Datasets: St. Louis River Estuary phytoplankton and water quality, 2022-2024

This document provides detailed information about data that were generated through a 2022-2024 Collaborative Research project titled *Building a Collaborative Water Quality Monitoring Strategy for a Changing St. Louis River Estuary.* This webpage provides information about the project. The project was supported by the National Estuarine Research Reserve System (NERRS) Science Collaborative, which is funded by the National Oceanic and Atmospheric Administration. All Science Collaborative supported projects that collect new data adhere to federal data sharing and archiving requirements.

About the Associated Project

Project page: https://nerrssciencecollaborative.org/project/Ramage22
Grant Type: Collaborative Research
Focus Area(s): Application of SWMP Data, Water Quality
Keyword(s): harmful algal bloom, water quality, nutrient pollution

Reserve(s): Lake Superior, WI

Project Duration: December 2022 - September 2024
Grant Amount: $399,833.00
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Project Description

The St. Louis River Estuary, located at the headwaters of Lake Superior, is nearing a major milestone: its anticipated delisting as a Great Lakes Area of Concern by 2030. Yet even as remediation and restoration successes are celebrated, new environmental stressors, particularly harmful algal blooms, raise concerns about the estuary's long-term water quality health. In response, a group of local, state, federal, and tribal partners who have long worked in and cared for the estuary began calling for a science-based monitoring strategy that could respond to emerging threats and support ongoing stewardship beyond delisting. Together, they shaped a

shared vision: a comprehensive program of observations, analyses, and public reporting that would protect remediation and restoration investments and inform future decision-making.

To advance this vision, this group of partners who had long advocated for a coordinated monitoring effort, collaborated closely with the Lake Superior National Estuarine Research Reserve to launch the project. The Reserve brought together a scientific team that included collaborators from the University of Minnesota's Natural Resources Research Institute, who contributed expertise in phytoplankton and bloom dynamics. The partners co-authored the proposal and remained actively engaged throughout the project, helping select sites, shape the study design, and review statistical analysis and draft recommendations. Together, the partners and project team developed a research approach that combined strong scientific design to build foundational understanding of phytoplankton dynamics with a focus on generating practical, actionable insights for a shared long term monitoring strategy. Eight high-priority sites were intensively sampled in 2023 and 2024, focusing on areas vulnerable to nutrient enrichment, low oxygen, and bloom formation. The study also prioritized public relevance by targeting restoration areas, heavily used public zones, and capturing rarely collected wintertime data.

The project successfully identified predictors of cyanobacteria biovolume in the estuary and actionable monitoring strategies to improve bloom detection and efficient water quality monitoring in the future. Important predictors of blooms included low nitrogen, warm temperatures, low dissolved organic carbon, and high pH. In addition, the team observed significant year-to-year differences in bloom composition and intensity suggesting bloom dynamics are highly responsive to variations in hydrology and nutrient stoichiometry which are driven by precipitation patterns. Further analysis evaluated the efficiency of different monitoring designs by assessing redundancy across space, sampling frequency, and parameters. These findings informed a science-based strategy that identified periods and locations of elevated bloom risk while accounting for the real-world capacity of agencies and partners. The resulting recommendations include a reduced set of priority sites and a tiered approach to sampling. This strategy is designed to be flexible with available funding and effort, while ensuring that high-risk bloom locations are monitored as a minimum standard. The project's result is not only a clearer picture of what drives blooms in the estuary, but also a durable and collaborative roadmap for long-term monitoring, co-created by the people who first called for a collaborative, comprehensive program.

Overview of Data Package

This data package supports the project Building a Collaborative Water Quality Monitoring Strategy for a Changing St. Louis River Estuary, funded by the National Estuarine Research Reserve System Science Collaborative. Led by the Lake Superior National Estuarine Research Reserve (LSNERR) and University of Minnesota's Natural Resources Research Institute (NRRI) datasets include 2022–2024 water quality, phytoplankton, and winter dissolved oxygen observations from eight estuary "hotspot" locations. Sampling captured seasonal variability and cyanobacteria bloom events. All samples were collected using standardized field and laboratory protocols. This dataset can be used to evaluate spatial and temporal patterns in water quality and phytoplankton dynamics, assess predictors of cyanobacterial blooms, and monitor winter under-ice hypoxia in the St. Louis River Estuary. It is well-suited for research on nutrient-bloom relationships, seasonal and spatial ecological shifts, and long-term monitoring strategy development.

Keywords:
Cyanobacteria, phytoplankton, water quality, winter, estuary, Great Lakes, algal blooms, nutrients

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Data access and archival:
The data package is available at the Environmental Data Initiative (EDI) Data Portal:
https://doi.org/10.6073/pasta/cf58e8c6af8a79077bf4330d60a6032c

Citation: Nicklay, H., E.D. Reavie, C. Filstrup, P. Birschbach, and A. Knoll. 2025. St. Louis River Estuary Phytoplankton and Water Quality, 2022 - 2024 ver 1. Environmental Data Initiative.

More About the Data:

Data Collection Period:
October 26, 2022 through November 11, 2024

Geographic extent:
Data was primarily collected either within Douglas County, WI or St. Louis County, MN within the St. Louis River Estuary and nearshore Lake Superior (Figure 1). The nearest towns are the City of Superior, WI and Duluth, MN.

Four samples were collected in conjunction with the Fond du Lac Band of Lake Superior Chippewa's Water Quality Monitoring Program on the St. Louis River within the Fond du Lac Reservation, the nearest town is Cloquet, MN. Complimentary data can be obtained from the U.S. EPA's Water Quality Portal (Water Quality Portal, 2021). The site codes for Fond du Lac Reservation site provided in our water quality dataset are equivalent to the "MonitoringLocationName" in the Water Quality Portal.

The project bounds are within these latitudes/longitudes in decimal degrees - NAD83

- North: latitude: 46.893700
- South: latitude: 46.641069
- West: longitude: -92.855460
- East: longitude: -91.955843

File format:
All files in the data package are comma separated values (.csv).

Files included in this package:

1. "water_quality.csv" includes physiochemical *in situ* field data using sensors and analytically derived nutrient parameters from water collection and further laboratory analysis. Size = 62 KB
2. "phytoplankton.csv" includes phytoplankton taxonomic cell density and biovolume data from samples collected concurrently with water quality data. Size = 279 KB
3. "taxon_list.csv" provides contextual information to the phytoplankton dataset, including full species names, shape, and average cell dimensions for all taxon identified in the phytoplankton dataset. Size = 14 KB
4. "dissolved oxygen.csv" contains all data across sites and seasons for dissolved oxygen, temperature, and atmospheric pressure. Size = 12,612 KB

5. “site_locations.csv” contains the full site name, geolocation, and notes about the nature of sampling at each site. Size = 4 KB

Data access and archival:
The data package is available at the Environmental Data Initiative (EDI) Data Portal: https://doi.org/10.6073/pasta/cf58e8c6af8a79077bf4330d60a6032c

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Maps and schematics for data collection:

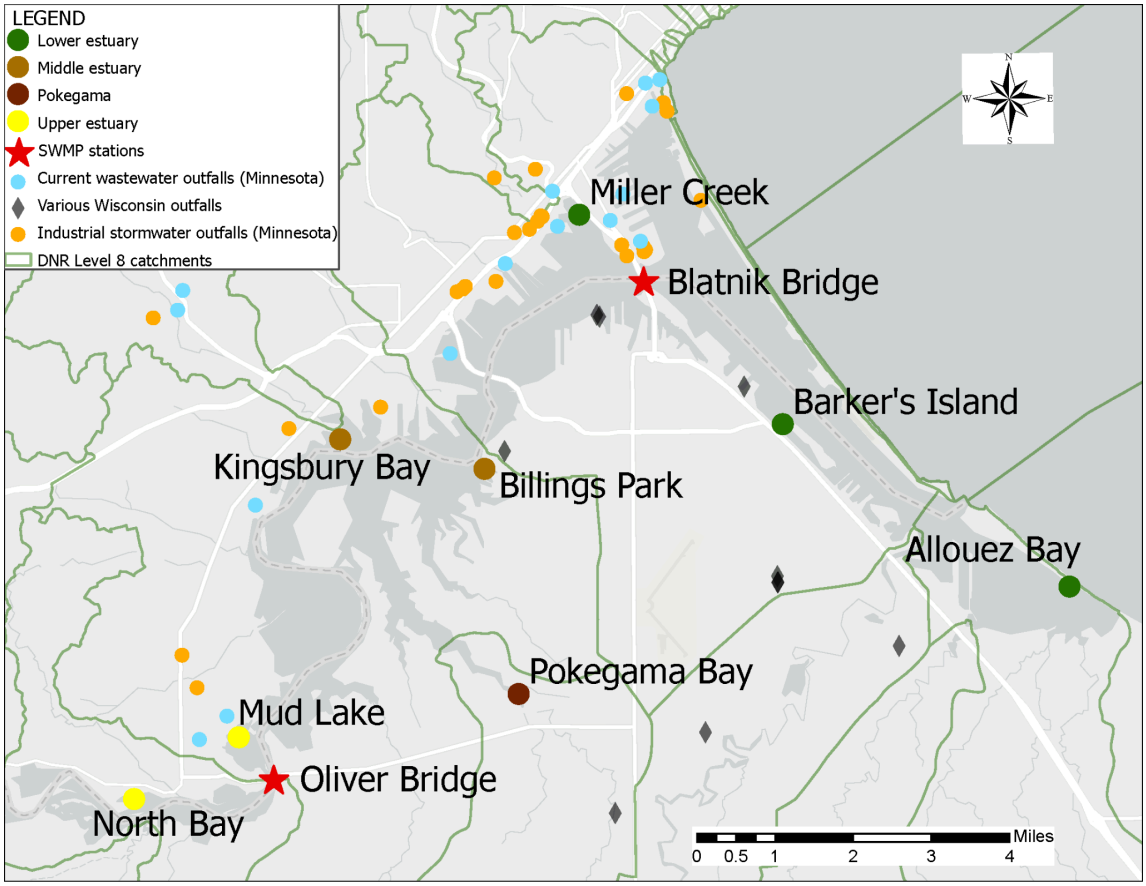

Figure 1. St. Louis River Estuary map showing the eight project sample locations (large circles), additional long-term monitoring stations from the System-wide Monitoring Program (stars), catchment regions and documented industrial and wastewater outfalls. Outfall data were sourced from the Wisconsin DNR’s Surface Water Data Viewer (https://dnr.wisconsin.gov/topic/SurfaceWater/swdv) and the Minnesota Natural Resource Atlas (https://mnatlas.org).

Sample Collection Methods

Site Selection

Within the St. Louis River Estuary, eight sampling locations were selected based on several "hotspot" criteria, including previously documented hypoxia (Gorano and Schooler 2015), degraded phytoplankton communities (increases in cyanobacteria and high-nutrient diatoms; Alexson et al. 2018), cyanobacteria blooms, and nutrient enrichment (Bellinger et al. 2016). Other considerations included proximity to impaired urban streams and stormwater outfalls, and recent or planned remediation and restoration projects (Table 1). They also span spatial-chemical gradients in the estuary. Two sites, Barker's Island and Pokegama Bay are also LSNERR System-wide Monitoring Program (SWMP) sampling locations, where continuous (15-minute) water quality and monthly nutrient and chlorophyll-a samples have been collected 2013 - 2024 (NOAA/NERRS 2025b).

Table 1: Study sites in the SLRE and their associated "hotspot" characteristics that informed site selection.

Sampling Location	Site Code	Hypoxia	HAB	Nutrient Enrichment	Proximal to Impaired Water	Current or Planned Remediation or Restoration
Allouez Bay	AL	Y	N	Y	N	Y
Barker's Island	BA	N	Y	Y	Y	Y
Miller Creek / WLSSD	MI	N	N	Y	Y	Y
Billing's Park	BI	Y	N	N	N	N
Kingsbury Bay	KI	N	N	N	Y	Y
Pokegama Bay	PO	Y	N	Y	Y	N
Mud Lake	MU / MU2	Y	N	N	Y	Y
North Bay	NO	N	N	N	Y	Y

There are 15 sampling site locations outside of the eight, high frequency sampled "hotspot" locations in Table 1, that were sampled only once or twice.

Sampling Design - Scheduled Sample and Bloom Response Sample

Routine/scheduled sampling was conducted at all eight sites during the 2023 open water season. Sampling frequency varied with expected cyanobacteria phenology: biweekly during spring and late fall, and weekly during the bloom-prone summer months (July–early October). In 2024, open water routine sampling was reduced to biweekly through August 13. Winter sampling was planned monthly for both years and was completed in winter of 2022 to 2023. Low ice cover in winter of 2023 to 2024 limited safe access; therefore, weekly to biweekly under ice sampling was conducted at Barker's Island and Billing's Park only because they had safe access. Overall,

53 routine sampling events were completed, but not all events contain all eight sites. Routine sampling events co-occurred with additional SWMP sampling at Blatnik Bridge (BL) and Oliver Bridge (OL) once per month during the summer (May-October) (see NOAA/NERRS 2025a for data for those two sites). For one routine sampling event, July 11th - 12th 2023, we sampled our eight hotspot locations and four additional thalweg sites (HWY 23, Spirit Lake, Bong Bridge, and Superior Bay) concurrent with Fond du Lac Band of Lake Superior Chippewa's Water Resources Program's sampling at four St. Louis River locations within the Reservation (SLR M38.5, SLR M40.4, SLR M51, SLR M53), to provide a snapshot of larger spatial variety in the watershed.

Between 2023–2024, 19 bloom response samples were collected across seven cyanobacteria bloom events, triggered by visible cyanobacteria aggregations or surface scums. One additional response sample was collected due to observed high dissolved oxygen and pH levels at site MI on 8/26/2024.

Field Sampling

At each site during each sampling event, vertical profiles of the water column were collected using a YSI/Xylem - EXO2 or EXO2s sonde, calibrated following SWMP protocols (NOAA/NERRS 2025b). Recorded parameters included temperature (temp_c), dissolved oxygen concentration (odo_mg_l) and saturation (odo_percent_sat), pH (p_h), specific conductivity (sp_cond_m_s_cm), turbidity (turbidity_fnu). Parameters were recorded at 1-Hz frequency as the sonde was slowly lifted from the bottom to the top of the water column. Photosynthetically active radiation (PAR) was measured using a spherical underwater quantum sensor (Li-COR Model LI-193) slightly above the water surface, just below the water surface and at 50 cm intervals from the surface to bottom or until PAR readings neared zero. Secchi disc depth was measured to determine water clarity by lowering the disc into the water column until it disappeared, then raising it up until it reappeared. Values reported are an average of the disappear and reappear water depths.

Discrete water chemistry samples were collected at 1.5m depth using a horizontal style Van Dorn sampler to be consistent with sampling protocols for SWMP (NOAA/NERRS 2025c). These samples were later analyzed for chlorophyll-a, Total Suspended Solids, Volatile Suspended Solids, nitrate+nitrite, soluble reactive phosphorus, ammonium, Total Nitrogen, Total Phosphorus, Total Organic Carbon, Dissolved Organic Carbon, and Alkalinity. Water chemistry samples were stored on ice in the dark until laboratory arrival, where they were processed.

CO_2 concentrations were measured using a specially modified Vaisala pCO2 sensor (Johnson et al. 2009) attached to a float for uniform depth-pressure corrections; generally, 15-30 minutes of equilibration time was required for readings to stabilize at each site prior to recording values.

Phytoplankton samples were collected as integrated water column samples to ensure that samples were representative of phytoplankters distributed throughout the water column, including surface-scum-forming and understory low-light-adapted species. Phytoplankton samples were collected from the water's surface to the sediment or to a maximum of 2m depth.

Phytoplankton samples were preserved with Lugol's solution in the field and stored at room temperature.

During winter, field observations and water samples were collected through holes in the ice following the open-water procedures described above. To monitor under-ice hypoxia at each sampling site, HOBO Dissolved Oxygen Loggers (model U26-001) were deployed at 0.5m depth above the bottom sediment and programmed to collect water temperature and DO concentration data at 15-minute intervals. Sensors were deployed February 2023 - May 2023 and October 2023 - April 2024, with sensors being retrieved after ice-out in both years. Barometric pressure data from SWMP weather station in Pokegama Bay (NOAA/NERRS 2025a) was used to calculate dissolved oxygen percent saturation using the "Dissolved Oxygen Assistant" tool in HOBOware Pro. Pressure data is included in the data file, but the authoritative dataset is at the Central Database Management Office (NOAA/NERRS 2025a).

Laboratory Procedures

Field samples collected for dissolved nutrients and chlorophyll-a were filtered in the LSNERR laboratory within 8 hours of collection. NRRI's Central Analytical Laboratory analyzed the following water quality variables following standard methods (SM, Baird and Bridgewater 2017). Total nitrogen (tn_ppb) and total phosphorus (tp_ppb) were measured on unfiltered water samples following potassium persulfate digestion (SM 4500-P J) using the automated cadmium reduction (SM 4500-NO3 F) and ascorbic acid (SM 4500-P E) methods, respectively. Ammonium (nh4n_ppb) (4500-NH3 G) and nitrate + nitrite (no2no3n_ppb) (4500-NO3 F) were measured on filtered water samples (0.45-µm pore size). Soluble reactive phosphorus (op_ppb) was measured on filtered water samples using the ascorbic acid method (SM 4500-P E). Total organic carbon (toc_ppm) and dissolved organic carbon (doc_ppm) were measured on unfiltered and filtered water samples (0.7-µm pore size), respectively, using a Shimadzu TOC-L analyzer (SM 5310 B). Acid neutralizing capability / alkalinity (anc_mgLcaco3) was measured on unfiltered water samples using the 2-endpoint method (SM 2320 B).

The following parameters were analyzed in LSNERR's laboratory. Total and volatile suspended solids (tss/vss) were measured as dry weight of particulates on GF/C filters (1.2-µm pore size) using the loss-on-ignition method (SM 2540 D, SM 2540 E). Chlorophyll-a (chla) was measured using the unacidified fluorometric method (SM 445.0) following a 24 hour, 90% acetone extraction.

Phytoplankton taxonomic samples were analyzed for total protists, largely phytoplankton but protozoans and zooplankton were also assessed if present. The highest possible taxonomic resolution was used for identification, which resulted in a mixture of species, genera, and lesser-defined groups, such as "ovoid cyanobacteria". Analysis followed the quantitative Utermöhl settling chamber method (Utermöhl 1958) unless protist concentrations were very high, in which an 1mL aliquot of sample water was placed in a Sedgewick-Rafter counting chamber, sometimes employing dilution with filtered estuary water if cell densities or debris were very high.

The Utermöhl method employed settling samples for 24 hours in a chamber to concentrate protists for counting. Counting of all samples occurred on an inverted microscope (Olympus BX51) at 400× magnification. At least 250 phytoplankton entities were counted per settled sample, and the transect area was recorded for quantitative calculations. To account for large, rare taxa (e.g., large colonies, *Ceratium hirundinella*), the full chamber was assessed at 100× magnification for these large entities. In calculations, the abundance of these large entities was downweighted by the actual area counted during 400× assessment. For biovolume assessments, up to the first 10 specimens of each taxon observed was measured (length, width, diameter, depth, as necessary based in shape) and biovolume calculations for each taxon were conducted based on standardized shape formulas for each taxon (Reavie et al. 2010 & Figure 2). When the necessary dimensions for a taxon could not accurately be measured because of a cell's orientation in the chamber, mean dimension values provided in the taxon_list dataset were used.

Shape	Dimensions Required				
	Code	Length	Width	Depth	Diameter
Ceratium	CER	L	W	DP	D
Cone	CON	L	W		
Crucigenia	CRU	L			
Cylinder	CYL	L	W	DP	D
Dumbell box	DBB	L	W	DP	
Dumbell	DBL	L	W	DP	
Diamond Box	DMB	L	W	DP	
Fusiform	FUS	L	W		
Ovoid box	OVB	L	W	DP	
Ovoid	OVO	L	W		
Rectangular box	RTB	L	W	DP	
Staurastrum	STR	L	W		
Tabellaria flocculosa v. *geniculata*	TFG	L	W	DP	D
Teardrop	TRP	L	W		

Figure 2: Required dimensions based on cell shape for the calculation of species/taxon biovolume. Average dimensions for each species supplied in taxon_list.csv from Reavie et al. 2010.

Method Detection Limits

Method detection limits for laboratory derived parameters are listed below. The data was not adjusted or flagged to reflect limits, rather we leave it to the data user's discretion. Slightly negative values for tss and vss did occur and were substituted with zero.

Table 2: Parameters with laboratory derived method detection limits and the percentage of values in the dataset below the detection limit

data header	definition	units	method detection limit	percent of values below detection limit
chla	chlorophyll-a concentration	ug/L	0.06	0
tp_ppb	total phosphorus concentration	ppb	4	0
op_ppb	soluble reactive phosphorus concentration	ppb	3	3.6
tn_ppb	total nitrogen	ppb	20	0
nh4n_ppb	ammonium nitrogen concentration	ppb	8	6.7
no2no3n_ppb	nitrite and nitrate nitrogen concentration	ppb	5	11.1
anc_mgLcaco3	acid neutralizing capacity or alkalinity	mg CaCO3/L	0.64	0
doc_ppm	dissolved organic carbon	ppm	0.3	0
toc_ppm	total organic carbon	ppm	0.3	0
tss	total suspended solids	mg/L	1.7	4.9
vss	volatile suspended solids	mg/L	1.5	51.1

Data quality checks

In general, procedures to ensure data quality including calibration, maintenance, and post deployment of sondes, the verification of data entry by multiple individuals, and plotting data to assess outliers, followed the procedures of the SWMP (NOAA/NERRS 2025b,c; NOAA/NERR 2024)

All data recorded in the field or on a laboratory bench sheet that was manually entered into a Microsoft Excel spreadsheet, was checked and verified by another individual. Each parameter was plotted and visually inspected for errors. Plots included boxplots by site and line plots over time for each parameter. This was done for each sonde depth profile before it was averaged, removing data points that had clear interference from bottom sediments or values logged when the sonde was out of the water. All obviously erroneous values, because they fell outside of expected ranges for the parameters, were removed from the datasets.

Data treatment considerations

The water quality and phytoplankton datasets can be merged by rows for analysis using the “site” and “event” fields. Please note that there are some sample sets that have either missing phytoplankton or missing water quality data. The phytoplankton dataset headers contain the SPP_codes within the taxon_list dataset.

Phytoplankton species (SPECIES) sometimes include the “cf.” qualifier. That is used to indicate specimens that were similar to (or may actually be) the nominate species. We leave treatment of these species to the data user.

There are two locations in Mud Lake: MU or Mud Lake West and MU2 or Mud Lake East. The MU location was sampled in all of 2023 and in January 2024. Both MU and MU2 locations were sampled in April 4 and 11, 2024 and just MU2 was sampled from April 25, 2024 through the rest of 2024. We leave it to the data user to decide if MU and MU2 are comparable enough for combination in data analysis. Although they are very close to one another, they are separated by a railroad causeway with a single opening that allows water exchange into Mud Lake West.

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