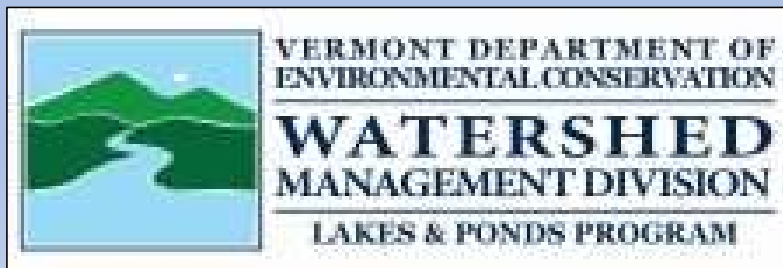


2023 Lake Willoughby Water Quality Monitoring Results: Lay Monitoring Program and LaRosa Partnership Program

Mark Mitchell, Limnologist

Lake Monitoring and Community Outreach Coordinator

UVM Lake Champlain Sea Grant and VT DEC Lakes & Ponds Program

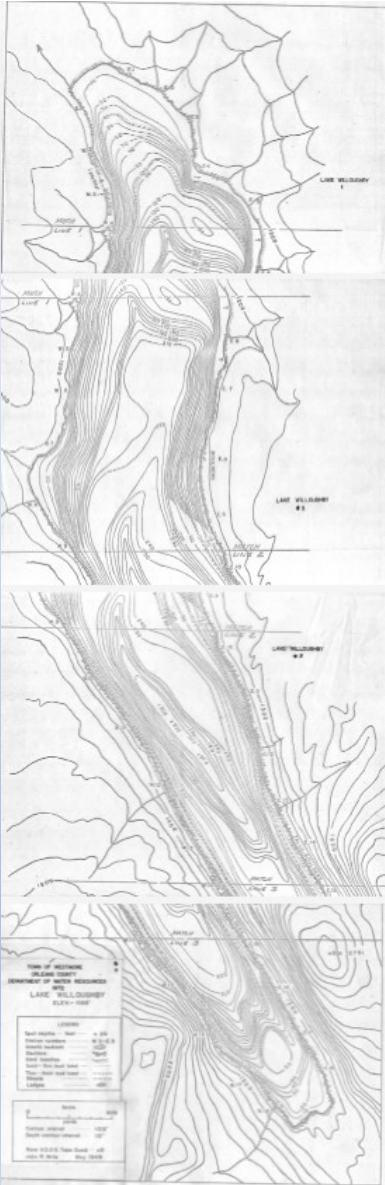




Lay Monitoring Program (LMP) 2023 Lake Sampling Overview

- Biweekly from June through August (total of 6 samples for summer mean):
 - *Basic Sampling*: Measure Secchi disk transparency depth (clarity)
 - *Supplemental Sampling*: Collect epilimnetic and hypolimnetic water samples that are lab tested for total phosphorus (nutrient) concentration and chlorophyll-a (algae) concentration
 - Pilot caffeine sampling (wastewater)
 - Complete a lake sampling webform (and report cyanobacteria conditions)





Lake Willoughby Monitoring Station #1

Vermont Agency of Natural Resources

vermont.gov

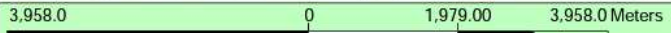


LEGEND

- Waterbody
- Town Boundary

NOTES

Map created using ANR's Natural Resources Atlas



WGS_1984_Web_Mercator_Auxiliary_Sphere
 © Vermont Agency of Natural Resources
 1" = 6493 FL
 1cm = 779 Meters
 THIS MAP IS NOT TO BE USED FOR NAVIGATION

DISCLAIMER: This map is for general reference only. Data layers that appear on this map may or may not be accurate, current, or otherwise reliable. ANR and the State of Vermont make no representations of any kind, including but not limited to, the warranties of merchantability, or fitness for a particular use, nor are any such warranties to be implied with respect to the data on this map.

1: 77,913

January 11, 2023



Vermont Lake Score Card

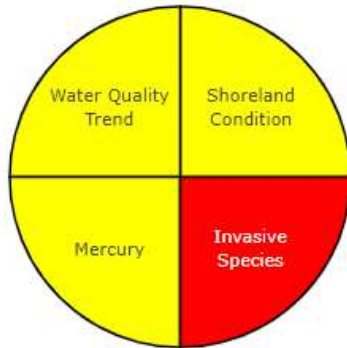
Lake Willoughby

<https://dec.vermont.gov/watershed/lakes-ponds/data-maps/scorecard>

Scores

Water Quality Data

Lake Information



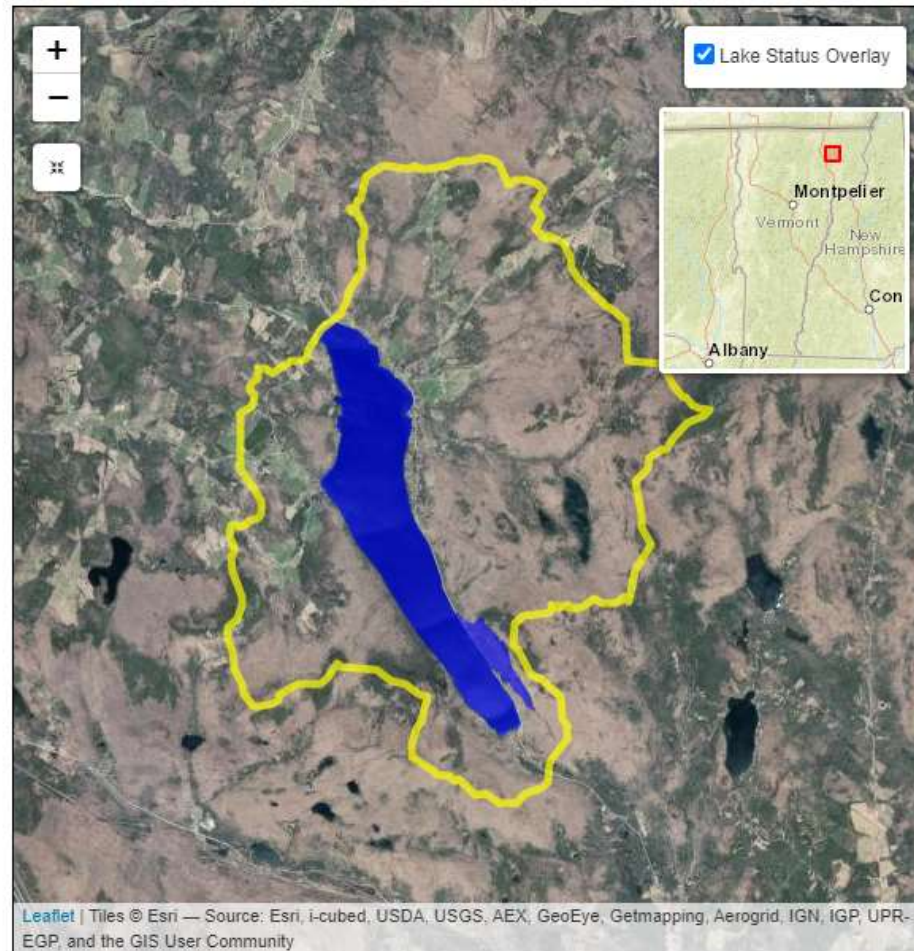
Watershed: **Moderately Disturbed**

WQ Standards: **Meets Standards**

Color Scoring System

- Good Conditions
- Fair Conditions
- Poor Conditions
- Insufficient Data

[Learn How Lakes Are Scored](#)



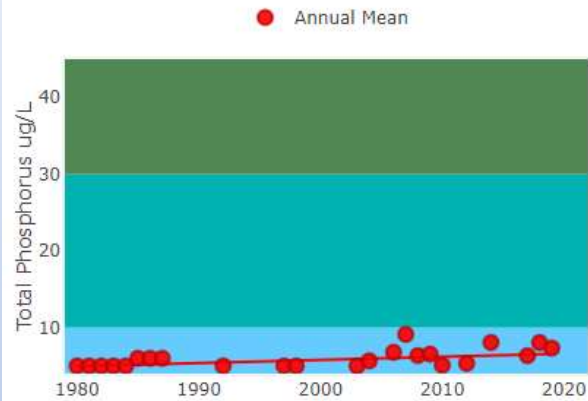
■ Hypereutrophic ■ Eutrophic ■ Mesotrophic ■ Oligotrophic

Click on "Daily Mean" or "Annual Mean" to toggle on or off the data layer.

LAKE WILLOUGHBY SCORE CARD WATER QUALITY ANNUAL MEANS

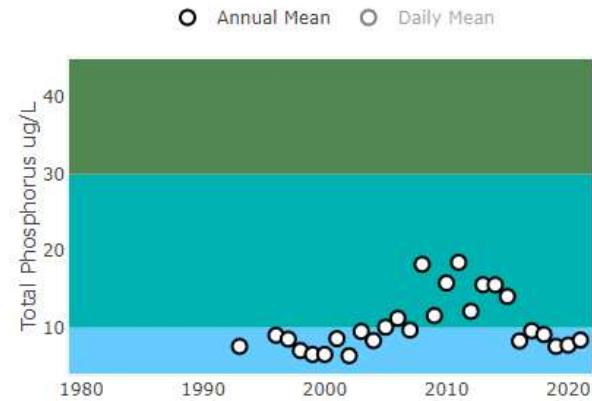
Spring Phosphorus

Trend: Highly Significantly Increasing (p-value=9e-04)



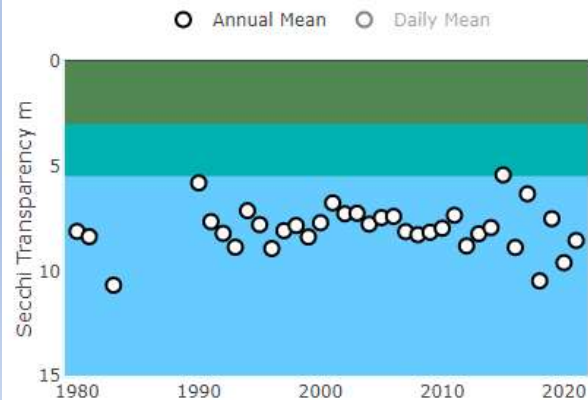
Summer Phosphorus

Trend: Stable (p-value=0.1228)



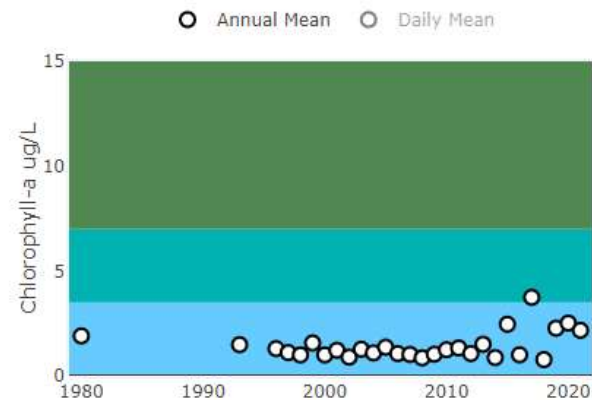
Summer Secchi

Trend: Stable (p-value=0.7014)



Summer Chlorophyll-a

Trend: Stable (p-value=0.4405)



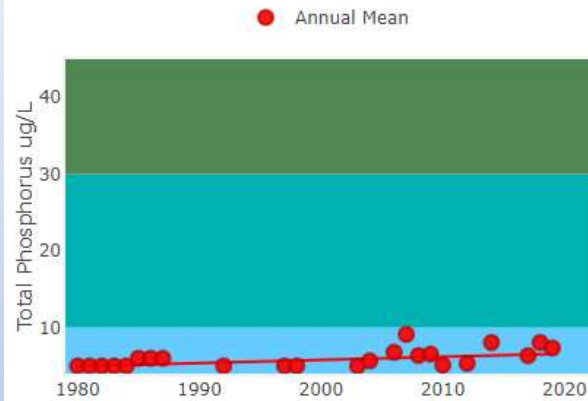
■ Hypereutrophic ■ Eutrophic ■ Mesotrophic ■ Oligotrophic

Click on "Daily Mean" or "Annual Mean" to toggle on or off the data layer.

LAKE WILLOUGHBY SCORE CARD WATER QUALITY ANNUAL RANGE

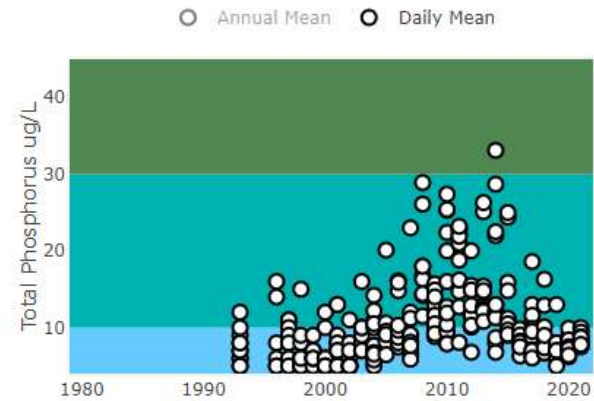
Spring Phosphorus

Trend: Highly Significantly Increasing (p-value=9e-04)



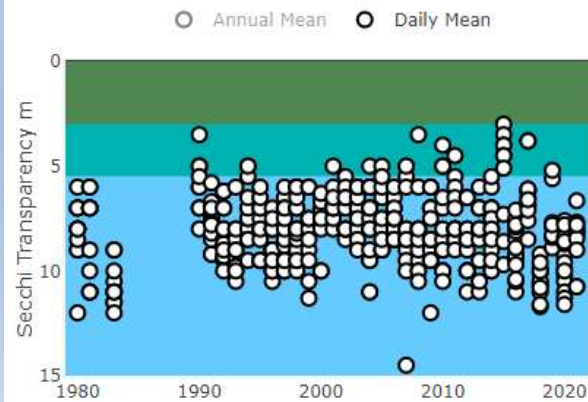
Summer Phosphorus

Trend: Stable (p-value=0.1228)



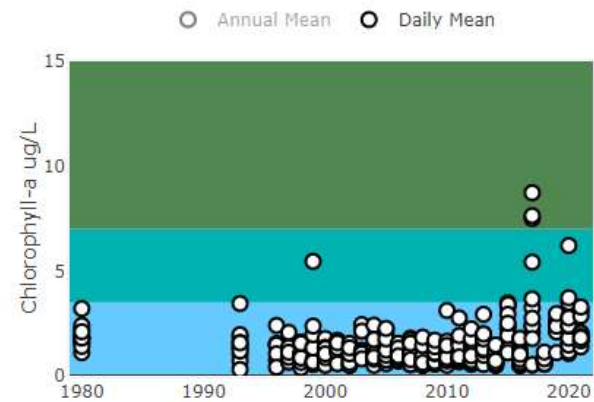
Summer Secchi

Trend: Stable (p-value=0.7014)

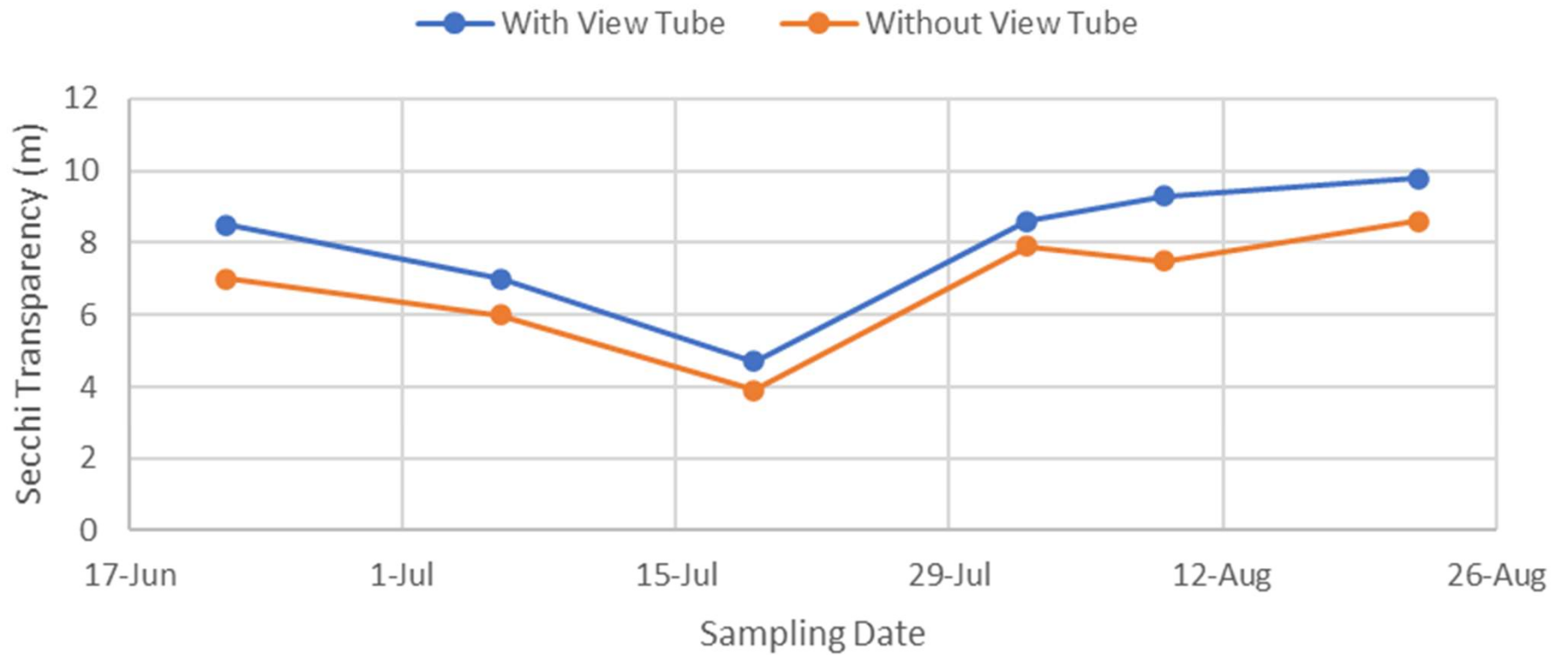


Summer Chlorophyll-a

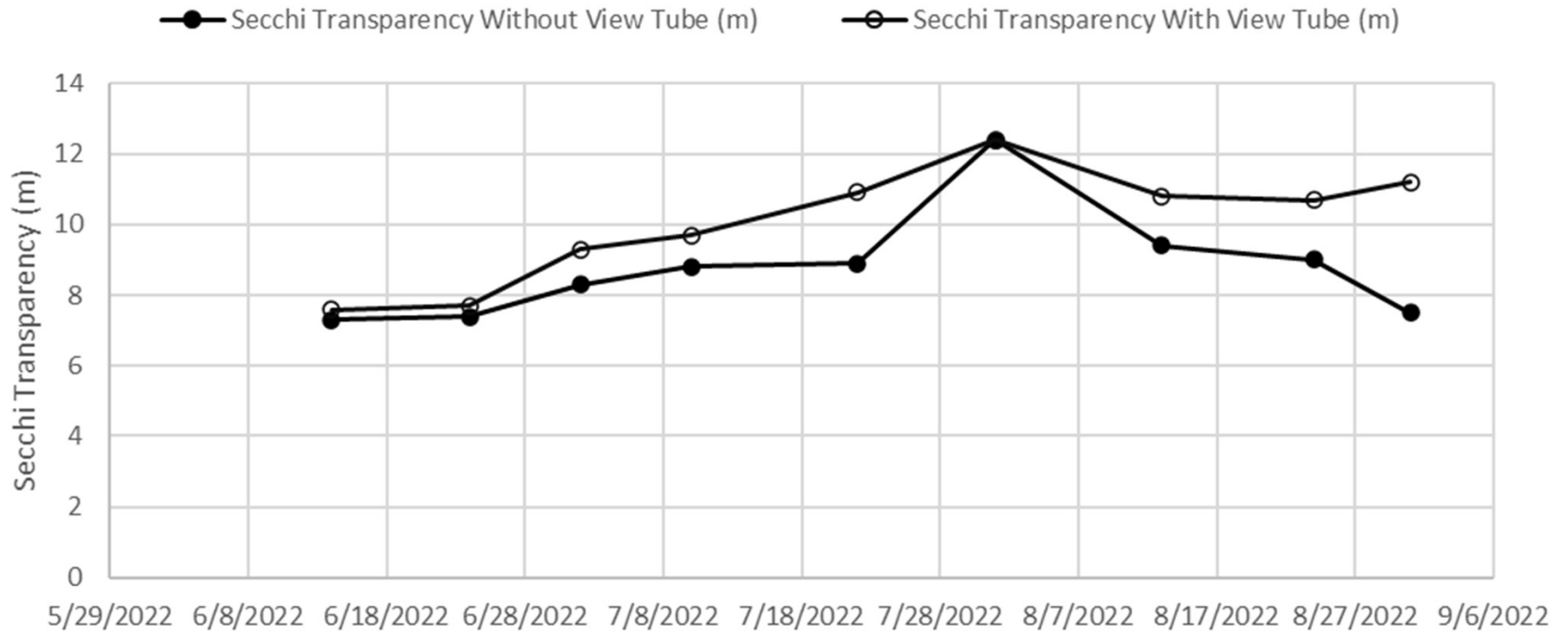
Trend: Stable (p-value=0.4405)



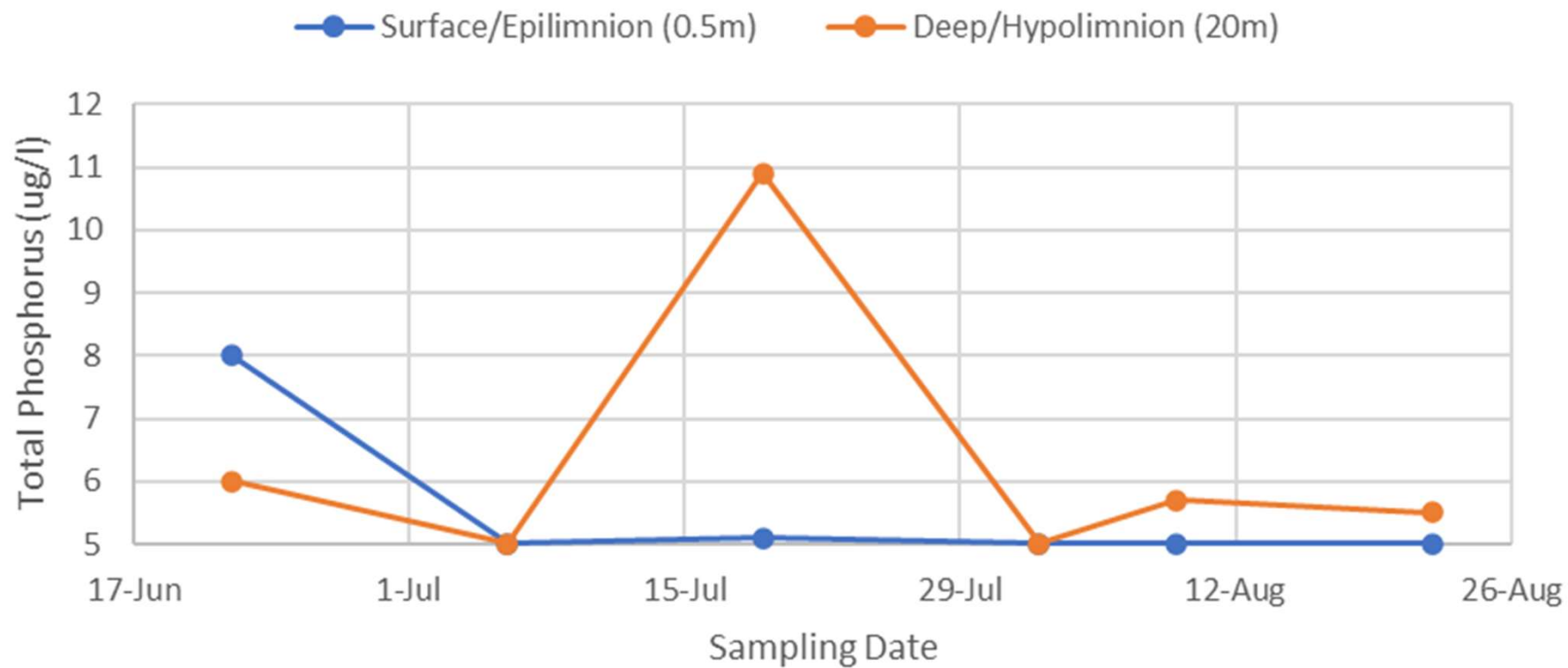
2023 Lake Willoughby Lay Monitoring Secchi Transparency



2022 Lake Willoughby Lay Monitoring Secchi Transparency Results

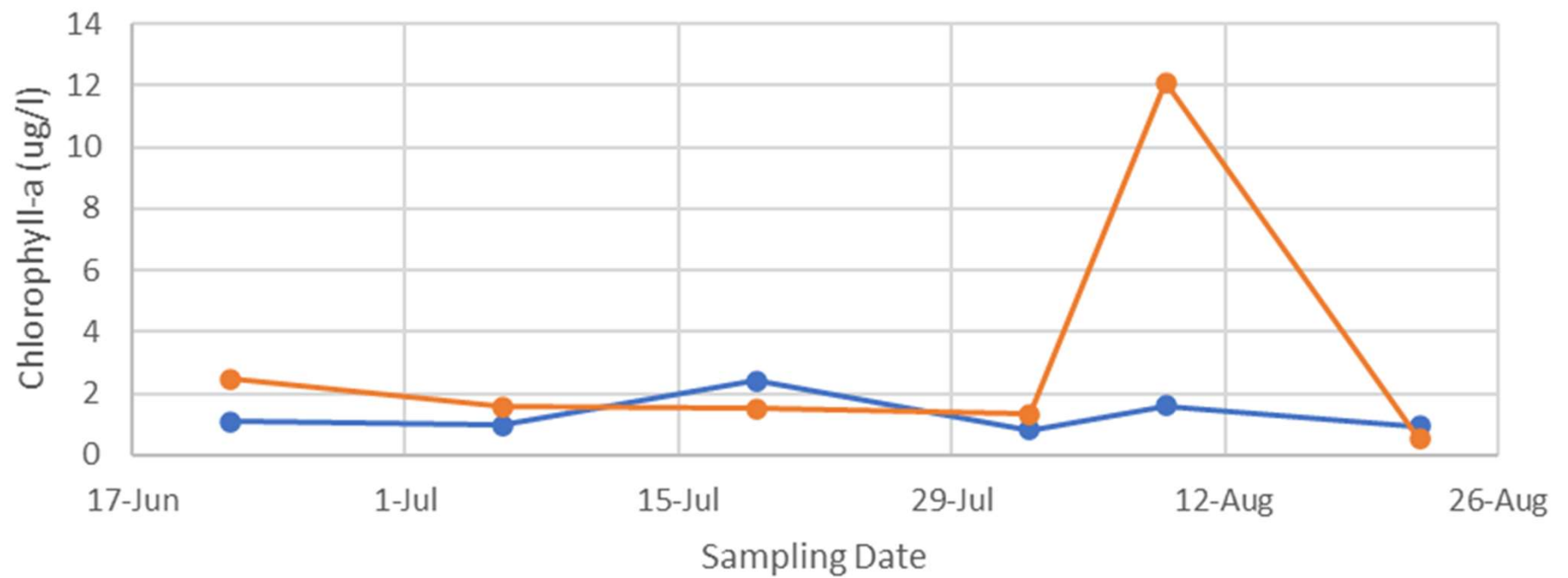


2023 Lake Willoughby Lay Monitoring Total Phosphorus



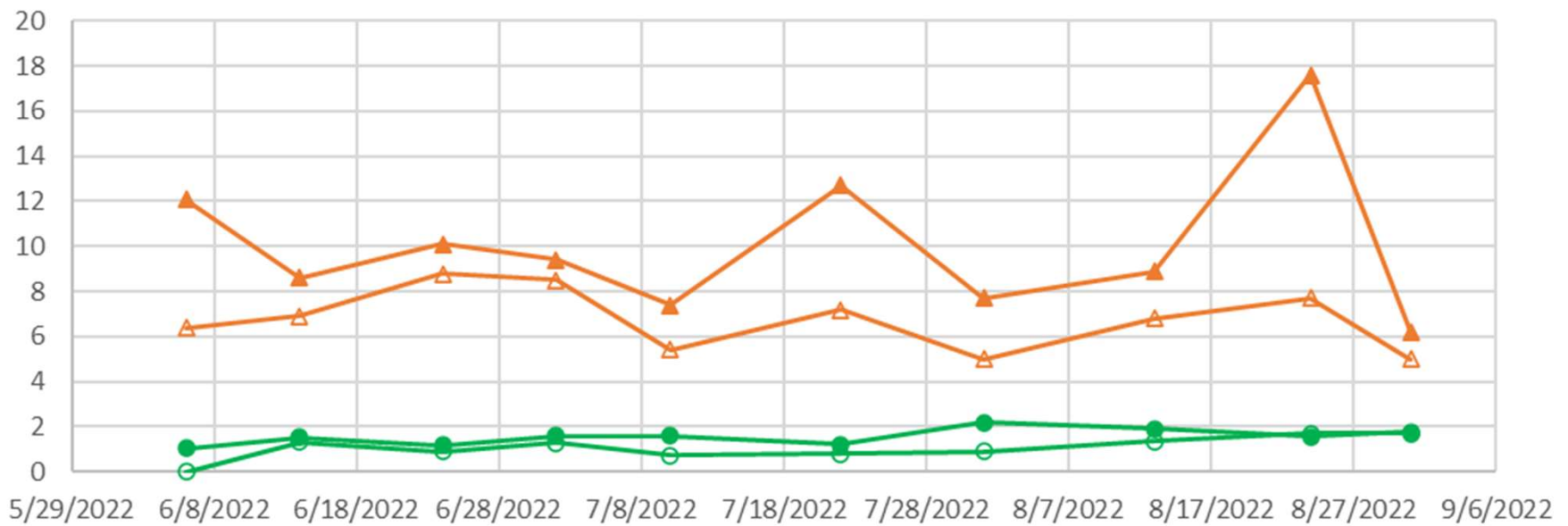
2023 Lake Willoughby Lay Monitoring Chlorophyll-a

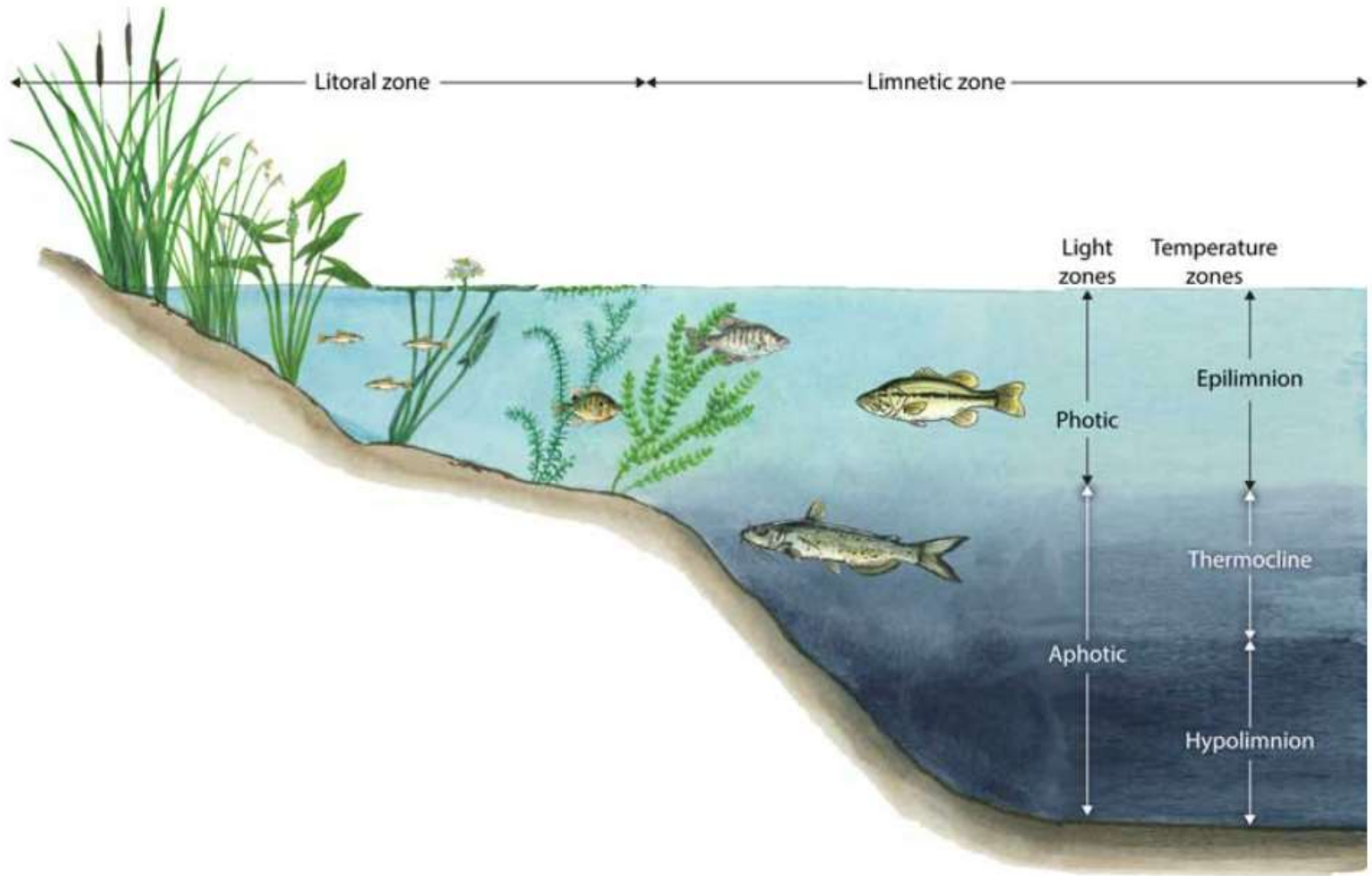
● Surface/Epilimnion (0.5m) ● Deep/Hypolimnion (20m)



2022 Lake Willoughby Lay Monitoring Total Phosphorus and Chlorophyll-a Results

—▲— Hose Total Phosphorus (ug/l) —△— Surface Total Phosphorus (ug/l)
—●— Hose Chlorophyll-a (ug/l) —○— Surface Chlorophyll (ug/L)



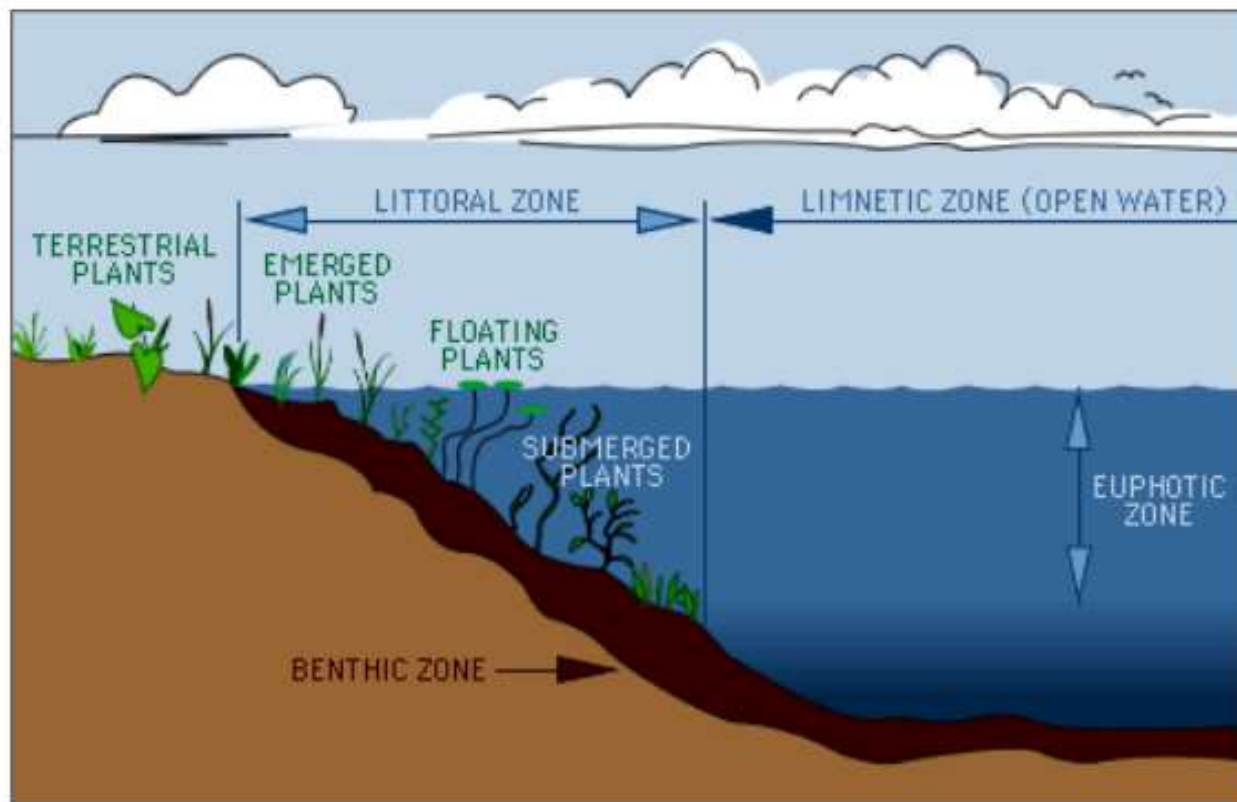


(Image courtesy of Kasco Marine)

<https://kascomarine.com/blog/pond-lake-zone-identification/>

Lake Zones

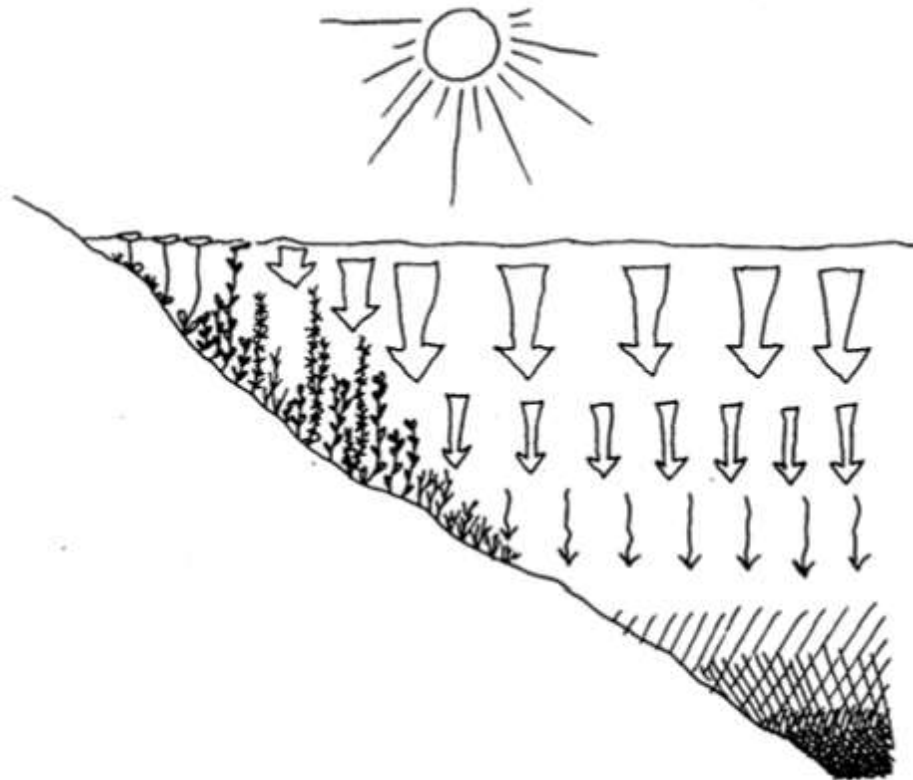
A typical lake has distinct zones of biological communities linked to the physical structure of the lake (Figure 10). The **littoral** zone is the near shore area where sunlight penetrates all the way to the sediment and allows aquatic plants (**macrophytes**) to grow. Light levels of about 1% or less of surface values usually define this depth. The 1% light level also defines the **euphotic zone** of the lake, which is the layer from the surface down to the depth where light levels become too low for **photosynthesizers**. In most lakes, the sunlit euphotic zone occurs within the **epilimnion**.



http://waterontheweb.org/under/lakeecology/10_biological_lakezones.html

4. *Light*

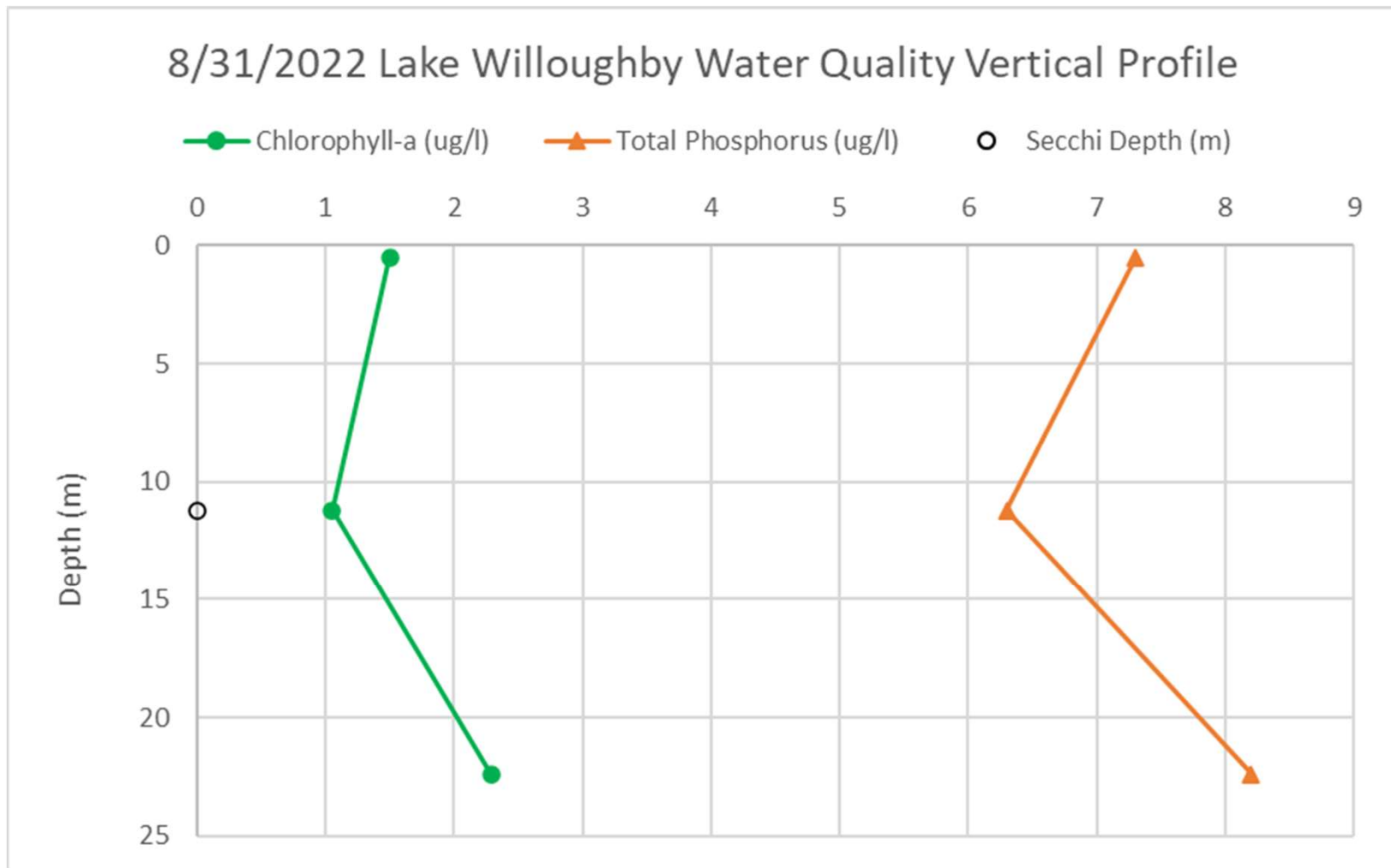
Plants need light to grow. Many lakes have deep water areas where rooted plants can't get enough light to survive. The maximum depth at which plants grow in a lake depends on the water clarity. In Vermont lakes, plants can generally be found growing out to water depths of **25 feet**.



From Lake Champlain Long-Term Monitoring Protocol:

During stratified conditions, two samples will be obtained, representing the epilimnion and hypolimnion, respectively.

<https://dec.vermont.gov/sites/dec/files/wsm/docs/20200605%20LTM%205yr%20QAPP-Workplan.pdf>



Sampling Date	Hose Sample Depth (m)	Hose Total Phosphorus (ug/l)	Surface Total Phosphorus (ug/l)	Hose Chlorophyll-a (ug/l)	Surface Chlorophyll (ug/L)	Secchi Transparency Without View Tube (m)	Secchi Transparency With View Tube (m)
6/6/2022		12.1	6.4	1.03	<0.50		
6/14/2022	15.2	8.6	6.9	1.53	1.32	7.3	7.6
6/24/2022	15.4	10.1	8.8	1.16	0.91	7.4	7.7
7/2/2022	18.6	9.4	8.5	1.61	1.29	8.3	9.3
7/10/2022	19.4	7.4	5.4	1.58	0.72	8.8	9.7
7/22/2022	21.8	12.7	7.2	1.22	0.81	8.9	10.9
8/1/2022	22.9	7.7	5	2.2	0.89	12.4	12.4
8/13/2022	21.6	8.9	6.8	1.9	1.36	9.4	10.8
8/24/2022	21.4	17.6	7.7	1.55	1.71	9	10.7
8/31/2022	22.4	6.2	5	1.77	1.7	7.5	11.2
Mean	19.9	10.1	6.8	1.56	1.19	8.8	10.0
A1 Criteria	Euphotic Zone	12	12	2.6	2.6	5	5

LAKE WILLOUGHBY

Annual Data (Station 1)

Year	Days Sampled	Secchi (m)	Secchi View Tube (m)	Chloro-a ($\mu\text{g/l}$)	Summer TP ($\mu\text{g/l}$)	Spring TP ($\mu\text{g/l}$)
1980	13	8.1		1.9		4.0
1981	11	8.4				4.0
1982						5.0
1983	11	10.7				4.0
1984						5.0
1985						6.0
1986						6.0
1987						6.0
1990	10	5.8				
1991	12	7.6				
1992	13	8.2				5.0
1993	12	8.9		1.5	7.5	
1994	12	7.1				
1995	12	7.8				
1996	15	8.9				
1997	16	8.1		1.1	8.5	4.0
1998	18	7.8		1.0	6.9	3.7
1999	10	8.4		1.6	6.5	
2000	10	7.7		1.0	6.3	

VT Standard*

* VT Water Quality Standards Nutrient Criteria for Class B2 Lakes > 20 acres.

Annual Data (Station 1)

Year	Days Sampled	Secchi (m)	Secchi View Tube (m)	Chloro-a ($\mu\text{g/l}$)	Summer TP ($\mu\text{g/l}$)	Spring TP ($\mu\text{g/l}$)
2001	9	6.8		1.2	8.6	
2002	11	7.3		0.9	6.3	
2003	10	7.3		1.3	9.5	5.0
2004	15	7.8		1.1	8.3	5.7
2005	12	7.5		1.4	10.1	
2006	10	7.4		1.1	11.2	6.8
2007	13	8.1		1.0	9.7	9.1
2008	11	8.3		0.9	18.2	6.4
2009	13	8.2		1.0	11.6	6.5
2010	14	8.0		1.2	15.8	5.1
2011	13	7.3		1.3	18.5	
2012	13	8.8		1.1	12.1	5.3
2013	11	8.2		1.5	15.6	
2014	15	7.9		0.9	15.6	7.9
2015	10	5.4		2.5	14.0	
2016	15	8.9		1.0	8.3	
2017	13	6.3		3.7	9.6	6.3
2018	12	10.5		0.8	9.1	8.0
2019	9	7.5		2.3	7.6	7.3
2020	14	9.6		2.5	7.7	
2021	10		8.5	2.2	8.4	

VT Standard*

* VT Water Quality Standards Nutrient Criteria for Class B2 Lakes > 20 acres.

LaRosa Partnership Program Tributary Sampling Overview

- Tributaries first sampled in 2021 ~biweekly (8X) from April/May to July/August + ~2 storm events
- 515882-Tr15 Roaring Brk: 30% algae cover at inlet 2 and since biology never lies, worth monitoring this tributary
- 523160-Tr17 Beavers: Includes runoff from farmstead and fields, high TP values in past
- 523161-Tr2Stoney Brk: Includes runoff from farmstead and fields, larger watershed, large delta formed at mouth of trib
- 523162-Tr4 Church: Very high CL readings, interesting for FPR as near site where new parking area and restoration projects are going in
- 523163-Tr5Mill Brk: Upsteam Orleans NRCDC Sampling to see impact of farm restoration efforts, could be useful to get a downstream value
- 523164-Tr9SE Beach: Very high TP value, needs follow up



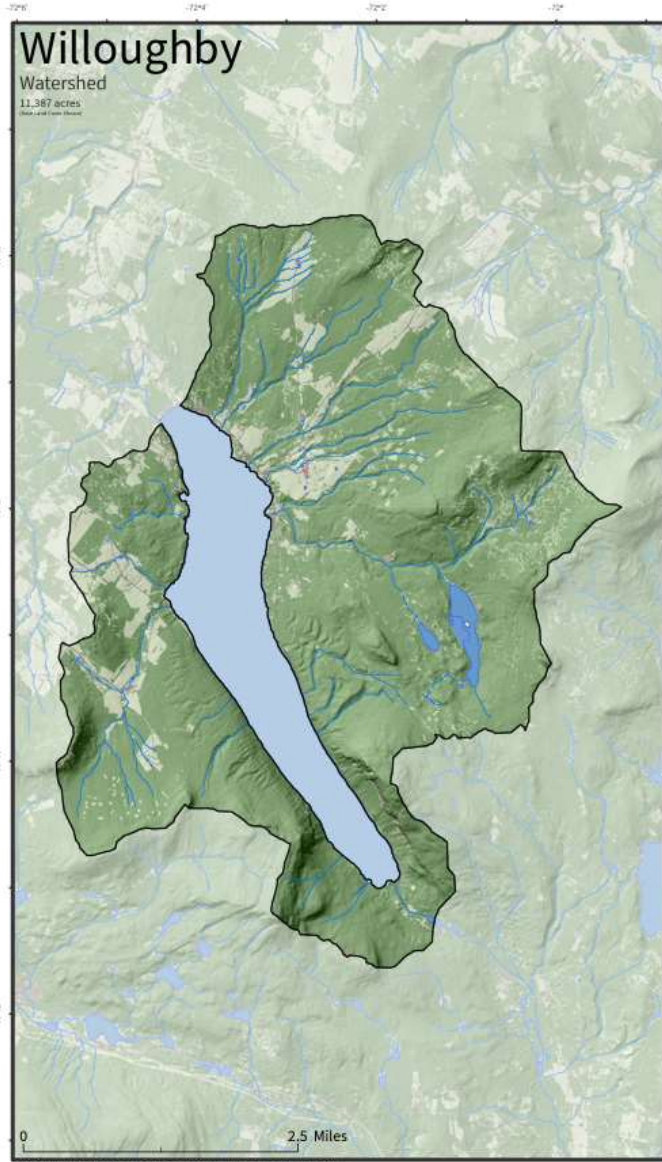
LPP Sample Parameters Overview: Total Phosphorus & Chloride

Total Phosphorus

- Sources
 - Developed land runoff, roads, driveways
 - Fertilizers – lawns and agriculture
- Impacts
 - Feeds plants, algae and cyanobacteria
 - Aesthetics, Recreation, Aquatic Life Uses
- Vermont Water Quality Standards Nutrient Criteria for Aquatic Biota Use (+ Biological Criteria)
 - Not to be exceeded at low median monthly flow (baseflow) during June through October
 - 12 ug/L for small high gradient streams (SHG)
 - 15 ug/L for medium high gradient streams (MHG)
 - 27 ug/L for warm-water medium gradient streams and rivers (WWMG)

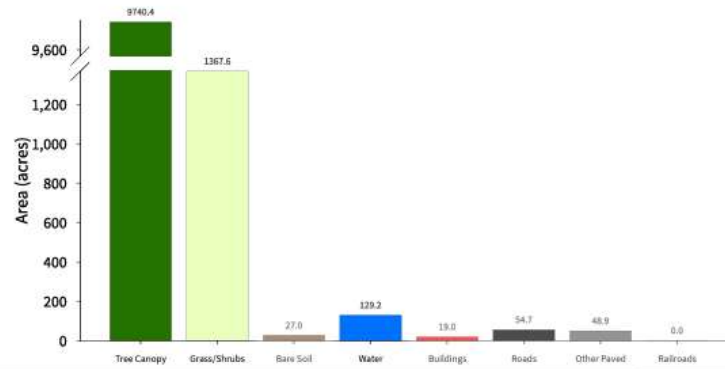
Total Chloride

- Sources
 - Road salt
 - Wastewater, water softeners
- Impacts
 - Affects chemical processes of biological organisms
 - Aquatic Life Use
- Vermont Water Quality Standards Chloride Criteria for Aquatic Biota Use
 - 860 mg/L maximum (acute)
 - 230 mg/L average (chronic)
 - Studies show chloride can impact organisms at lower concentrations



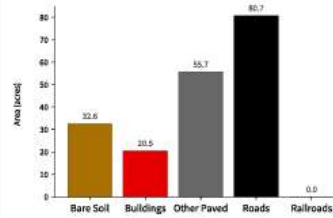
High-Resolution Land Cover Summary

Base Land Cover (Top-Down*)

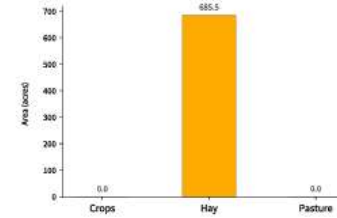


Supplemental Land Cover

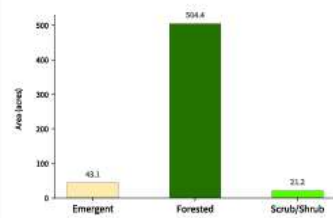
Impervious Surfaces (189.55 acres - 1.7% of total) (Bottom-Up**)



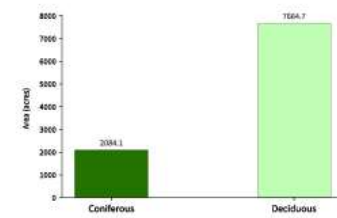
Agriculture (685.55 acres - 6% of total)



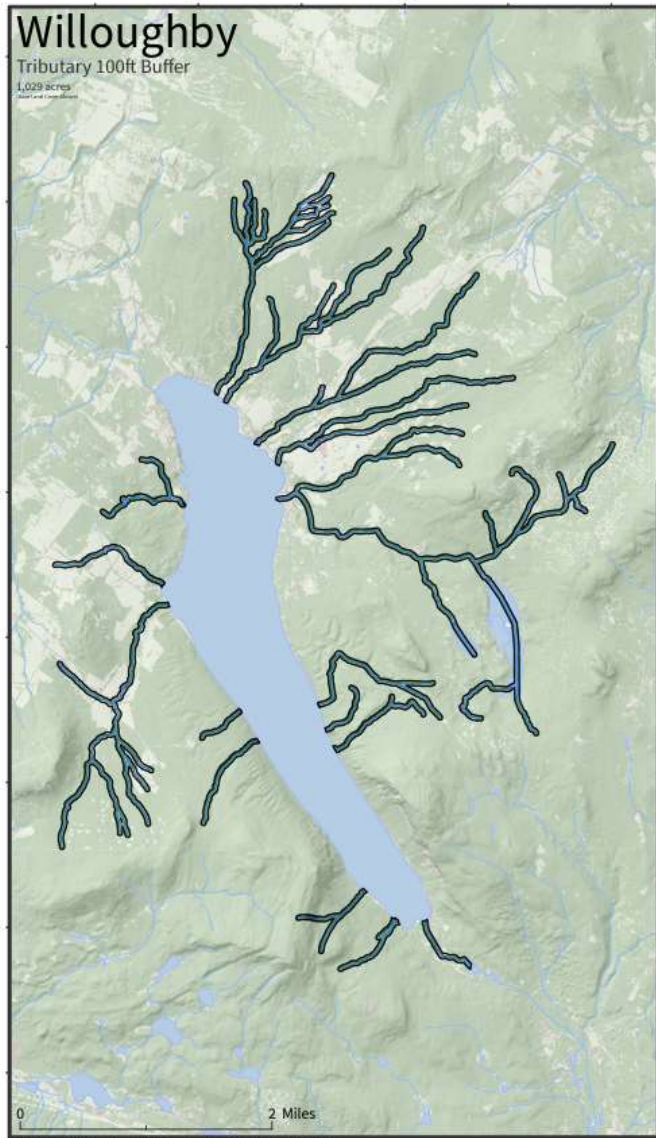
Wetlands (568.73 acres - 5% of total)



Tree Canopy (9,748.76 acres - 85.6% of total)

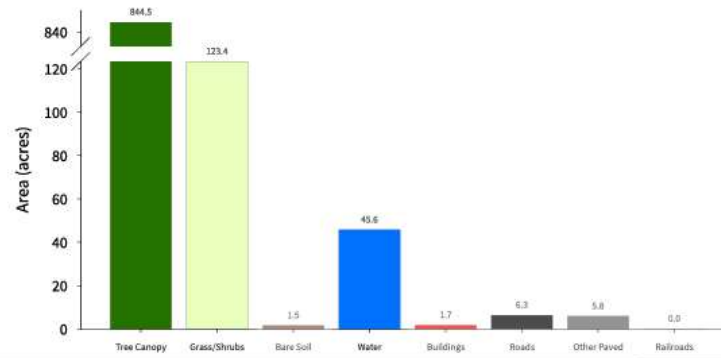


*Top-Down: A land cover classification based on satellite imagery. Land cover is reported as the observed land cover class.
 **Bottom-Up: A land cover classification based on satellite imagery. Land cover is reported as the observed land cover class. This approach results in improved mapping of features not typically observed by satellite imagery.



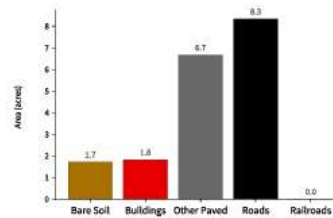
High-Resolution Land Cover Summary

Base Land Cover (Top-Down*)

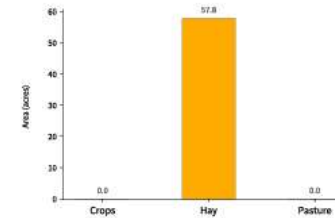


Supplemental Land Cover

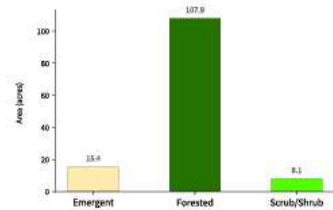
Impervious Surfaces (18.53 acres - 1.8 % of total) (Bottom-Up**)



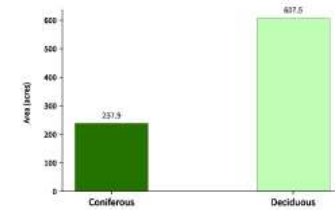
Agriculture (57.81 acres - 5.6 % of total)



Wetlands (131.49 acres - 12.8 % of total)

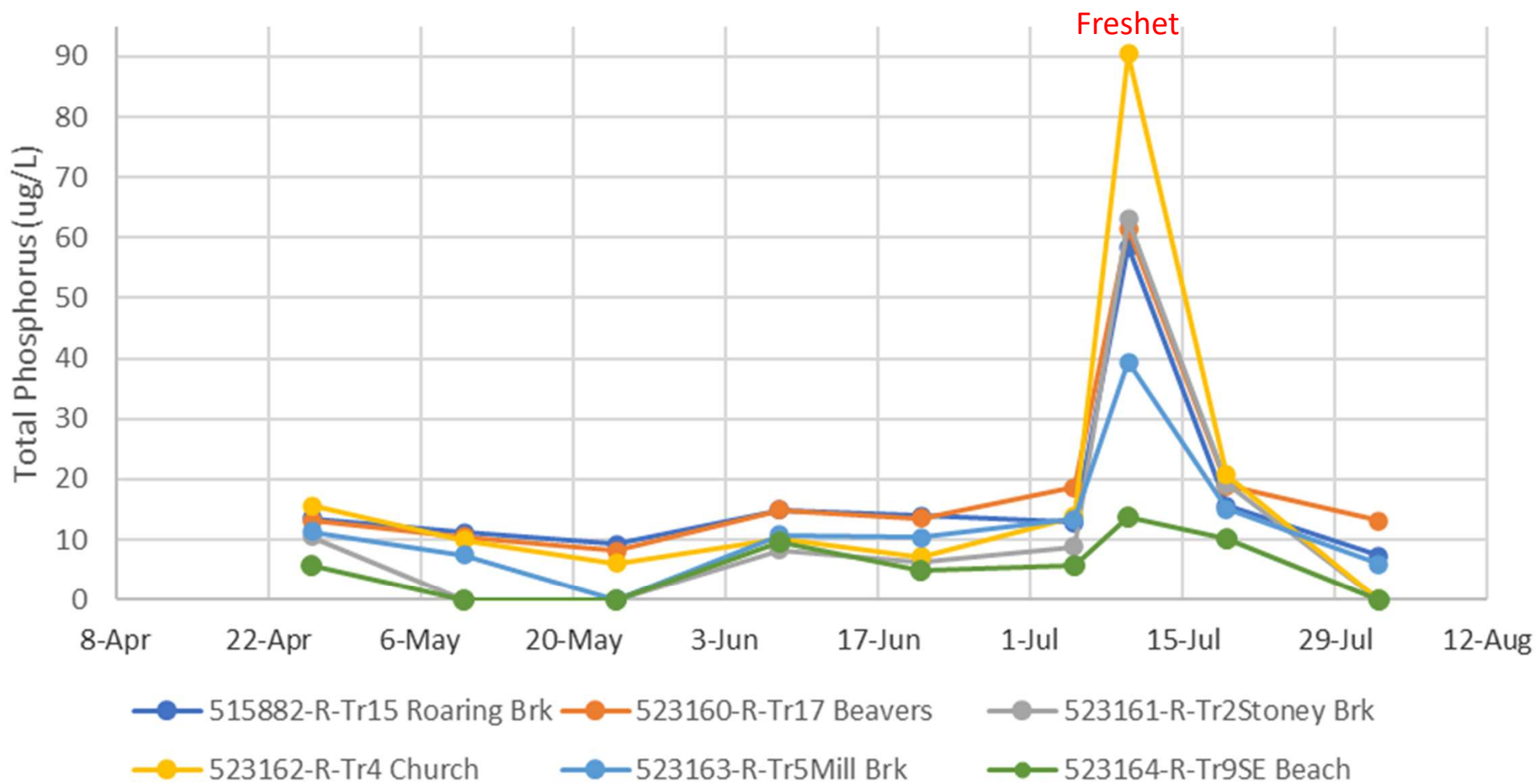


Tree Canopy (845.35 acres - 82.2 % of total)

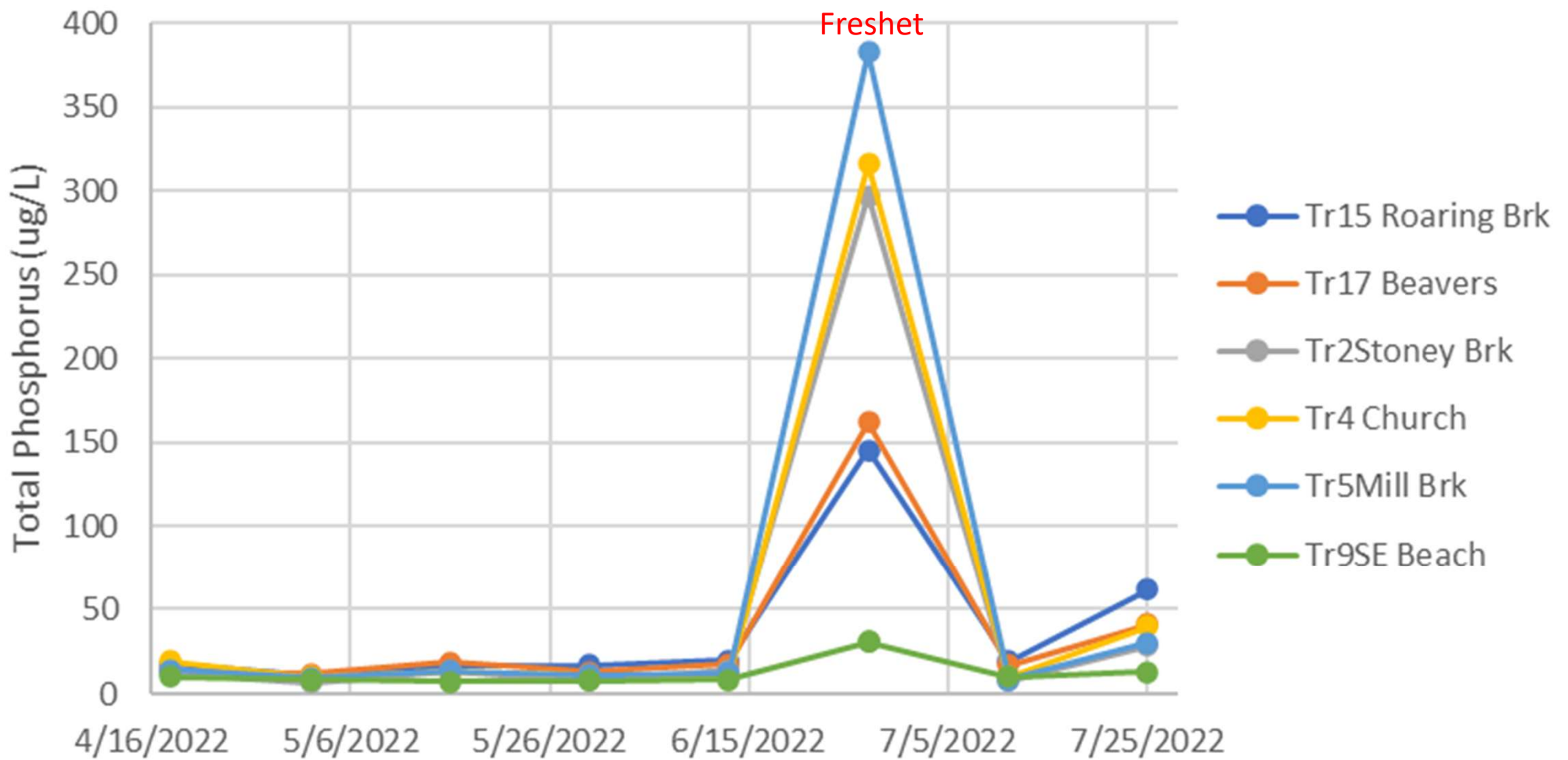


*Top-Down: A hierarchical land cover mapping approach. Land cover is mapped as the uppermost land cover class.
 **Bottom-Up: An iterative land cover mapping approach. Land cover is mapped as the uppermost land cover class. The approach results in a final mapping of features and dependent features by other features.
 Data: USGS 30m High-Resolution Land Cover 2019 Release (10m resolution)

2023 Lake Willoughby Tributary Total Phosphorus Monitoring



2022 Willoughby Tributary TP Monitoring Results

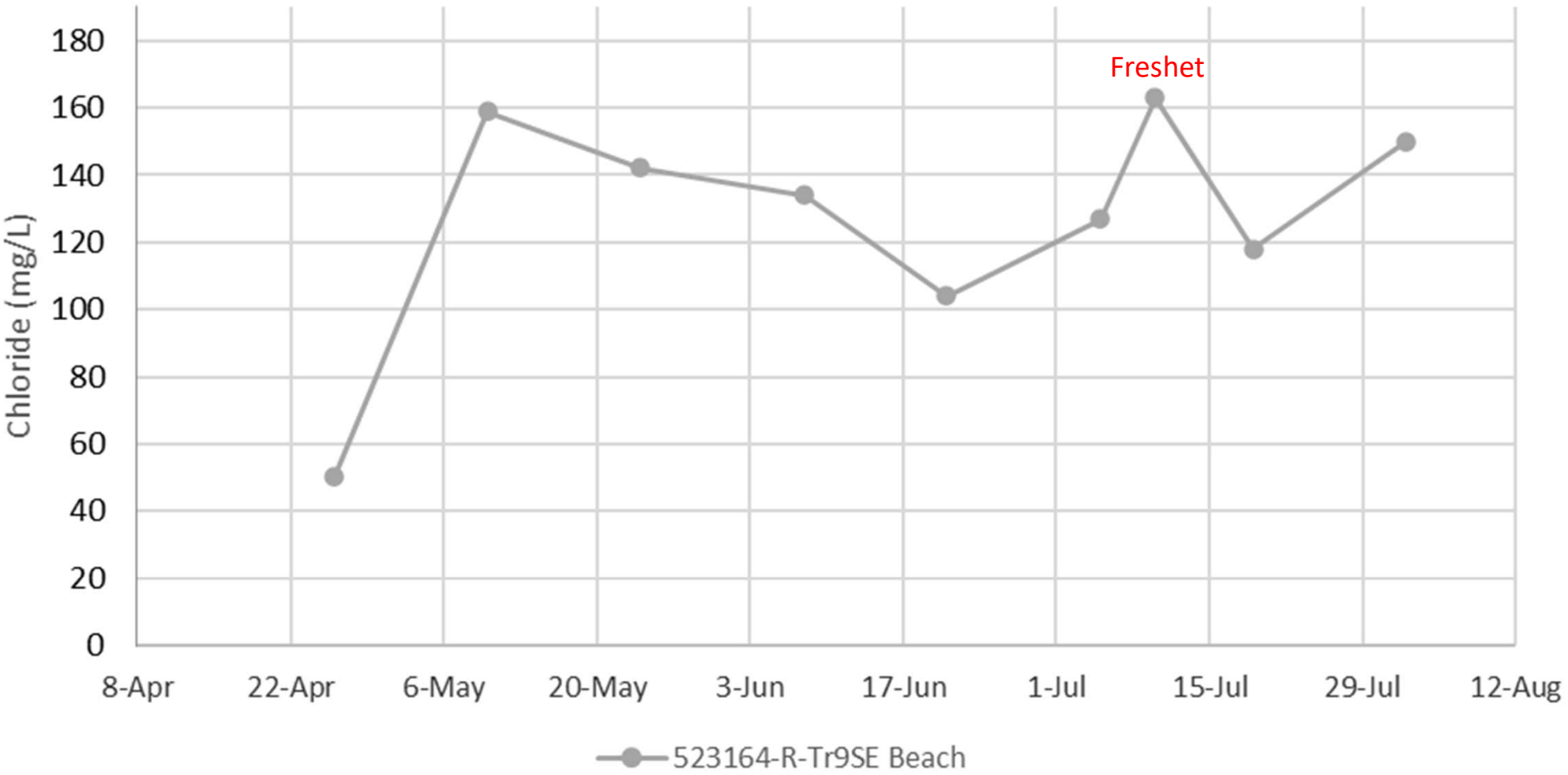


2021-2022 Comparison of Tributary TP Results

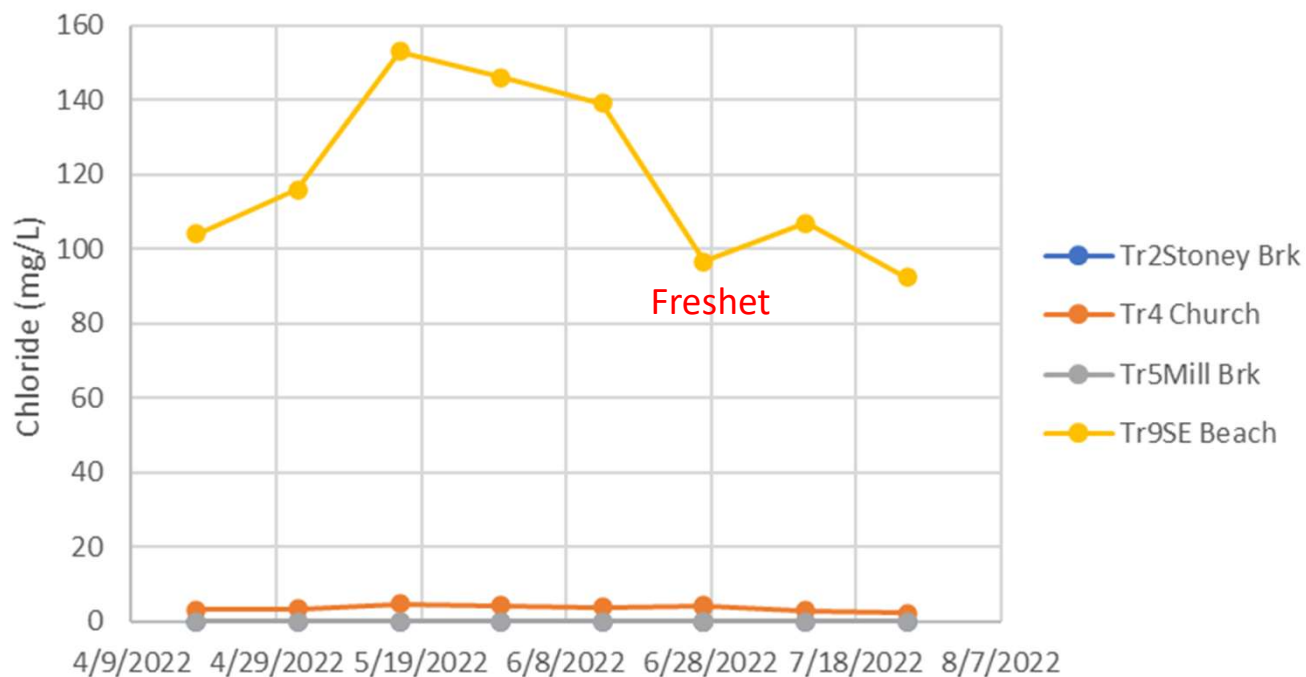
Tributary	Minimum TP (ug/L)		Average TP (ug/L)		Maximum TP (ug/L)	
	2022	2021	2022	2021	2022	2021
Tr15 Roaring Brk	10.7	11.6	38.4	48	145	255
Tr17 Beavers	11.5	11.6	36.7	26.7	162	84.6
Tr2Stoney Brk	6.5	7.2	48.4	44.7	297	248
Tr4 Church	9.9	6.1	53.7	42	316	237
Tr5Mill Brk	8.5	7.4	60.3	37.5	383	180
Tr9SE Beach	7.1	6.1	12	9.5	30.8	16.2

Date	Tr15 Roaring Brk	Tr17 Beavers	Tr2Stoney Brk	Tr4 Church	Tr5Mill Brk	Tr9SE Beach
21-22 Ave Base flow	19.6	17.8	11.9	13.0	11.7	8.9
21-22 Ave freshet	127.7	77.6	158.8	167.3	159.1	16.2
21-22 Ave overall	43.7	31.1	46.4	47.3	46.4	10.6

2023 Lake Willoughby Tributary Chloride Monitoring

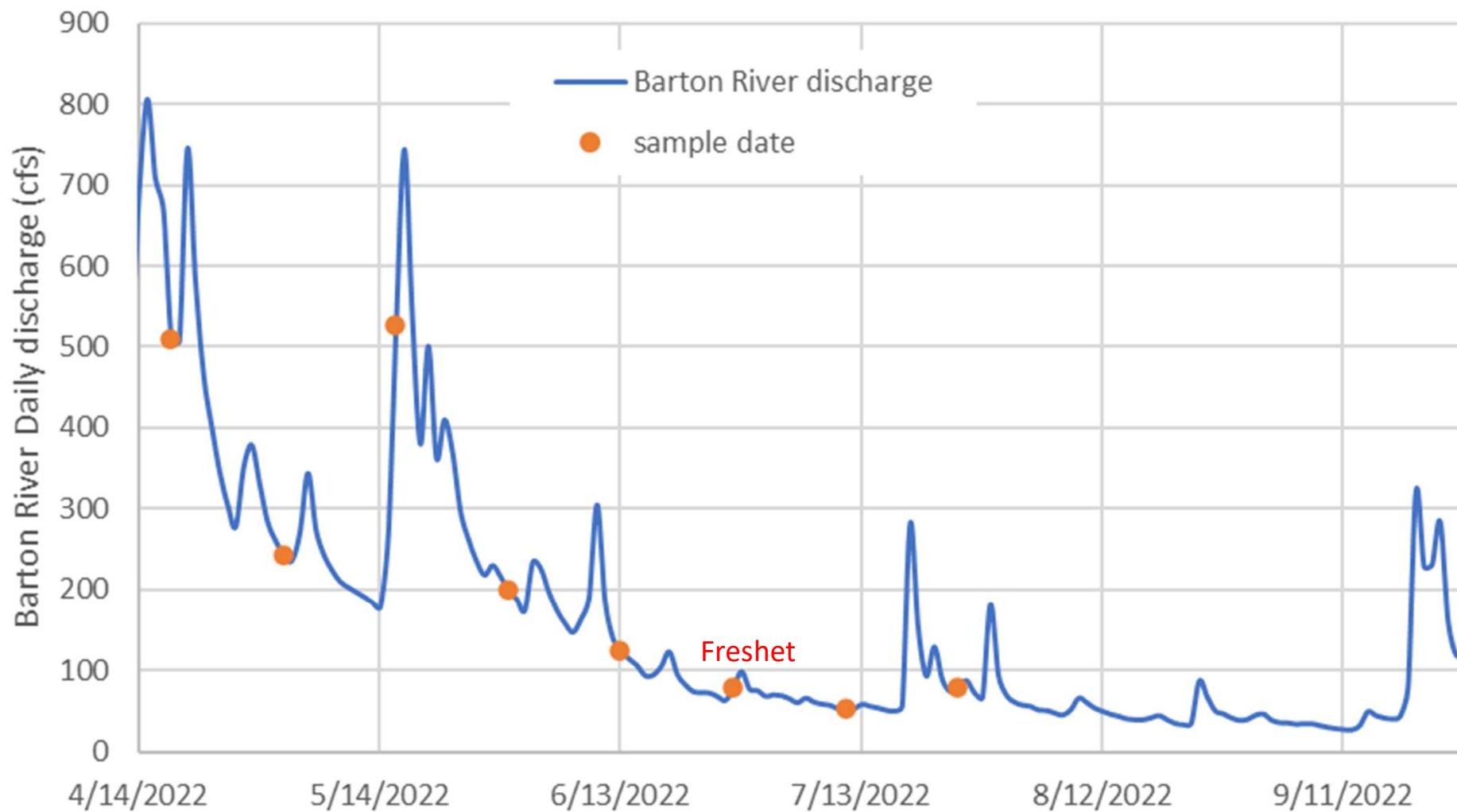


2022 Lake Willoughby Tributary Chloride Monitoring Results



Tributary	Minimum Chloride (mg/L)		Average Chloride (mg/L)		Maximum Chloride (mg/L)	
	2022	2021	2022	2021	2022	2021
Tr15 Roaring Brk	N/A	N/A	N/A	N/A	N/A	N/A
Tr17 Beavers	N/A	N/A	N/A	N/A	N/A	N/A
Tr2Stoney Brk	<2.0	<2.0	<2.0		<2.0	2.0
Tr4 Church	2.2	2.0	3.7	3.4	4.8	4.4
Tr5Mill Brk	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Tr9SE Beach	92.4	42.4	119.3	78.2	153.0	101.0

USGS Barton River Flow With Sample Dates



2023 Monitoring Summary & 2024 Next Steps



- Lay Monitoring Program (LMP)
 - 2023 Summary: Lake in great condition overall except after July 10th floods led to a dip in clarity with a hypolimnetic spike in TP and delayed spike in chlorophyll-a.
 - 2024 Next Steps: LMP volunteer continues collecting biweekly epilimnetic (0.5 m) and hypolimnetic (20 m) samples. Caffeine testing will also continue at a lower lab reporting limit (≤ 0.1 ug/L). LMP staff collects duplicate samples, vertical profile data, and additional metalimnetic (~10 m) sample during annual visit.
- LaRosa Partnership Program (LPP)
 - 2023 Summary: High TP during Freshet (July 10th floods) at all sites except 523164-Tr9SE Beach, where there is consistent high chloride
 - 2024 Next Steps: LPP volunteer continues collecting biweekly samples June through August (align with LMP)