms has decreased by 25% and the acreage tilled has decreased by only 6%. Corn and soybeans are important to the region, but producers also grow 25% of the entire state's crop of wheat. Livestock production, including dairy, swine, poultry, and beef cattle is a significant industry, especially in Clinton, Randolph, and Washington Counties.

Carlyle Lake is located in south central Illinois at river mile 94.2 on the Kaskaskia River, upstream from its confluence with the Mississippi River and about one-half mile upstream from the town of Carlyle, Illinois. Carlyle is located in Clinton County, approximately 50 miles east of St. Louis, Missouri. Carlyle Lake is the largest man-made lake in the state and is approximately 12 miles long and 1-3 miles wide and has approximately 24,710 acres of water surface at summer pool elevation 445.0 feet NGVD (National Geodetic Vertical Datum). There are 88 miles of shoreline and approximately 12,800 acres of public land associated with the project. The lake is situated in gently rolling land with alluvial valleys with moderately low relief. The lake provides outdoor recreation opportunities for over 2.5 million visitors annually, which generates over $80 million in visitor spending within 30- miles of the Lake. There are 41 recreation areas that include: 424 picnic sites, 726 campsites, 670 marina slips, 24 boat ramps, and 25 miles of hiking trails. The CEMVS manages and operates two large reservoirs on the Kaskaskia River, Lake Shelbyville and Carlyle Lake, as well as the 36 mile long navigable channel and lock and dam at the Kaskaskia River Project.

Carlyle Lake is managed and operated by the CEMVS for the authorized purposes of flood risk management, navigation, water supply, water quality, fish and wildlife conservation, and recreation. The lake serves as a heavy recreational usage lake. The land surrounding the lake is used predominately for agriculture. Surrounding communities have existing industrial/commercial operations and residents which discharge wastewater into municipal wastewater treatment plants that ultimately discharge treated water into the Kaskaskia River basin. Agricultural runoff and municipal wastewater treatment facilities are the primary potential source of pollution into the Carlyle Lake watershed. Additional sources are marinas, recreational watercraft discharges and wildlife fecal material runoff.

Water quality is of paramount importance for sustaining ecological integrity and services provided by the Kaskaskia River and Carlyle Lake. Water quality is influenced by a range of both point and nonpoint pollution sources, which may include natural processes, industrial and municipal effluents, and surface runoff from agricultural arenas.

The USACE has implemented a Water Quality Management Plan (WQMP) as part of the operation and maintenance activities associated with managing USACEs' civil works projects throughout the District which includes, among other reservoirs and rivers, the Kaskaskia River and Carlyle Lake. The WQMP addresses surface water quality management issues and adheres to the guidance and requirements specified by Clean Water Act (CWA), as well as the self-imposed Engineering Regulation (ER) 1110-2-8154, "Water Quality and Environmental Management for USACE Civil Works Projects" (USACE, 2018). Water quality monitoring is implemented to fulfill five primary objectives that drive the CEMVS WQMP:

1) Establish baseline conditions, identify significant water quality trends, and document problems and accomplishments.
2) Ensure that surface water quality, as affected by CEMVS projects, is suitable for project purposes, existing water uses, public health and safety, and in compliance with applicable state and federal water quality standards.
3) Provide support to water control, project operations, and navigation for regulations and modifications.
4) Investigate special problems, design and implement modifications, and improve water management procedures
5) Establish and maintain strong working partnerships and collaborations with appropriate entities within and outside USACE regarding water quality.

This report is intended to document and assess water quality conditions occurring at Carlyle Lake. The report describes conditions observed in 2021, as well as baseline data collected from 1971-2020. Data are available upon request.

CARLYLE LAKE WQMP COVERAGE

The WQMP for Carlyle Lake includes water samples taken at the following locations: major tributaries (CAR-13 and CAR-12), main body of the lake (CAR-4, CAR-2, and the marinas), and just downstream of the dam (CAR-1). See figure 1 and Table 1 for a site map and site coordinates.

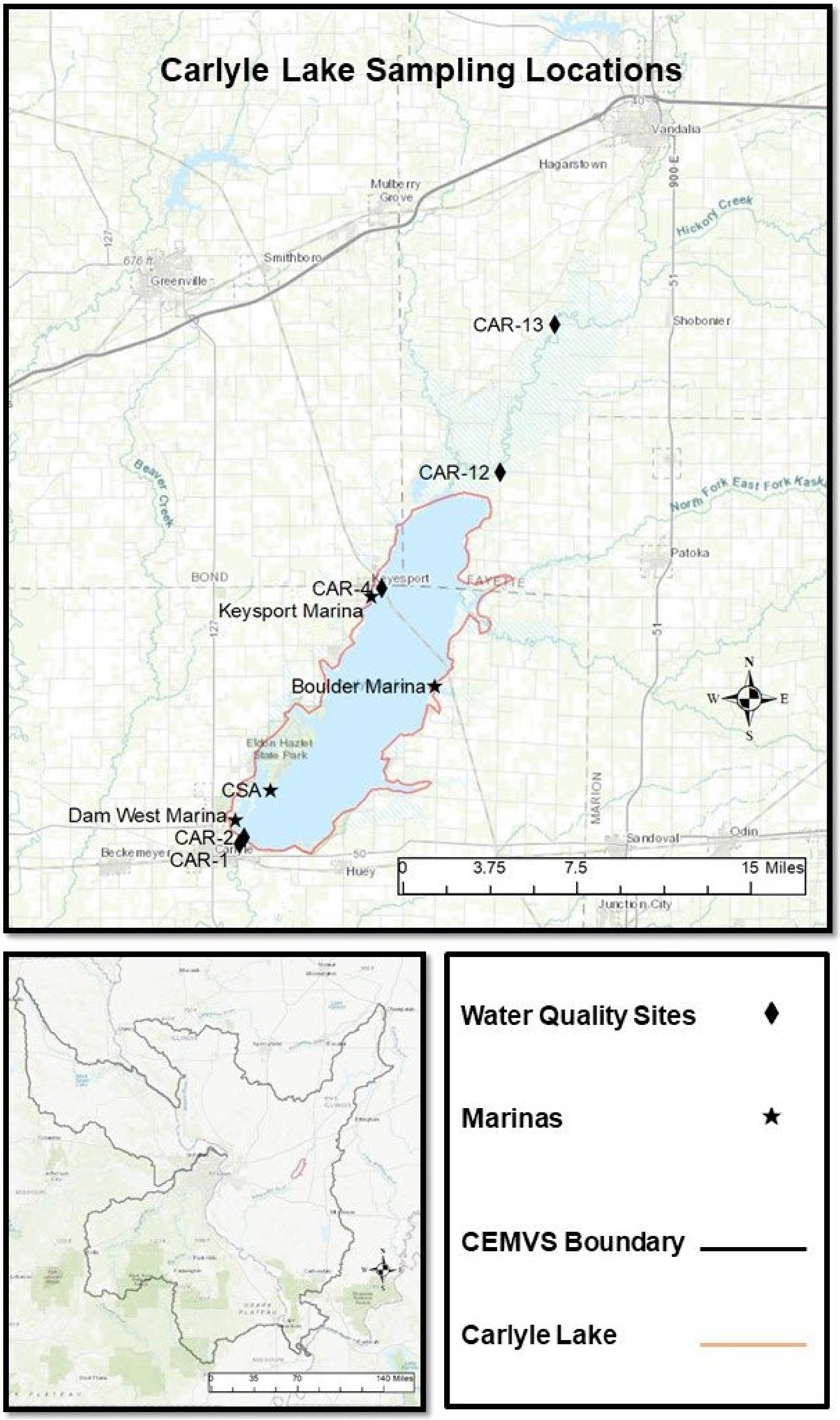


Figure 1. Water Quality (WQ) Sampling Locations in 2019 at Carlyle Lake

Sample Location Summary Table

Table 1: Sample Location Summary and Geographic Location (NAD 1983)

Sample Location Type	Abbreviation	Site Name	Latitude	Longitude
Major Tributary	TRIB	CAR-13	38.868961	-89.159605
	TRIB	CAR-12	38.868961	-89.193475
Main Reservoir Surface	RS	CAR-2	38.619492	-89.352747
	RS	CAR-4	38.740632	-89.267266
	RS	CAR-BL	38.693092	-89.234040
	RS	CAR-DW	38.627955	-89.358246
	RS	CAR-KP	38.736930	-89.273674
	RS	CAR-CSA	38.642647	-89.336805
Reservoir Benthic	RB	CAR-2-10	38.619492	-89.352747
Tail Race (below dam)	TR	CAR-1	38.616240	-89.355828

Samples at Marinas are not always taken in the exact same location. *BL=Boulder Marina, DW=Dam West Marina, KP=Keyesport Marina, CSA=Carlyle Sailing Association.*

METHODS AND ANALYSIS: WATER QUALITY

Data Collection and Historical Reference Data

During 2021, water quality samples were collected and analyzed for 10 locations during four separate sampling events (n=40; Table 1). One duplicate sample was also collected during each sampling event for quality control purposes. Samples were collected from the upper one meter of the water column, preserved, and transported to the Applied Research and Development Laboratory (ARDL) in Mount Vernon, Illinois for analysis.

For the purpose of this report, historical reference data refers to water quality data collected during the previous years ranging as far back as 1971 (parameter dependent) at Carlyle Lake. Historical reference data are intended to represent the current condition of Carlyle Lake.

Statistical Summary and Comparison to Applicable Water Quality Standards

Statistical analyses were performed on water quality monitoring data collected for 10 locations, and classified as TRIB (n= 2), RS (n=6, RB (n=1), and TR (n=1). For comparison, statistical analyses were also performed on historical water quality monitoring data and, although some sampling locations may have been removed, they were classified in the same manner. Descriptive statistics were calculated to describe central tendencies and boxplots created to illustrate comparisons between groups. Monitoring results were compared to applicable water quality standard criteria established by the appropriate state agencies pursuant to the Federal Clean Water Act. If state water quality standard criteria were not available, recommended criteria from the literature were considered.

Seasonal data are classified as: Winter (December 01 - March 14), Spring (March 15 – May 31), Summer (June 1 – September 15), Fall (September 16 – November 30).

Quality Assurance

The United States Army Corps of Engineers, Saint Louis District quality assurance procedures considers two primary focus areas: (1) those that involve laboratory analysis of samples, and (2) those concerning the collection and processing of the water samples in the field.

Since 2012, ARDL has analyzed water quality samples for CEMVS. Their quality assurance program includes the use of quality control charts, check standards, field and in-house matrix spikes, laboratory blanks and performance evaluation samples. In addition, one blind duplicate sample is submitted for at least every 20 samples, or, in this case, every sampling event (one event/day at Carlyle Lake has 6 lab samples and one duplicate).

Internal checks are also used for field sampling. This includes adherence to operating procedures for data collection and periodic evaluation of sampling personnel. Field sampling equipment and multimeters are calibrated/serviced in accordance with factory recommendations.

Water Quality Parameters and Criteria

Parameters used to characterize water quality have been generally accepted criteria for assessing aquatic life and human health include:

<u>Temperature (Temp)</u> is important because it controls several aspects of water quality. Colder water holds more dissolved oxygen which is required by aquatic organisms. Plants grow more rapidly and use more oxygen in warmer water. Decomposition of organic matter which uses oxygen is accelerated in warmer water. Temperature can also determine the availability of toxic compounds such as ammonia. Since aquatic organisms are cold blooded, water temperature regulates their metabolism and ability to survive. The number and kinds of organisms that are found in streams or lakes is directly related to temperature. Certain organisms require a specific temperature range, such as Salmonids, which require water temperatures below 20^{o}C. Water temperature criteria for warm water bodies in Illinois is within 2.8^{o}C of the seasonal norm.

<u>Dissolved Oxygen (DO)</u> refers to the measurement of free oxygen molecules (O_2) that are not bonded to any other elements; thus, oxygen bonded in water (H_2O) would not be considered in a measurement of dissolved oxygen. Oxygen is dissolved in surface waters through interactions with the atmosphere and as a waste product of photosynthesis (CO_2 + H_2O (CH_2O) + O_2) from phytoplankton and aquatic vegetation. Additional factors influencing DO include temperature, pressure, and salinity.

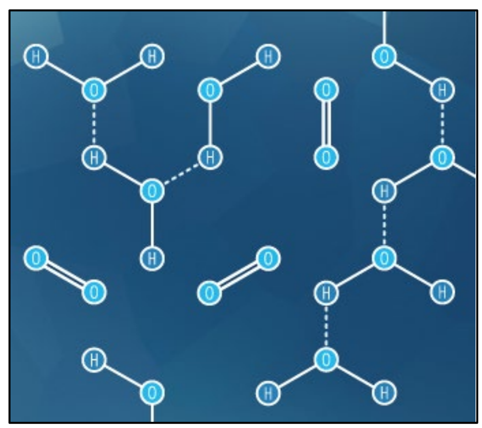


Figure 1: Dissolved oxygen (O_2) vs oxygen bonded in water (H_2O).

Dissolved oxygen is required for most aquatic life including fish, invertebrates, bacteria, and plants. Fish and invertebrates utilize DO for respiration through gills and cutaneous breathing, and plants require dissolved oxygen for respiration when photosynthesis is not possible. Smaller microbes and bacteria utilize DO for decomposition of organic materials, a process essential for nutrient cycling. Bottom feeders such as worms and mussels can persist when DO is $\geq$1mg/L, while most inland fish species require a minimum DO of 4mg/L. The DO water quality criteria for Illinois is $\geq$5mg/L.

<u>Potential of Hydrogen (pH)</u> is a measure of how acidic or basic water is. Potential of Hydrogen is reported on a logarithmic scale ranging from 0 – 14, with 7.0 being neutral. As pH increases from 7.0, water increases in alkalinity, whereas a decrease from 7.0 indicates an increase in acidity. Since pH is measured on a logarithmic scale, every one-unit change in pH indicates a 10-fold change in acidity; thus, a pH of 6.0 is ten times more acidic than a pH of 7.0 and a pH of 4.0 would be one-thousand times more than a pH of 7.0.

The pH of water varies considerably beyond the local level. Natural variation in bedrock and soil composition through which water moves has been reported as one of the most influential factors. Additional factors include decomposition of organic materials, acidity of local precipitation, discharge of effluents and chemicals, and mining operations.

Most freshwater streams and rivers have a natural pH ranging from 6 to 8. As pH approaches 5 (acidic), less tolerant fish and aquatic invertebrate assemblages may be extirpated, and a pH below 4.5 would be without most desired aquatic life. Conversely, when pH exceeds 9.5 (alkaline), aquatic fish and invertebrate begins to rapidly decrease and beyond 10, fish become extirpated. The pH water quality criteria for Illinois ranges from 6.5 – 9.0.

Conductivity is a measure of water's ability to conduct electrical current. In its purist form, water has a *near* neutral charge, indicating that it is an inefficient conductor of electrical current. Thus, the ability to carry electrical current is driven by water soluble ions (atoms and molecules with a charge) such as salts and other inorganic materials. Conductivity is also influenced by water temperature; as temperature increases, conductivity increases. For this reason, conductivity is commonly reported as Specific Conductivity (SpCond), which is the measurement of conductivity at 25 degrees Celsius.

Conductivity in streams and rivers is affected by the geology of the area. Streams running through granite tend to have lower conductivity due to granite being composed of inert material; materials that do not ionize or dissolve into ionic compounds in water. Conversely, streams that run through areas of limestone or clay soils tend to have higher conductivity readings because of the presence of materials that ionize. Conductivity is useful as a general measure of water quality. A stream tends to have a relatively constant range of conductivity that, once established, can be used as a baseline. Significant changes, either increases or decreases, might indicate a source of pollution has been introduced into the water. The pollution source could be a treatment plant, which raises the conductivity, or an oil spill, which would lower the conductivity. In general, there are no water quality criteria for SpCond. The District threshold of 500 µS/cm is a rule of thumb value that is often associated with some form of biological impairment.

Oxidation Reduction Potential (ORP) is a measurement of the net status of all the oxidation and reduction reactions in a given water sample. Oxidation involves an exchange of electrons between 2 atoms. The atom that loses an electron is oxidized and the one that gains an electron is reduced. Oxidation reduction potential sensors measure the electrochemical potential between the solution and a reference electrode. Readings are expressed in millivolts. Positive readings indicate increased oxidizing potential and negative readings increased reduction. Oxidation reduction potential values are used much like pH values to determine water quality. While pH readings characterize the state of a system relative to the receiving or donating hydrogen ions (base or acid), ORP readings characterize the relative state of losing or gaining electrons. Generally, ORP readings above 400mV are harmful to aquatic life; however, ORP is a non-specific measurement, which reflects a combination of effects of all the dissolved materials in the water. Therefore, the measurement of ORP in relatively clean water has only limited utility unless a predominant redox-active material is known to be present.

Total Suspended Solids (TSS) concentrations, which cause the photosynthetic activity to be reduced by more than 10% from the seasonably established norm, can have a detrimental effect on aquatic life. Soil particles, organic material, and other debris comprise suspended solids in the water column. **Turbidity (FNU)** measurements are inverse to suspended solid measurements. As TSS increases, the FNU or water transparency decreases. Total suspended solids can be an important indicator of the type and degree of FNU. Total Suspended Solids measurements represent a combination of **Volatile Suspended Solids (VSS)**, which consist of organic material, and **Nonvolatile Suspended Solids (NVSS)**, which is comprised of inorganic mineral particles in the water. In order to more accurately determine the types and amounts of suspended solids, VSS are analyzed. Volatile suspended solid concentration represents the organic portion of the total suspended solids. Organic material often includes plankton, and additional plant and animal debris present in water. Total VSS indicates the presence of organics in suspension; and, therefore, show additional demand levels of oxygen. The Illinois Environmental Protection Agency suggests that generally NVSS above 15 mg/L could highly impair recreational lake use while NVSS of 3 to 7 mg/L may cause slight impairment (Hudson, 1998). Illinois does not currently have standard criteria for TSS, NVSS or VSS.

Total Organic Carbon (TOC) is a measure of the amount of organic carbon in a water body. In addition to natural organic substances, TOC includes insecticides and herbicides, as well as domestic and industrial waste. Industrial waste effluent may include carbon-containing compounds with various toxicity levels. Further, a high organic content means an increase in the growth of microorganisms which contribute to the depletion of oxygen supplies.

Currently, there are no state or federal water quality standard criteria set for TOC. Because carbon occurs naturally, its concentration varies based on physical and chemical attributes in a watershed; thus, this study relies on historical reference conditions to identify unfavorable conditions.

Metals Iron (TFe) and Manganese (TMn) (T=total) are nutrients for both plants and animals. Living organisms require trace amounts of metals. However, excessive amounts can be harmful to the organism. Heavy metals exist in surface waters in three forms, colloidal, particulate, and dissolved. Water chemistry determines the rate of adsorption and desorption of metals to and from sediment. Metals are desorbed from the sediment if the water experiences increases in salinity, decreases in redox potential, or decreases in pH. Metals in surface waters can be from natural or human sources. Metal levels in surface water may pose a health risk to humans and the environment.

Pesticides are commonly used throughout much of the agricultural landscape that the Kaskaskia River flows. This study considers one insecticide and seven herbicides. Atrazine and Alachlor herbicides are commonly used agricultural chemicals which can be readily transported by rainfall runoff. Both compounds are suspected of causing cancer; and therefore, were monitored for the protection of human and aquatic health. Herbicides which are pesticides used to kill vegetation are the most widely used and sampled. Two of the most widely used herbicides are Atrazine and Alachlor. Atrazine is a preemergence or postemergence herbicide use to control broadleaf weeds and annual grasses. Atrazine is most commonly detected in ground and surface water due to its wide use, and its ability to persist in soil and move in water. Alachlor is a Restricted Use Pesticide (RUP) due to the potential to contaminate groundwater. The water quality standards for the pesticides sampled are located in Table 2.

Nitrogen occurs naturally in water through several forms including nitrogen (N2), nitrite (NO2-N), nitrate (NO3-N), ammonia (NH3), and ammonium (NH4). Nitrates are the most commonly reported form of nitrogen and may have a meaningful influence on a water body's trophic status. Algae and other plants use NO3-N as a food source, thus excess levels of NO3-N can promote increases in algae production and hypereutrophic conditions.

In general, NO3-N does not have a *direct* effect on fish or aquatic insects. Illinois has set criteria standards for NO3-N to 10 mg/L to accommodate safe drinking waters for human and livestock; however, this threshold likely exceeds the concentration that is appropriate for assessing ecosystem health.

Total Ammonia Nitrogen (TAN) includes NH3 and NH4. Total ammonia nitrogen is a colorless gas with a strong pungent odor. Ammonia occurs naturally and is a biological requirement for aquatic life, however elevated concentrations can be toxic to freshwater organisms. Unnatural sources of ammonia include, accidental releases of ammonia rich fertilizer, effluent from sewage treatment plants, improper disposal of ammonia products, and livestock waste.

Toxic concentrations for freshwater organisms range from 0.53 – 22.8 mg/L and are strongly dependent on both pH and temperature. In general, an increase in pH and/or temperature corresponds with an increase in toxicity. Additional information in regard to the relationship between pH, temperature, and ammonia, as it relates to toxicity, can be reviewed in Aquatic Life Ambient Water Quality Criteria for Ammonia – Freshwater (USEPA 2013).

Total Phosphorus (TP) is analyzed as phosphorus and has been monitored due to the potential for uptake by nuisance algae. Levels of phosphate can indicate the potential for rapid growth of algae (algae bloom) which can cause serious oxygen depletion during the algae decay process. Phosphorous is typically the limiting nutrient in a water body; therefore, any addition of phosphorous to the ecosystem stimulates the growth of plants and algae. Phosphorous is delivered to lakes and streams by way of runoff from agricultural fields and urban environments. Other sources of phosphorous are anaerobic decomposition of organic matter, leaking sewer systems, and point source pollution. The general standard for phosphorous in lake water is 0.05 mg/L. Dissolved phosphorous, also called **Orthophosphate (PO_4-P)** is generally found in much smaller concentrations than total phosphorous and is readily available for algal uptake. Orthophosphate concentrations in a water body vary widely over short periods of time as plants take it up and release it.

Chlorophyll a (CHL_a) is a measure of the number of algae growing in a waterbody, and therefore can be used to classify trophic status. Although algae are a natural part of freshwater ecosystems, too many algae can cause aesthetic problems such as green scums and bad odors and can result in decreased levels of DO.

Pheophytin a (PHEO a) is a natural degradation product or digestion of CHL_a. The ratio of PHEO_a to CHL_a can provide an indication of the decline or growth in eukaryotic algae and cyanobacteria populations.

Trophic Status is determined using a modified **Trophic State Index (TSI)**, as described by Carlson (1977). Trophic State Index is calculated from Secchi-depth transparency, total phosphorus, and chlorophyll-a measurements. Values for these three parameters are converted to an index number ranging from 0-100 according to the following equations:

$$\text{TSI (Seechi Depth)} = 10(6 - (\ln SD/\ln 2))$$
$$\text{TSI (Chlorophyll-}a\text{)} = \text{TSI(Chl)} = 10(6 - ((2.04 - 0.68 \ln \text{Chl})/\ln 2))$$
$$\text{TSI (Total Phosphorus)} = \text{TSI(TP)} = 10(6 - (\ln (48/TP)/\ln 2))$$

where ln indicates the Natural Logarithm

A TSI average value, calculated as the average of the three individually determined TSI metrics, is used as an overall indicator of a water body's trophic state. The relationship between TSI and trophic condition is defined as follows:

TSI	Trophic Condition
0-40	Oligotrophic
40-50	Mesotrophic
50-70	Eutrophic
70-100	Hypereutrophic

Laboratory Methods and Water Quality Criteria Summary Table

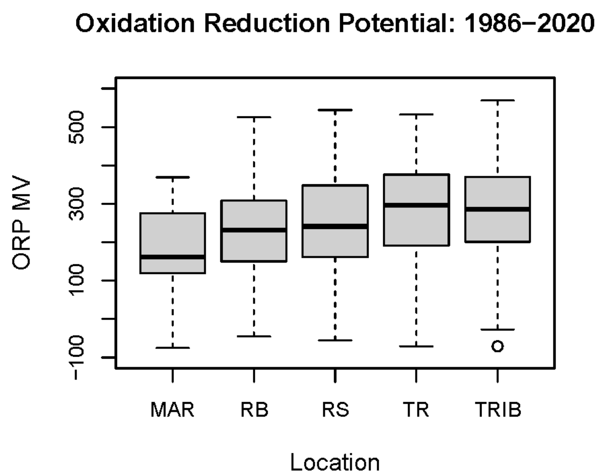
Table 2: Metrics, Methods, and Water Quality Criteria Used for Evaluating Water Quality

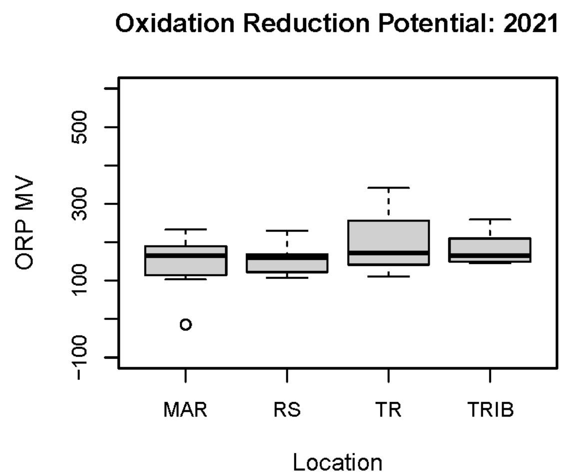
Metric	Abbreviation	Analysis Method	Water Quality Criteria	Source
Alachlor		EPA Method 8270C	< 2µg/L PWS or <1100 µg/L: aquatic life	Illinois EPA
Ammonia Nitrogen	NH_3	EPA Method 350.1	<15 mg/L	Illinois EPA
Atrazine	Atrazine	EPA Method 8270C	9 µg/L: Chronic or 82 µg/L: Acute or 3 µg/L DWS	Illinois EPA
Bacteria: E. Coliform	E Col	EPA Method 1604	< 235 E. Col per 100/mL for single sample	Illinois EPA
Chlorophyll a	Chl_a	SM Method 10200H	< 25 mg/m^3 (Eutrophic Upper Limit)	Carlson 1977
Chlorpyrifos		EPA Method 8270C	< .11 µg/L: aquatic life	Illinois EPA
Cyanazine		EPA Method 8270C	< 30 µg/L: chronic or < 370 ug/L acute (aquatic life)	Illinois EPA
Depth	Depth	Multiparameter Meter	Measurements reported at ~1 meter	-----
Dissolved Oxygen	DO	Multiparameter Meter	Greater than 5.0mg/L	Illinois EPA
Metolachlor		EPA Method 8270C	30.4 µg/L: Chronic or 380 µg/L: Acute	Illinois EPA
Metribuzin		EPA Method 8270C	8.4 mg/L: aquatic life or 8.3 mg/L: human health	Illinois EPA
Nitrate as Nitrogen	NO_3	Green Method	< 10 mg/L	Illinois EPA
Non-Volatile Suspended Solids	NVSS	TSS - VSS	-----	-----
Orthophosphate	Ortho	EPA Method 365.2	-----	-----
Pendmethalin		EPA Method 8270C	< 30 µg/L: chronic or < 350 µg/L acute (aquatic life)	Illinois EPA
Pheophytin a	Phpy_a	SM Method 10200H	-----	-----
Potential of Hydrogen	pH	Multiparameter Meter	Range: 6.5 – 9.0pH	Illinois EPA
Specific Conductivity	SpCond	Multiparameter Meter	500 µS/cm	-----
Temperature	Temp	Multiparameter Meter	Less than rise of 2.8°C above normal seasonal temperature	Illinois EPA
Total Dissolved Solids	TDS	Multiparameter Meter	< 500 mg/L	Illinois EPA
Total Manganese	TMn	EPA Method 6010C	< 1 mg/L	Illinois EPA

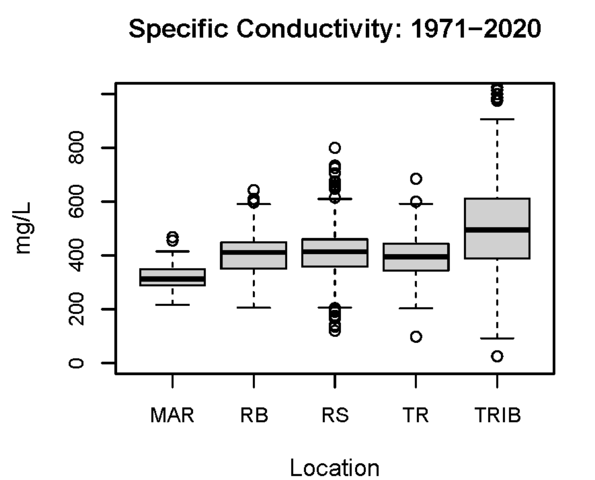
Metric	Abbreviation	Analysis Method	Water Quality Criteria	Source
Total Organic Carbon	TOC	EPA Method 415.1	-----	-----
Total Iron	TFe	EPA Method 6010C	< 1 mg/L	Illinois EPA
Total Phosphorus	TP	EPA Method 365.2	Less than 0.05 mg/L	Illinois EPA
Total Suspended Solids	TSS	EPA Method 160.2	-----	Illinois EPA
Trifluralin		EPA Method 8270C	< 1.1 μg/L: chronic or < 26 μg/L acute (aquatic life)	Illinois EPA
Turbidity	Turb	Multiparameter Meter	-----	-----
Volatile Suspended Solids	VSS	EPA Method 160.4	-----	-----

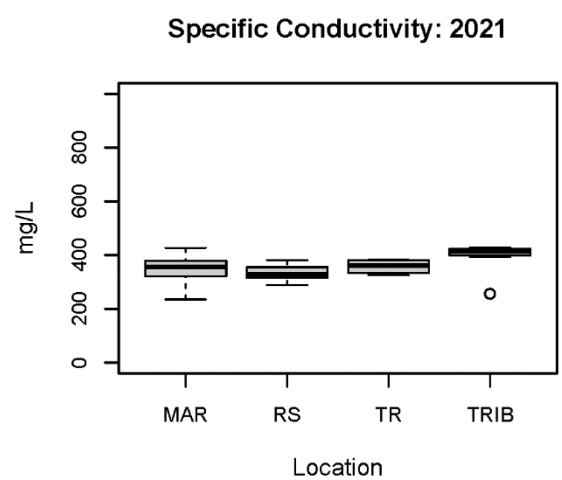
**1 mg/L is equivalent to 1 drop in two bathtubs and 1 ug/L is equivalent to 1 drop in an Olympic size swimming pool. PWS is public water supply. DWS is drinking water standard.*

RESULTS AND SUMMARY STATISTICS: WATER QUALITY



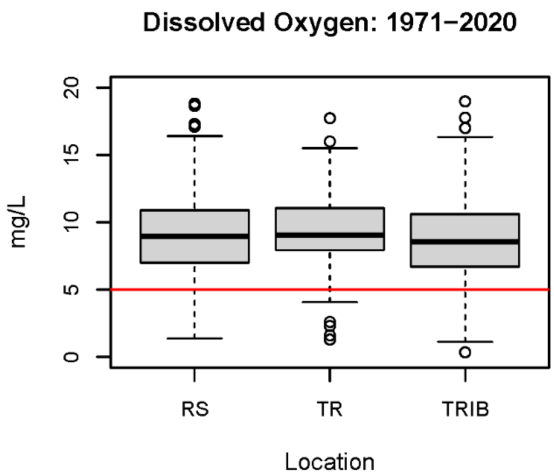


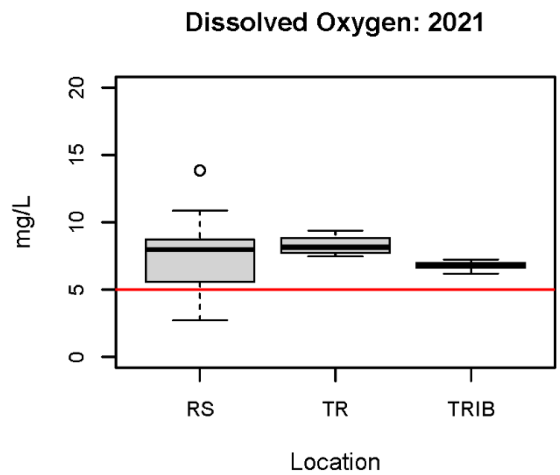


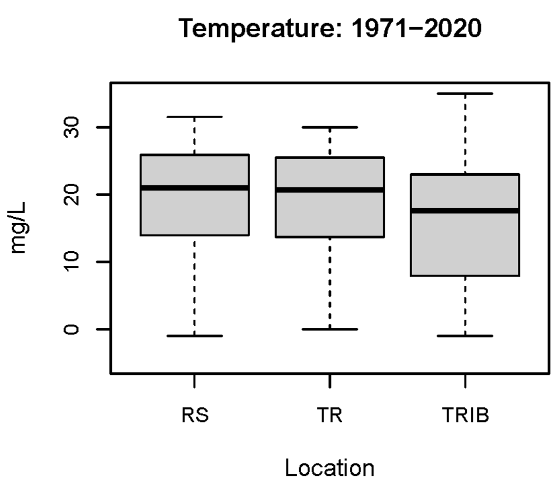


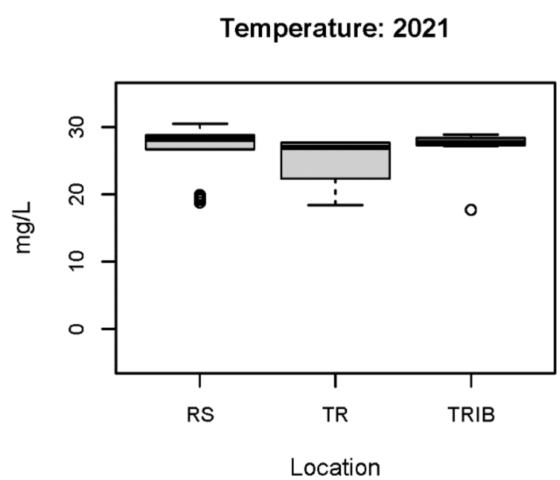
Historical Reference 1971-2020					2021		
	Location	Mean	Median	n	Mean	Median	n
ORP	RB	228.07	231.0	134	----	----	----
	RS	242.74	235.0	277	150.35	161.3	16
	TR	283.03	296.0	132	208.17	172.1	3
	TRIB	278.85	286.5	172	185.70	164.5	5
SpCond	RB	405.18	411.0	239	----	----	----
	RS	406.99	411.0	637	341.77	334.8	22
	TR	397.38	395.0	248	357.68	361.4	4
	TRIB	518.89	495.0	605	392.44	414.7	7

**This report does not acknowledge a water quality criteria for SpCond or ORP.*





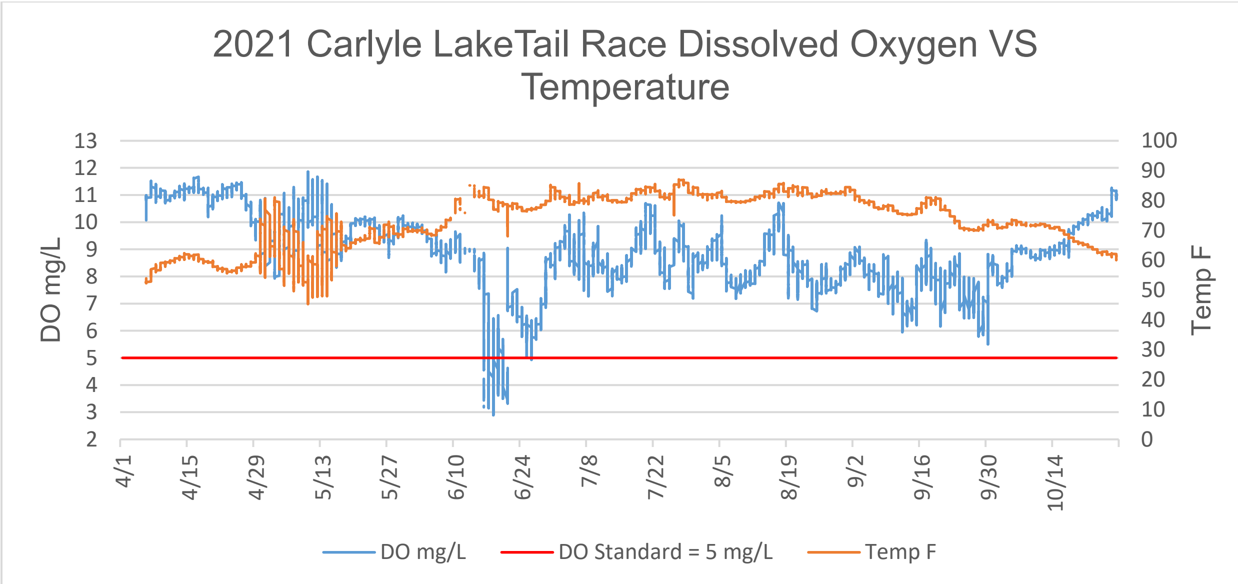




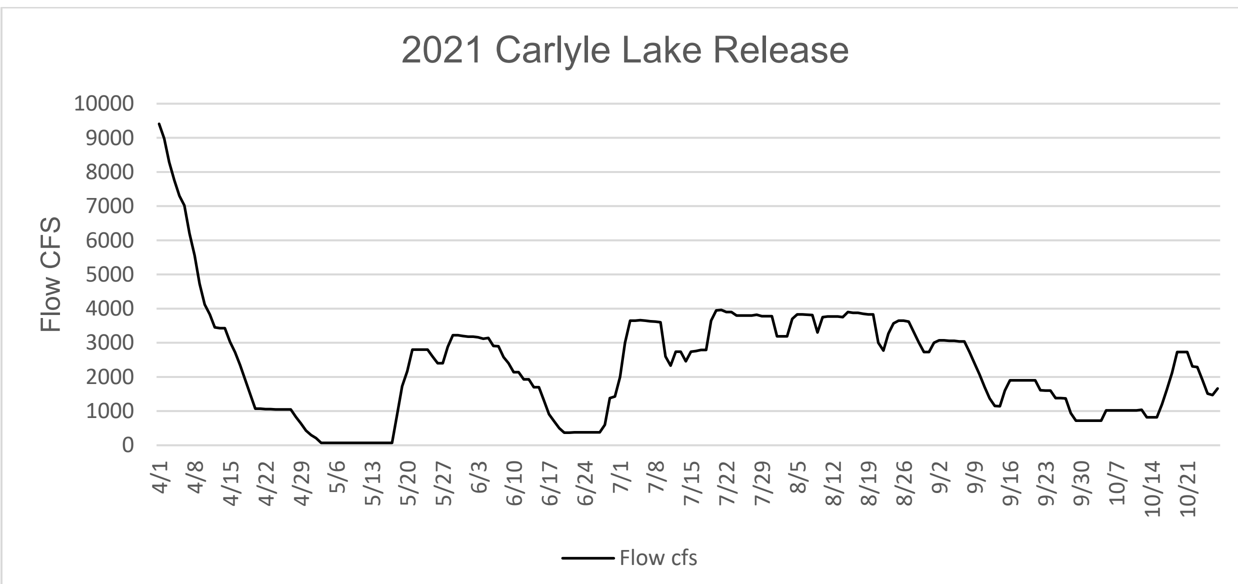
** Red line placed at the 5 mg/L level for DO.*

	Historical Reference 1971-2020				2021		
	Location	Mean	Median	n	Mean	Median	n
DO	RS	9.07	8.96	630	7.71	7.96	22
	TR	9.42	9.06	244	8.28	8.15	4
	TRIB	8.65	8.55	594	6.77	6.78	7
Temp	RS	18.88	21.00	639	26.52	28.20	22
	TR	18.83	20.70	250	25.03	27.00	4
	TRIB	15.61	17.60	611	26.53	27.70	7

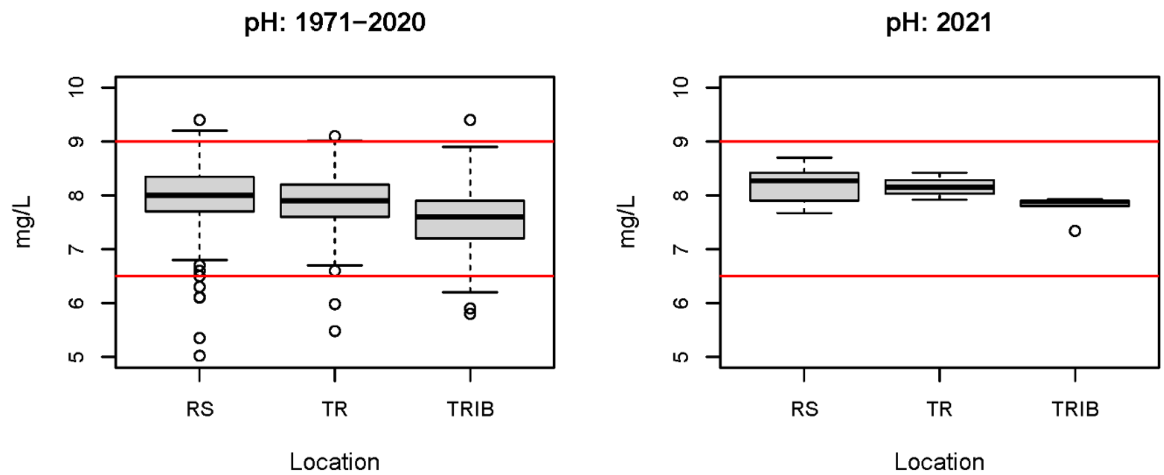
** During the four sampling events surface water DO was measured below the standard twice at two Marinas. In 2021 temperature was recorded above the standard (rise of 2.8° C above the natural temperatures) during the spring. The historical seasonal mean temperature by class was used as the natural temperature.*



**Data recorded by multi-parameter sonde at tail race. 15 minute data shown. Red line placed at the 5 mg/L level. DO was recorded below the standard of 5 mg/L during mid-late June coinciding with a low flow. All other observations were greater than 5 mg/L during 2021.*



**Daily flow.*

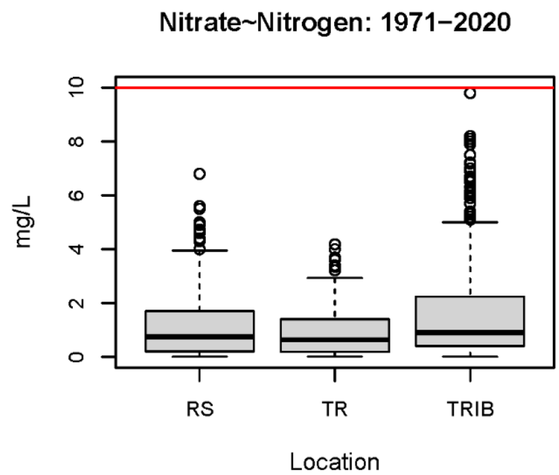


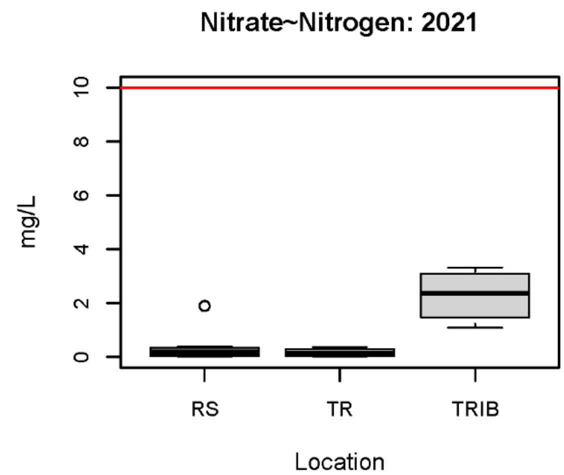
Red lines indicate the upper and lower water quality criteria standards (9 and 6.5).

Historical Reference 1971-2020					**2021**		
	Location	Mean	Median	n	Mean	Median	n
pH	RS	7.99	8.0	633	8.18	8.3	16
	TR	7.87	7.9	247	8.16	8.2	3
	TRIB	7.56	7.6	598	7.77	7.9	5

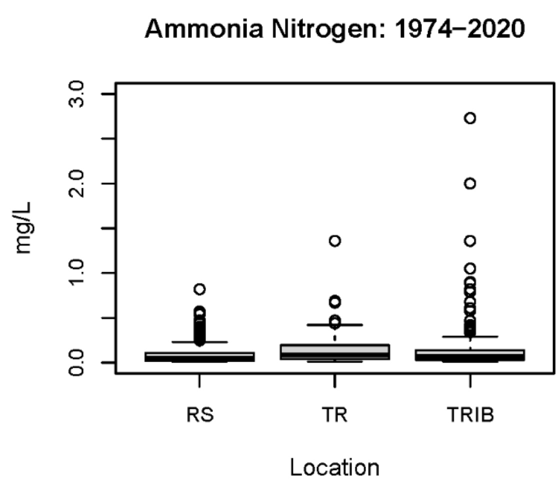
Historical Reference 1984-2020					**2021**		
	Location	Mean	Median	n	Mean	Median	n
pH	RS	8.20	8.22	324	8.38	8.46	17
	TR	7.71	7.70	142	8.24	8.08	3
	TRIB	7.78	7.80	202	8.07	7.99	6

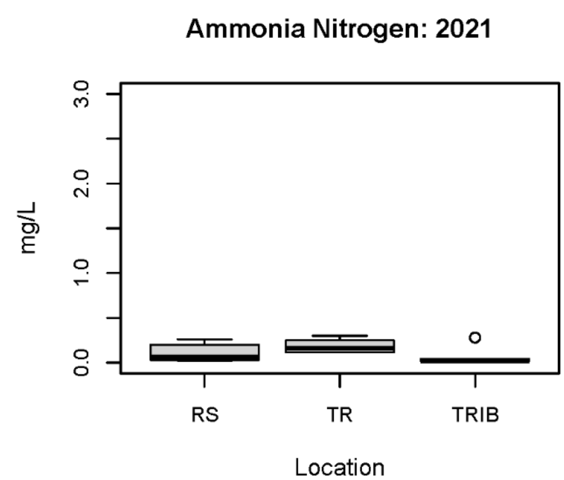
All readings were within water quality standards during 2021.





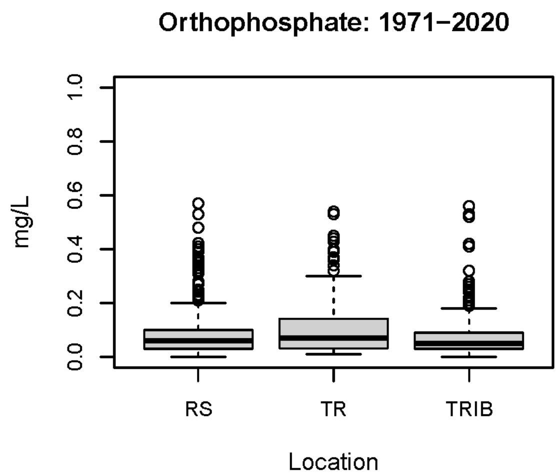
**Red line indicates the water quality standard (10 mg/L).*

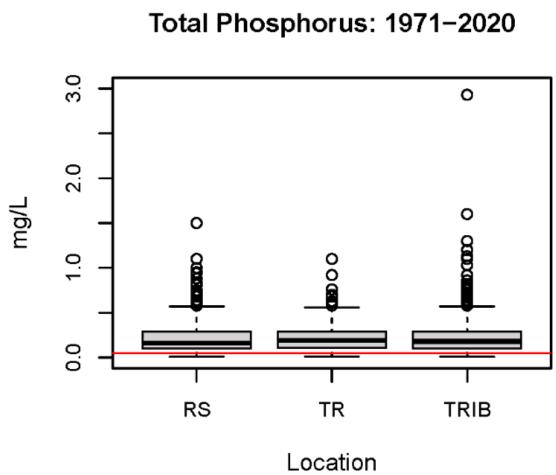


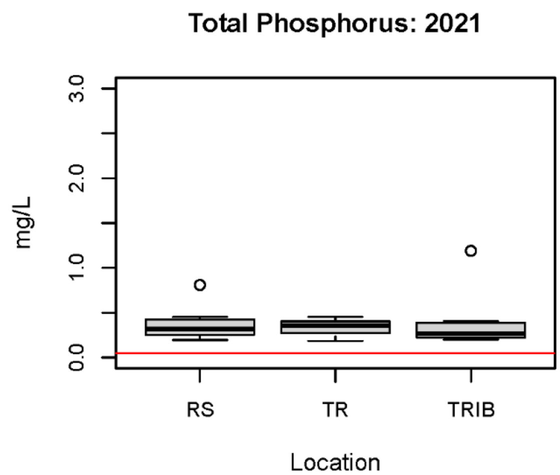


Historical Reference 1971-2020					**2021**		
	Location	Mean	Median	n	Mean	Median	n
NO3-N	RS	1.11	0.8	605	0.37	0.2	8
	TR	0.91	0.6	246	0.16	0.1	4
	TRIB	1.63	0.9	598	2.27	2.4	7
NH3N	RS	0.08	0.1	500	0.11	0.1	8
	TR	0.14	0.1	212	0.18	0.2	4
	TRIB	0.12	0.1	417	0.06	0.0	7

**All observations of nitrate and ammonia nitrogen were within the water quality standard.*



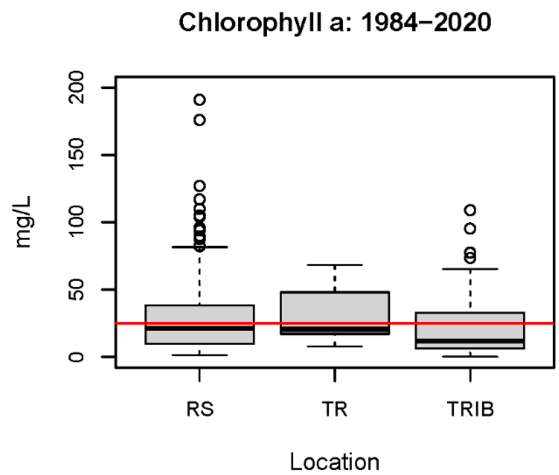


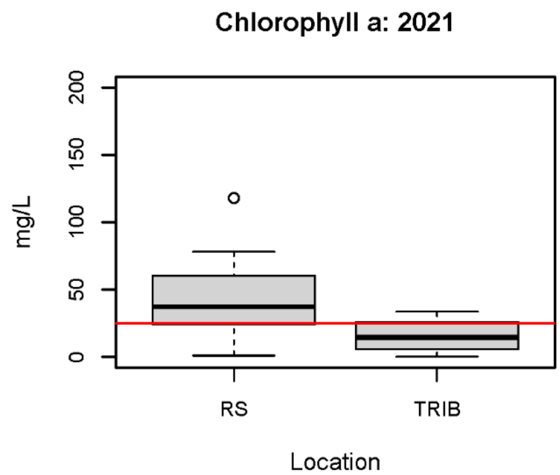


**Red line indicates the water quality standard of 0.05 mg/L.*

	Historical Reference 1971-2020				2021		
	Location	Mean	Median	n	Mean	Median	n
PO4	RS	0.08	0.1	600	----	----	----
	TR	0.10	0.1	243	----	----	----
	TRIB	0.07	0.1	598	----	----	----
TP	RS	0.22	0.2	612	0.37	0.3	8
	TR	0.22	0.2	246	0.33	0.4	3
	TRIB	0.23	0.2	609	0.41	0.3	7

**Total phosphorus exceeded the standard of 0.05 mg/L for all locations in 2021. This study does not acknowledge a standard for orthophosphate.*

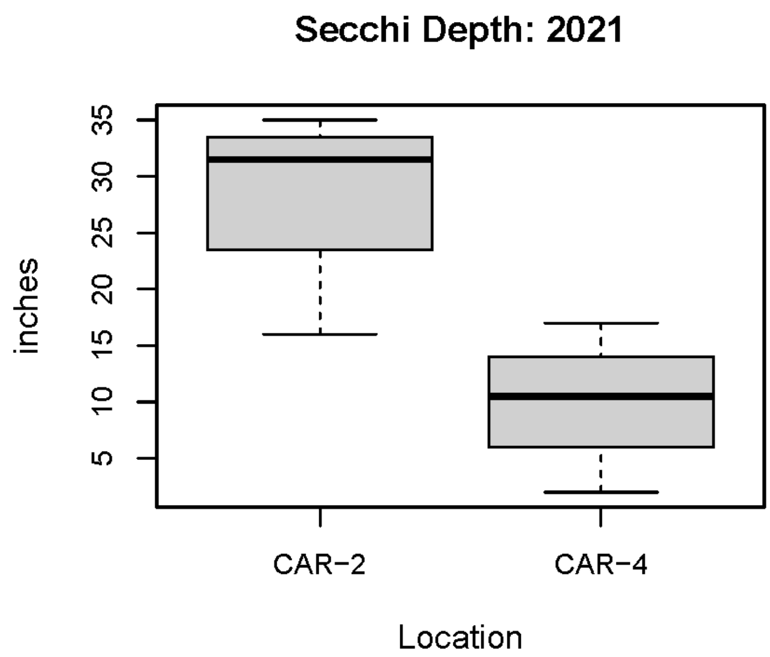


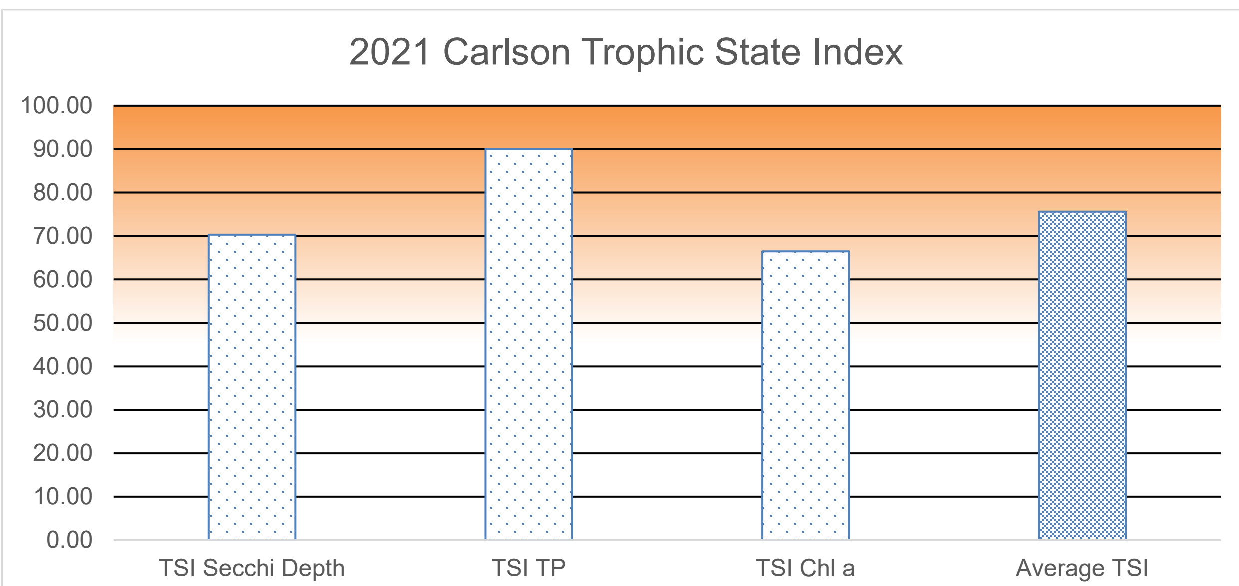


**Red line approximately indicates the reference water quality standard of 25 mg/cm^3. See Carlson 1977.*

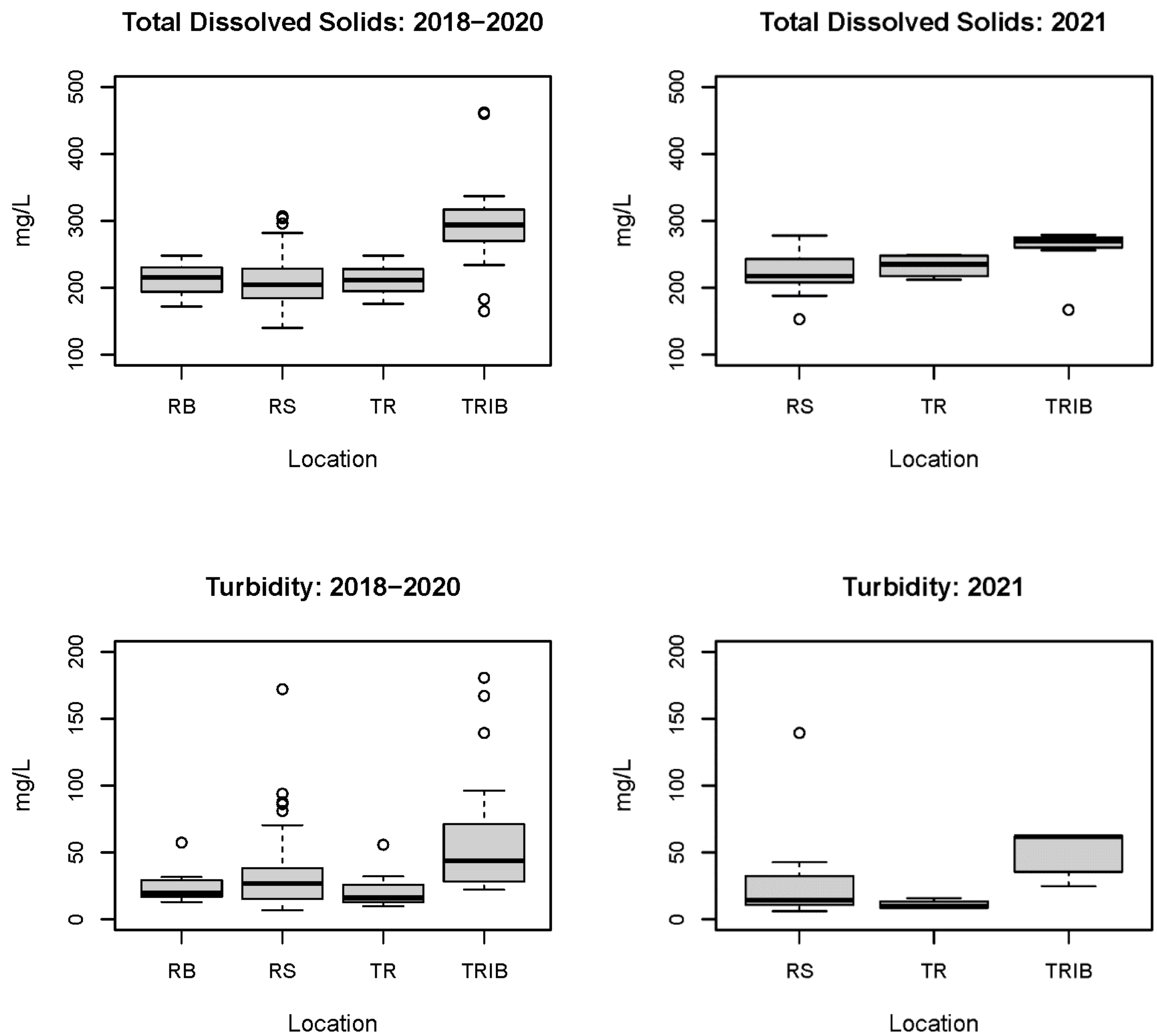
	Historical Reference 1984-2020				2021		
	Location	Mean	Median	n	Mean	Median	n
Chl_a	RS	29.87	21.3	274	45.39	37.2	8
	TR	32.30	20.5	5	----	----	----
	TRIB	24.11	11.9	64	15.73	14.6	4

**The reference standard for chlorophyll-a of 25mg/cm^3 was exceeded at the lake sites in July and August in 2021. This study does not acknowledge a standard for pheophytin.*



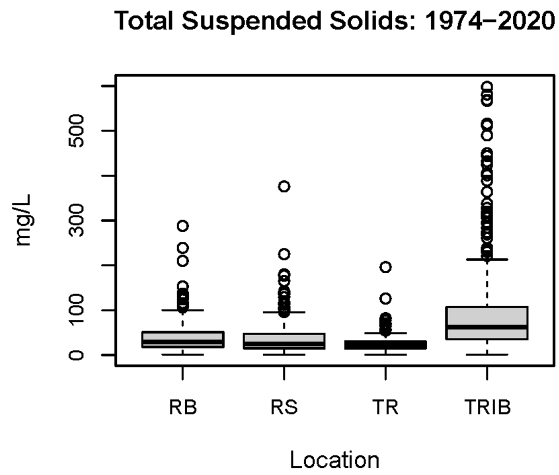


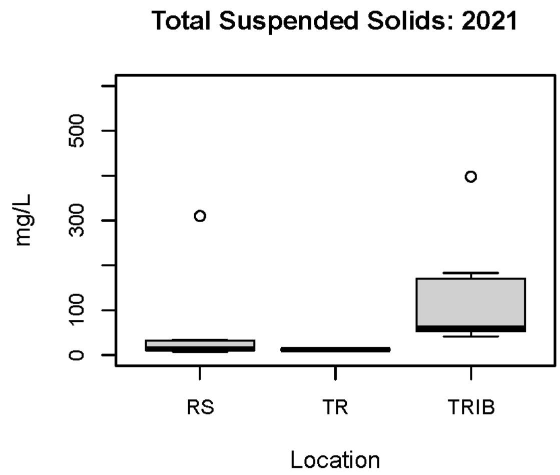
<40 = Oligotrophic __ 40-50 = Mesotrophic __ 50-70 = Eutrophic __ >70 Hypereutrophic



	Historical Reference 2018-2020				2021		
	Location	Mean	Median	n	Mean	Median	n
TDS	RB	212.17	215.5	12	----	----	----
	RS	212.29	204.5	56	222.09	217.5	22
	TR	211.50	211.5	12	232.75	235.0	4
	TRIB	296.46	294.0	24	255.29	270.0	7
FNU	RB	24.26	19.5	12	----	----	----
	RS	40.79	26.8	55	35.50	14.3	22
	TR	20.84	16.0	12	10.81	9.5	4
	TRIB	59.62	43.8	24	89.63	61.7	7

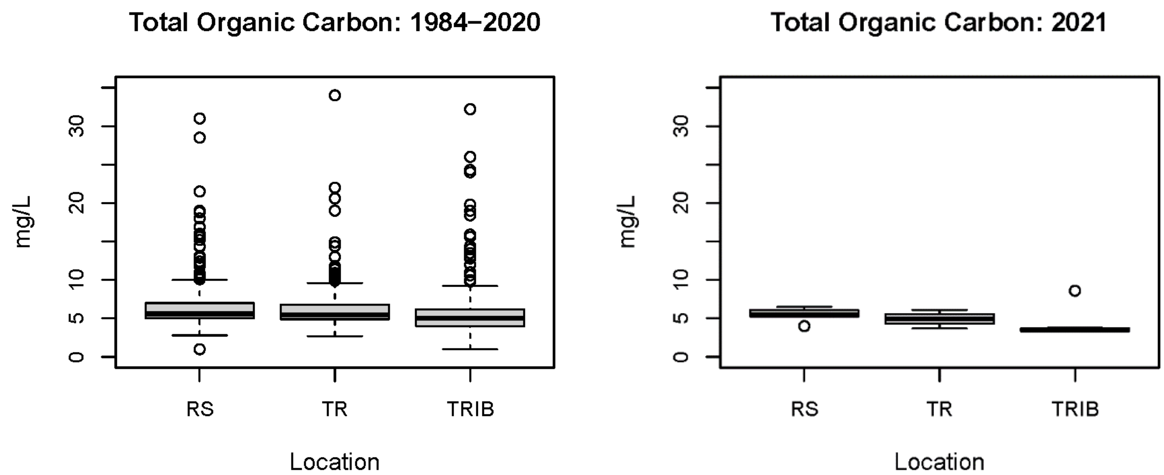
* *All observations of TDS were within the referenced water quality standard.*





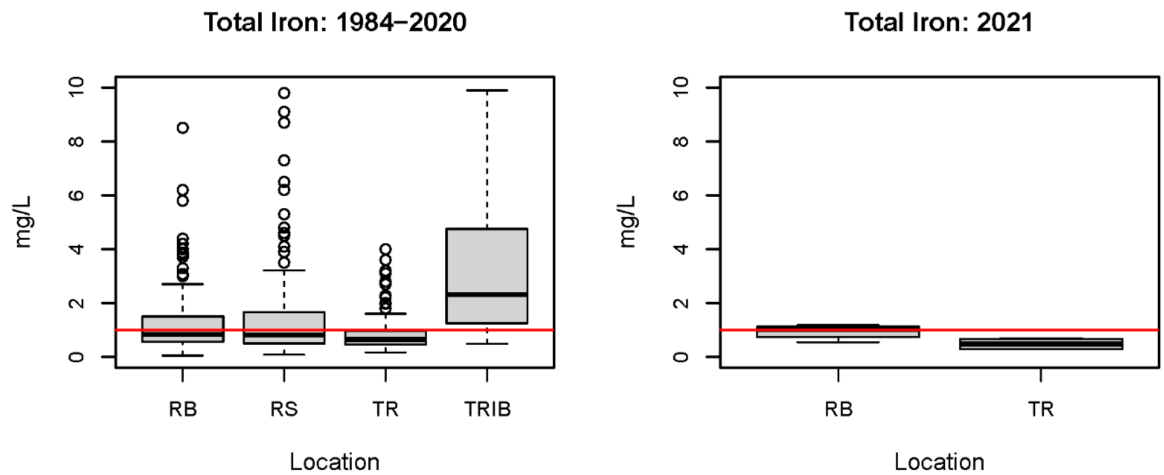
	Historical Reference 1974-2020				2021		
	Location	Mean	Median	n	Mean	Median	n
TSS	RB	41.47	29.0	225	----	----	----
	RS	34.36	25.0	513	53.94	14.4	8
	TR	25.40	21.0	214	12.05	11.9	4
	TRIB	105.38	62.5	429	135.14	61.2	7

**The mean total suspended solids data measured in 2021 were greater at RS and TRIB locations, and less at the TR when compared to the historical data. There is no numeric standard for TSS.*

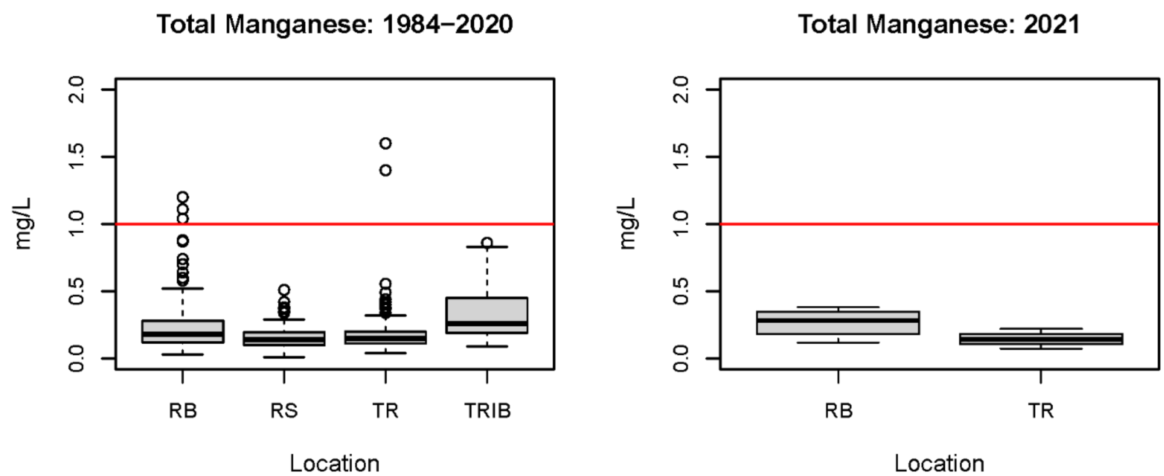


Historical Reference 1984-2020					2021		
	Location	Mean	Median	n	Mean	Median	n
TOC	RS	6.53	5.6	310	5.50	5.5	8
	TR	6.63	5.5	146	4.93	5.0	4
	TRIB	6.10	5.0	202	4.24	3.5	7

**This study does not recognize a water quality criteria for TOC.*



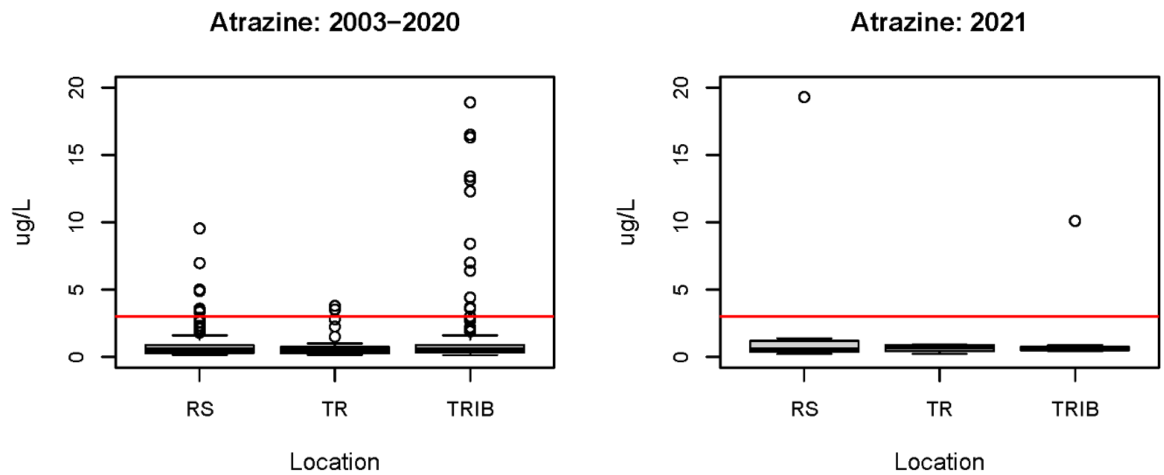
Red line indicates the water quality standard of 1 mg/L.



Red line indicates the water quality standard of 1 mg/L.

	Historical Reference 1984-2020				**2021**		
	Location	Mean	Median	n	Mean	Median	n
TFe	RB	1.23	0.8	178	0.94	1.0	4
	RS	1.44	0.8	170	----	----	----
	TR	0.88	0.7	147	0.48	0.5	4
	TRIB	3.82	2.3	68	----	----	----
TMn	RB	0.23	0.2	178	0.27	0.3	4
	RS	0.16	0.1	160	----	----	----
	TR	0.19	0.2	145	0.15	0.1	4
	TRIB	0.33	0.3	61	----	----	----

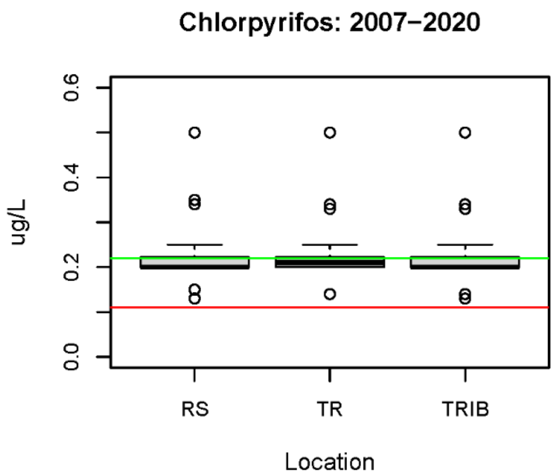
**In 2021 iron exceeded the standard of 1 mg/L near the lake bottom in front of the dam twice. Manganese did not exceed the criterion.*

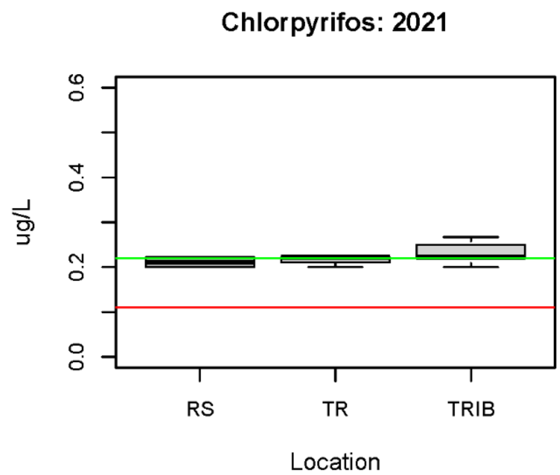


Red line indicates the standard of 3 ug/L.

	Historical Reference 1996-2020				2021		
	Location	Mean	Median	n	Mean	Median	n
Atrazine	RB	0.69	0.7	2	----	----	----
	RS	0.95	0.5	120	2.97	0.5	8
	TR	0.70	0.5	60	0.65	0.7	4
	TRIB	1.65	0.5	116	1.95	0.6	7

**Atrazine was measured above the DWS criterion of 3 ug/L on May 19, 2021 in the lake and the tributary.*

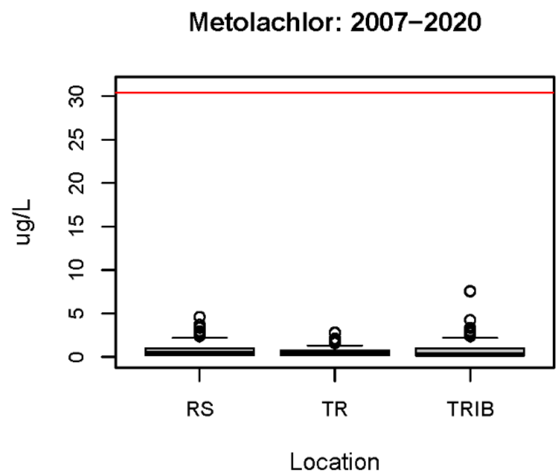


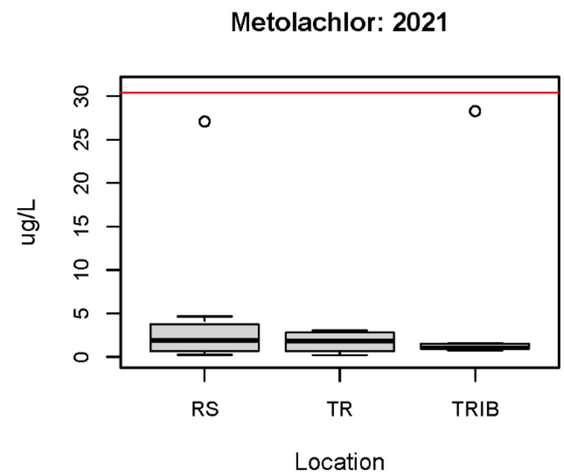


**Green line indicates the detection limit of 0.22 ug/L. Red line indicates the standard of 0.11 ug/L.*

	Historical Reference 2007-2020				2021		
	Location	Mean	Median	n	Mean	Median	n
Chlorpyrifos	RS	0.22	0.2	82	0.21	0.2	8
	TRIB	0.22	0.2	77	0.23	0.2	6
	RS	0.22	0.2	82	0.21	0.2	8

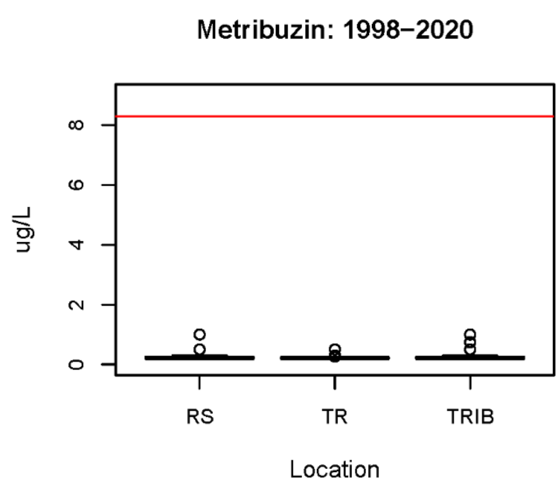
**The standard of 0.11 ug/L is below the detection limit for Chlorpyrifos. Chlorpyrifos was measured above the detection limit and the standard twice in the tributaries – once in May and once in July 2021.*

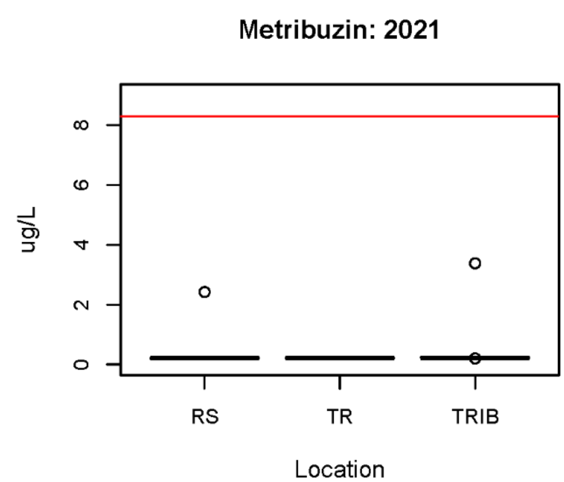




	Historical Reference 2007-2020				2021		
	Location	Mean	Median	n	Mean	Median	n
Metolachlor	RS	0.85	0.4	82	5.00	1.9	8
	TR	0.75	0.4	41	1.73	1.8	4
	TRIB	0.93	0.3	78	5.00	1.0	7

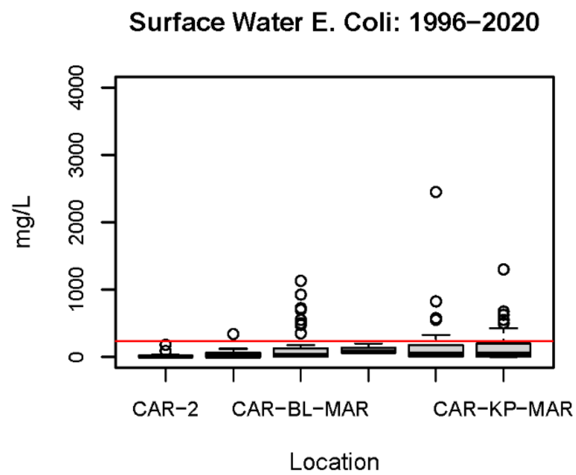
**Metolachlor did not exceed water quality criteria in 2021.*

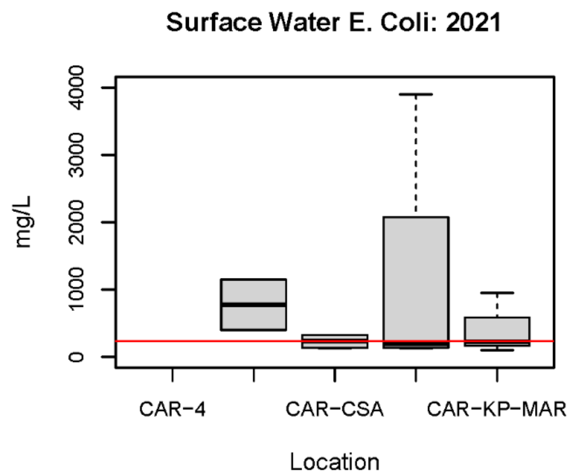




	Historical Reference 1998-2020				2021		
	Location	Mean	Median	n	Mean	Median	n
Metribuzin	RS	0.32	0.2	93	0.49	0.2	8
	TR	0.22	0.2	41	0.22	0.2	4
	TRIB	0.31	0.2	86	0.67	0.2	7

**Metribuzin did not exceed water quality criteria in 2021.*





**Red line indicates the water quality standard of 235 col per 100 mL.*

Historical Reference 2001-2020					2021		
	Location	Mean	Median	n	Mean	Median	n
E col	CAR-2	29.00	8.0	13	----	----	----
	CAR-4	51.38	5.0	13	6250.00	6250.0	1
	CAR-BL-MAR	149.96	28.0	46	775.00	775.0	2
	CAR-CSA	108.67	75.0	3	231.25	237.5	4
	CAR-DW-MAR	159.98	40.0	46	1106.25	200.0	4
	CAR-KP-MAR	158.72	41.0	46	425.00	225.0	3

**Marina bacteria levels exceeded the standard throughout the lake during the four sampling events in 2021.*

2021 Swimming Beach Bacteria Levels (E. Coli / 100mL)									
	McNair	Keyesport	Dam West	Harbor Light	Coles Creek	Boulder Marina	Carlyle Sailing Assoc. Marina	West Access Marina	Trade Winds Marina
6/24/2021	32	47	64	164	102	86	54	86	64
6/30/2021	24	74	14	64	104	54	32	24	106
7/7/2021	54	68	32	180	148	100	56	112	88
7/14/2021	67	48	65	176	164	145	122	110	96
7/21/2021	76	64	32	44	120	22	48	45	200
7/28/2021	76	110	42	124	98	154	56	142	200+
8/4/2021	64	63	42	168	146	120	62	148	200+
8/25/2021	74	68	74	180	165	42	128	170	150
9/1/2021	32	65	46	154	120	157	86	147	188
9/8/2021	65	43	61	122	120	145	59	175	180
9/15/2021	12	40	36	80	120	180	38	24	110
9/22/2021	54	62	38	123	85	102	46	95	187
9/29/2021	43	29	38	112	53	75	37	97	112

**Bacteria levels at the swimming beaches remained below the standard in 2021. Of the additional bacteria samples taken all were below the standard except for two samples at Trade Winds Marina which only indicated a result of greater than 200.*

DISCUSSION: WATER QUALITY

Water quality metrics assessed by CEMVS can be sporadic and highly variable from year to year, thus long-term data collection using consistent and comparable methodology is critical to identify trends or patterns. In general, conditions observed during 2021 did not deviate far from conditions observed during the reference period (1971-2020). Nevertheless, concerns regarding bacteria, TP, iron, DO, temperature, and pesticides were evident. In addition, CHL_a and subsequent TSI levels were indicative of a hyper eutrophic system.

E. Coliform levels were observed above the swimming standard of 235 E. Coli per 100/mL (single sample) eight out of the 14 samples during the four sampling events in the lake. The high levels were recorded once at CAR-4 and Keyesport, and twice at CSA, Dam West and Boulder marinas. Bacteria levels can be highly variable and high levels may not necessarily be representative of the entire system. There were significant precipitation events which proceeded the higher bacteria results recorded in May and August. Conversely, all of the swimming beach bacteria results monitored by project staff during the recreation season were below the standard. Given that 2021 high bacteria levels in the Marinas are not swimming areas, there is a lower risk to humans. Long term bacteria monitoring, and analyses will be important to assess changes over time.

Phosphorus levels have surpassed the 0.05 mg/L criterion for several years. In 2021 the TP criterion was exceeded at all locations with a mean concentration across all sites of 0.37 mg/L. This is 65% greater than the historical mean of 0.23 mg/L, but similar to the 2020 mean of 0.36 mg/L. The mean surface NO3-N concentration in 2021 (0.93 mg/L) was comparable with the historic mean (1.22 mg/L) and did not exceed the criterion of 10 mg/L in 2021. Phosphorus is a limiting nutrient for primary producers (algae and plants) due to its relatively low amount in the environment. Higher inputs of TP and NO3-N into the lake contribute to a highly productive environment which stimulates algal growth that can lead to blooms that deplete the oxygen levels during die off. In addition, blooms can sometimes contain toxins which may be harmful to humans and wildlife.

Living organisms require trace amounts of metals, excessive levels can be harmful. TFe exceeded the criterion of 1 mg/L two times at the bottom reservoir location in front of the dam in May and July 2021. Comparably, there are multiple times TFe was high historically (1984-2021) at the same locations. The 2021 TFe mean concentrations were lower (RB: 0.94 mg/L, TR: 0.48) than the historical means (RB: 1.23 mg/L, TR 0.88 mg/L). Iron cycling is a function of oxidation-reduction processes. Elevated levels of iron near the bottom of a lake are not immediately detrimental to the overall lake system. Iron oxidizes relatively rapidly (minutes to hours); therefore, any iron released through the spillway will be oxidized in a short period of time.

In 2020 all 33 discrete observations of DO were within the state guidelines except for Dam West Marina and Boulder Marina. On July 25 DO was recorded at 4.8 mg/L at Dam West Marina while on August 25 DO was recorded at 4.29 mg/L. Since 1972, there have been 23 routine lake surface measurements observed in the summer in which DO was below 5 mg/L. DO was measured at the tail race in 15-minute intervals from April 6 through October 27, 2021. DO was recorded below the standard of 5 mg/L at the tail race during middle-to-late June. These lower measurements occurred during a period of low outflow. All other measurements of DO were greater than the standard. It is not abnormal during warm air and water temperatures to experience low DO. DO has an inverse relationship with temperature. As temperature increases, the ability of water to contain DO decreases, therefore the DO concentration decreases. Water temperature measurements made during 2021 indicate an increase from the historical data. This finding assumes that the historical reference 1971-2020 is the normal seasonal temperature. In a comparison of 2021 mean surface temperatures to historical mean temperatures, the water quality standard of <2.8°C was exceeded during the spring (3.71°C). Discrete measurements of temperature were exceeded at multiple locations in the lake during the spring and summer sample events.

Pesticides are commonly used throughout much of the agricultural landscape that the Kaskaskia River flows. Of the eight pesticides tested, only Atrazine, Chlorpyrifos, Metolachlor, and Metribuzin were detected between 1998 and 2021. Of those four, only Atrazine and Chlorpyrifos were found to exceed the criteria. In 2021 the Atrazine drinking water standard (3 ug/L) was exceeded on May 19 in the lake and the tributary. Atrazine levels were recorded over the standard multiple times in the lake and tributaries historically. The 2021 Atrazine overall mean (1.85 ug/L) is slightly greater than the historic Atrazine mean (1.00 ug/L). Atrazine is a commonly used agricultural chemical which can be readily transported by rainfall runoff. Atrazine is suspected of causing cancer; and therefore, is monitored for the protection of human and aquatic health. Atrazine is most commonly detected in ground and surface water due to its wide use, and its ability to persist in soil and move in water. The laboratory detection limit for Chlorpyrifos is lower than the standard of 0.11 ug/L. Chlorpyrifos was measured above the detection limit twice in the tributaries; once in May (0.267 ug/L) and once in July (0.25 ug/L) 2021. The acute standard of 0.11 ug/L is set for the protection of aquatic life. Chlorpyrifos is an insecticide which has been used primarily to control foliage and insect pests since 1965. Low dose exposure may cause minor sickness while high dose exposure may cause serious sickness and even death in humans. Chlorpyrifos does not mix well with water and tends to stick to soil. If it does get into a water body, it will tend to remain on the surface where it will evaporate easily. It will also be broken down by sunlight and bacteria in the environment. The potential for human exposure to Chlorpyrifos in the lake is very low due to its rapid degradation in the environment.

Although there is not a state criterion for CHL_a the proposed standard of 25 mg/cm^3 was exceeded at the lake sites in July and August in 2021. The 2021 combined (lake and tributary) CHL_a mean concentration of 30.56 mg/cm^3 was similar to the historical mean of 28.76 mg/cm^3. CHL_a is an indicator of the abundance of phytoplankton. Any water environment with a level recorded above 25 mg/cm^3 is considered to be eutrophic (nutrient enrichment increases algal and plant growth and negative effects). The 2021 TSI level, an average of the individual trophic state indexes for Secchi depth, CHL_a, and TP, for Carlyle Lake is 75.62. Carlyle Lake is considered hyper-eutrophic based on this TSI level. This does not necessarily mean the water quality is poor, but that its trophic level indicates nutrient levels are abundant, which can support an abundance of plants and algae. Long term monitoring and analyses are important to assess changes over time.

Total suspended solids can affect water quality by increasing temperature through the absorption of sunlight by suspended particles in the water column, and consequently reduce DO. TSS are also strongly correlated with water clarity and the presence of Macrophytes. Though there are no numeric water quality standards for total solids, Carlyle Lake was previously listed as impaired by TSS, but has been delisted in the latest 303d report. The 2021 TSS mean concentration in the lake (53.94 mg/L) was greater than the historical mean (34.36 mg/L) while the 2021 tail race TSS mean (12.05 mg/L) was lower than the historical mean (25.4 mg/L). However, the 2021 TSS tributary mean concentration was greater (135.14 mg/L) than the historical tributary mean (105.38 mg/L). The higher TSS levels observed in 2021 in the tributary and lake may be due to the significant rain events which occurred in the days preceding the sampling.

All remaining parameters evaluated during the 2021 water quality monitoring effort were within designated criteria or within historical reference norms.

MONITORING PROGRAM RECOMMENDATIONS

The IEPA currently has listed Carlyle Lake as impaired for total phosphorous and mercury while the Kaskaskia River upstream from the Lake is impaired for fecal coliform, and mercury. In addition, the North Fork Kaskaskia River is impaired for phosphorus, Atrazine, and Terbufos. The lists of sources for these impairments are contaminated sediments, crop production, and unknown sources. At present the only tributary being sampled by CEMVS is the Kaskaskia River. IEPA also has the following listed as impaired: Hurricane Creek, North Fork Kaskaskia, and East Fork Kaskaskia. It is recommended to add these three tributaries as well as mercury in the lake to the routine sampling plan to increase the dataset and improve our ability to assess the water quality condition of Carlyle Lake.

In accordance with EM-1110-2-1201, sediment samples should be taken to monitor and assess potential impacts to aquatic and human health. Sediment sampling and analyses occurred at Carlyle Lake in 2018, and prior to that in 2007. During these last analyses multiple exceedances over the recommended criteria were observed. Identifying trends over time is much more achievable with more consistent data. Contaminated sediments may have negative impacts on ecological processes. It is recommended, if possible, to sample and analyze for sediment metals and nutrients, as well as grain size analyses yearly or every two years.

Given the above-mentioned high bacteria levels observed at the Marinas in 2020, it is recommended to continue routine bacteria sampling at the marinas while adding the tributaries (CAR-12, CAR-13, and any additional tributaries). This would be useful in capturing a larger picture of bacteria coming into the lake. It may also be useful to execute a review of all NPDES permits and other potential contributors to high bacteria levels in the marinas.

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APPENDIX A: FIELD DATA

Date	Location	Depth (m)	Temp (°C)	ORP (mV)	Sp Cond (µS/cm)	pH	ODO (% Sat)	ODO (mg/L)	TDS (mg/L)	Turbidity (FNU)	Secchi (in)
5/19/2021	CAR-1	0.813	18.4	172.1	382.4	7.92	99.8	9.37	249	15.78	
5/19/2021	CAR-1	2.685	18.8	170.3	384.9	7.98	99.9	9.3	250	14.95	
5/19/2021	CAR-2	0.781	18.8	168.1	381.9	7.92	88	8.2	248	10.75	35
5/19/2021	CAR-2	2.233	18.8	181.7	381.9	7.88	88.4	8.23	248	11.46	
5/19/2021	CAR-2	3.197	18.7	182.1	381.9	7.88	88.1	8.21	248	10.55	
5/19/2021	CAR-2	3.838	18.5	181	381.9	7.88	86.2	8.08	248	13.08	
5/19/2021	CAR-2	4.869	18.6	183.6	381.9	7.85	86.7	8.1	248	13.23	
5/19/2021	CAR-2	6.116	18.3	184	382	7.85	85.6	8.04	248	14.28	
5/19/2021	CAR-2	7.046	18.3	184.3	382.1	7.85	85.4	8.03	248	13.42	
5/19/2021	CAR-2	8.138	18.2	181.2	382	7.88	84.8	7.99	248	86.78	
5/19/2021	CAR-4	1.012	19.3	154.4	313.3	7.67	78.4	7.22	204	256.33	2
5/19/2021	CAR-4	1.783	19.4	154.5	314	7.64	77.7	7.15	204	251.1	
5/19/2021	CAR-4	3.123	19.4	154.5	316.4	7.62	77.7	7.15	206	253.52	
5/19/2021	CAR-4	4.107	19.4	154.6	317.4	7.61	77.5	7.13	206	240.15	
5/19/2021	CAR-4	5.078	19.4	154.4	316.9	7.6	77.7	7.15	206	246.65	
5/19/2021	CAR-13	0.061	17.7	149.8	256.3	7.34	72.1	6.86	167	346.05	
5/19/2021	CAR-CSA	1.189	19.6	156.5	382.8	7.9	90	8.23	249	25.39	
5/19/2021	CAR-DW-MAR	1.098	19.2	181.1	383.8	7.83	75.2	6.94	249	13.21	
5/19/2021	CAR-DW-MAR	1.664	18.7	63.2	382.8	7.78	75.5	7.03	249	14.73	
5/19/2021	CAR-KP-MAR	0.826	19.9	174.6	427.2	7.9	86.8	7.89	278	139.35	
7/6/2021	CAR-1	1.86	26.3		380.1		103.2	8.32	247	8.5	
7/6/2021	CAR-2	1.127	26.7		372.3		135.9	10.87	242	5.98	32
7/6/2021	CAR-2	2.129	26.3		378.5		93.5	7.55	246	5.34	
7/6/2021	CAR-2	3.047	25.9		385.9		48.9	3.97	251	8.68	
7/6/2021	CAR-2	4.206	25.8		387.4		35.7	2.91	252	13.72	
7/6/2021	CAR-2	5.167	25.7		388.5		27.2	2.22	253	18.45	
7/6/2021	CAR-2	5.954	25.6		389.5		22.5	1.84	253	23.92	
7/6/2021	CAR-4	1.219	28.6		331.8		139.8	10.82	216	42.74	17
7/6/2021	CAR-4	2.174	27.9		327.2		101.1	7.91	213	46.32	
7/6/2021	CAR-4	3.072	27.6		329.8		72.2	5.69	214	62.77	

Date	Location	Depth (m)	Temp (°C)	ORP (mV)	Sp Cond (µS/cm)	pH	ODO (% Sat)	ODO (mg/L)	TDS (mg/L)	Turbidity (FNU)	Secchi (in)
7/6/2021	CAR-4	4.112	27		313.5		50.5	4.02	204	65.69	
7/6/2021	CAR-4	5.063	26.8		306.7		44.9	3.59	199	66.25	
7/6/2021	CAR-12	0.5	27.7		428.5		84.7	6.66	279	24.59	
7/6/2021	CAR-13	1.05	27.2		429.1		85.6	6.78	279	61.7	
7/6/2021	CAR-13	2.783	27.2		429.2		85.8	6.8	279	71.48	
7/6/2021	CAR-BL-MAR	1.011	29.9		374.2		129.9	9.83	243	13.58	
7/6/2021	CAR-CSA	1.09	27.7		377.7		130.9	10.3	245	12.49	
7/6/2021	CAR-DW-MAR	1.027	27.5		371.1		110.4	8.71	241	8.94	
7/6/2021	CAR-KP-MAR	1.04	29.3		303.4		181.1	13.85	197	21.22	
7/26/2021	CAR-1	0.899	27.7	341.4	342.6	8.42	101.5	7.98	223	8.49	
7/26/2021	CAR-2	1.203	28.1	230.1	337.7	8.59	89.8	7.02	219	6.72	31
7/26/2021	CAR-2	2.01	28	231.8	339.1	8.58	88.8	6.95	220	6.46	
7/26/2021	CAR-2	3.131	28	234.2	342.8	8.49	83.9	6.57	223	6.43	
7/26/2021	CAR-2	4.259	27.5	248	352.8	8.12	46.7	3.69	229	11.48	
7/26/2021	CAR-2	5.225	27.6	242.5	350.8	8.15	51	4.02	228	10.5	
7/26/2021	CAR-2	6.299	27	250.9	359.7	7.82	17.5	1.39	234	28.46	
7/26/2021	CAR-2	7.212	26.8	221.5	362.9	7.74	5.5	0.44	236	91.65	
7/26/2021	CAR-4	1.07	28.4	166.1	323.2	8.37	71.7	5.57	210	32.21	11
7/26/2021	CAR-4	2.106	28.3	171.5	319.5	8.29	66.1	5.14	208	40.1	
7/26/2021	CAR-4	3.086	28.3	173.9	319	8.27	64.8	5.04	207	65.32	
7/26/2021	CAR-12	0.5	28.1	259	393.1	7.8	79.1	6.18	256	44.17	
7/26/2021	CAR-13	0.5	27.4	209.8	414.7	7.88	83.2	6.57	270	61.86	
7/26/2021	CAR-CSA	1.074	27.9	233.1	330.9	8.26	66.2	5.19	215	33.71	
7/26/2021	CAR-DW-MAR	0.202	28.3	190.1	354.3	8.28	62.6	4.86	230	9.18	
7/26/2021	CAR-DW-MAR	1.005	27.9	199.2	358.7	7.95	34.8	2.72	233	13.89	
8/25/2021	CAR-1	0.239	27.7	111	325.6	8.15	94.8	7.46	212	10.47	
8/25/2021	CAR-2	1.183	28.4	107.6	319.6	8.61	97.6	7.58	208	9.91	16
8/25/2021	CAR-2	2.097	27.9	125.2	321.8	8.42	71.5	5.6	209	9.48	
8/25/2021	CAR-2	3.008	27.4	131.7	326	8.09	42.5	3.36	212	11.55	
8/25/2021	CAR-2	3.973	27.4	133.2	326.2	8.07	39.4	3.12	212	12.49	

Date	Location	Depth (m)	Temp (°C)	ORP (mV)	Sp Cond (µS/cm)	pH	ODO (% Sat)	ODO (mg/L)	TDS (mg/L)	Turbidity (FNU)	Secchi (in)
8/25/2021	CAR-2	5.081	27.4	134.3	326.7	8.05	36.9	2.92	212	13.31	
8/25/2021	CAR-2	5.268	27.3	137.7	327.7	7.92	25.4	2.01	213	29.85	
8/25/2021	CAR-2	6.307	27.3	136.1	327	7.99	33.1	2.62	213	15.75	
8/25/2021	CAR-4	1.146	29.8	122.3	289	8.3	106	8.03	188	38.53	10
8/25/2021	CAR-4	2.291	29.1	122.7	281.7	8.02	78.4	6.01	183	59.04	
8/25/2021	CAR-12	1.425	28.9	164.5	419.2	7.9	93.9	7.23	272	26.83	
8/25/2021	CAR-13	1.102	28.7	145.4	406.2	7.93	92.3	7.13	264	62.24	
8/25/2021	CAR-BL-MAR	1.26	30.5	-14.1	235.1	7.79	57.2	4.29	153	30.09	
8/25/2021	CAR-CSA	1.02	28.8	113.6	320.6	8.7	104.1	8.03	208	14.77	
8/25/2021	CAR-DW-MAR	1.084	28.6	119.8	324.9	8.29	66.7	5.16	211	13.26	
8/25/2021	CAR-KP-MAR	0.393	30.3	103.1	305.5	8.46	110.2	8.29	199	28.81	

APPENDIX B: LABORATORY DATA