

Visualizing Internal Phosphorus Release from Lake Sediments Using Volunteer Collected Data

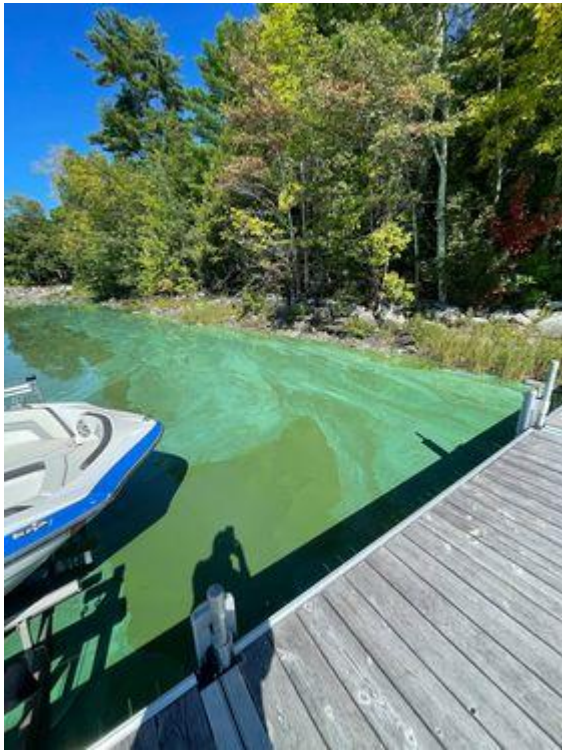


Photo: Maine Lakes/LightHawk

Overview

1. Internal phosphorus loading in lakes
2. Examples of successful volunteer monitoring efforts
3. Methods & types of data needed for the analysis
4. Interpreting P mass graphs from different lakes
5. Use of P mass for assessing changes in internal loading over time

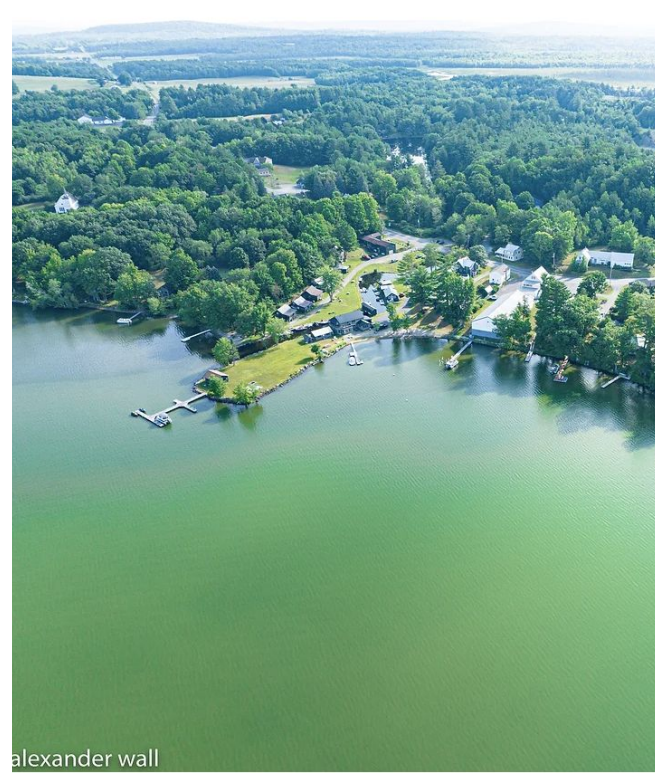




Lake Winnecook, Unity



Georges Pond, Franklin



North Pond, Smithfield



Seabasticook Lake, Newport

What is Causing Algae Blooms

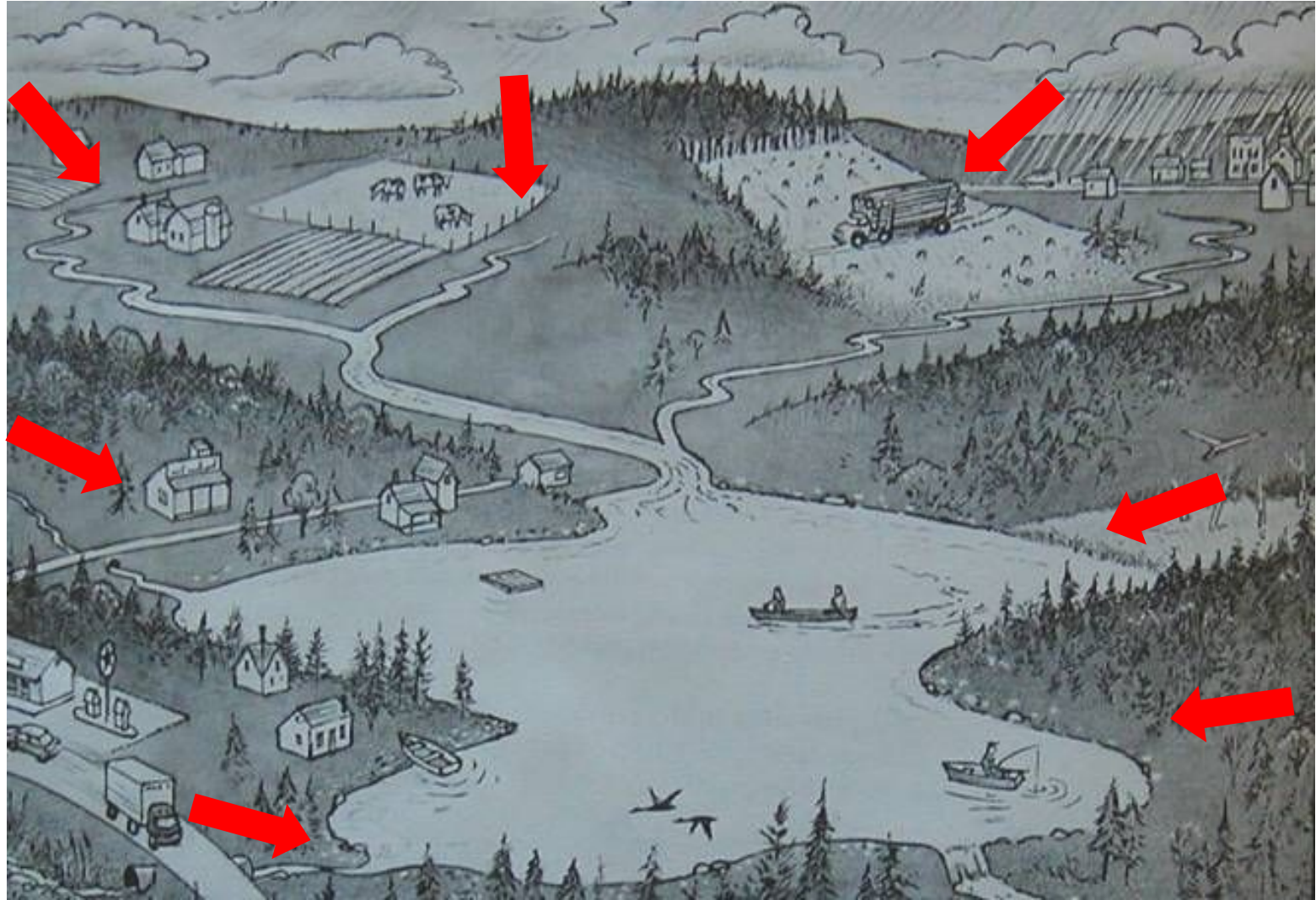


Photo: FOLW

EXCESS PHOSPHORUS (P)

- ❖ Phosphorus (P) is a nutrient – feeds algae
- ❖ The “limiting nutrient” in freshwater lakes
- ❖ Measured in very small amounts (parts per billion)

Watershed Runoff Carries P to Lakes



Algae Blooms

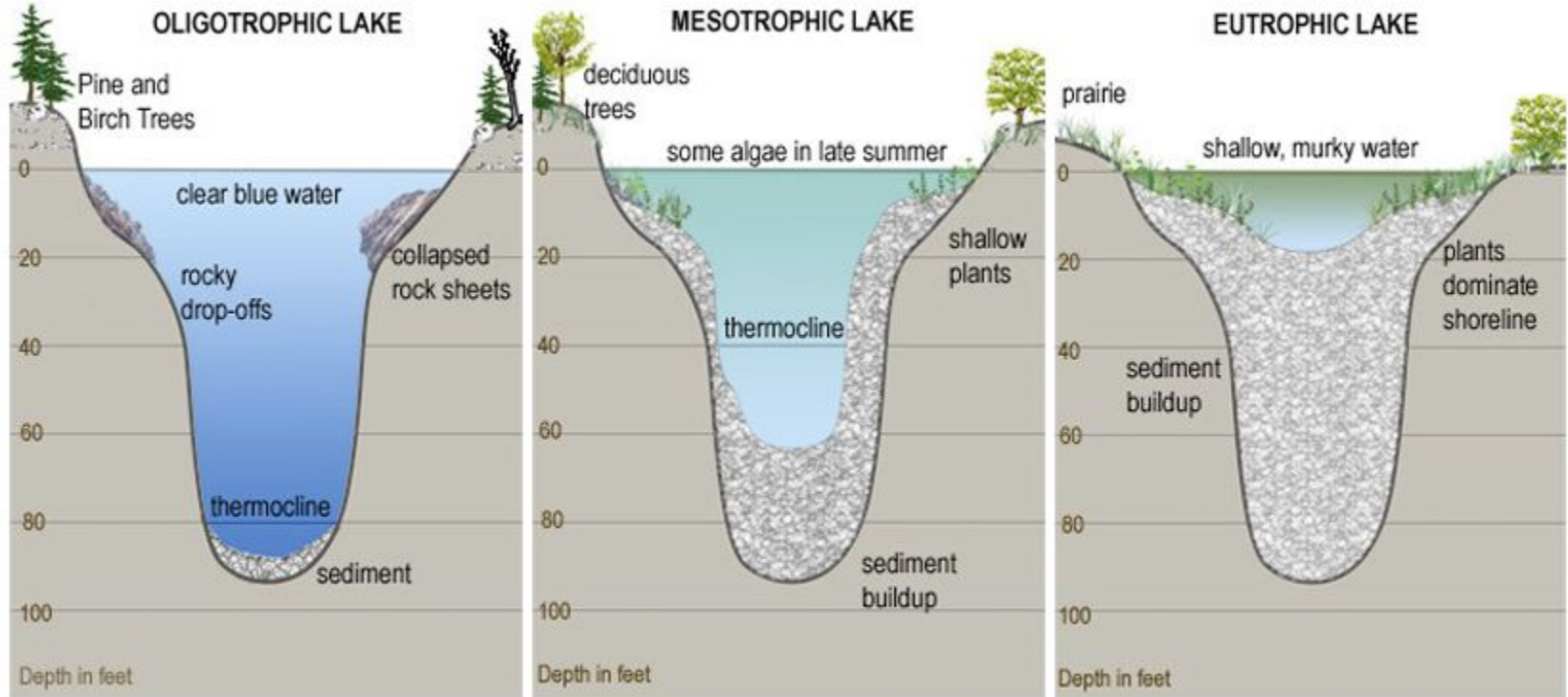
- Loss of recreational and aesthetic value
- Threat to the drinking water supply
- Loss of property value
- Possibility of toxic algal bloom
 - Cyanotoxins are toxins produced by blue-green algae
 - Algae blooms do not always produce toxins
 - 2014 study of 7 Maine lakes showed highest counts of toxins in downwind scum



More Info at the Maine DEP Website:

<https://www.maine.gov/dep/water/lakes/algalbloom.html>

Trophic State

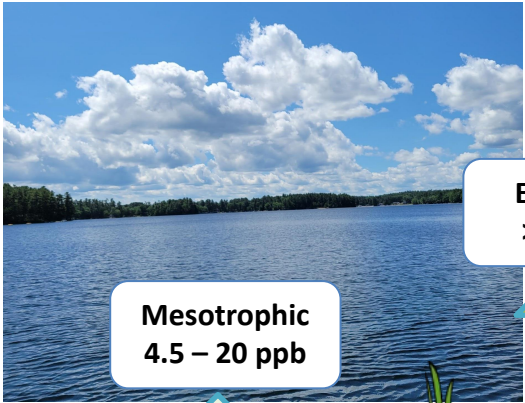


Images from: <http://www.rmbel.info/reports/Static/trophicstates.aspx>

Lake Productivity & Trophic State



< 4.5 ppb



Mesotrophic
4.5 – 20 ppb

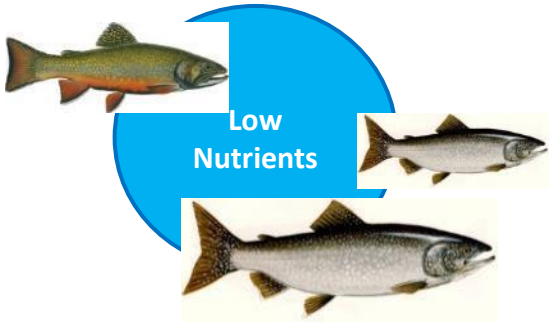


Eutrophic
> 20 ppb

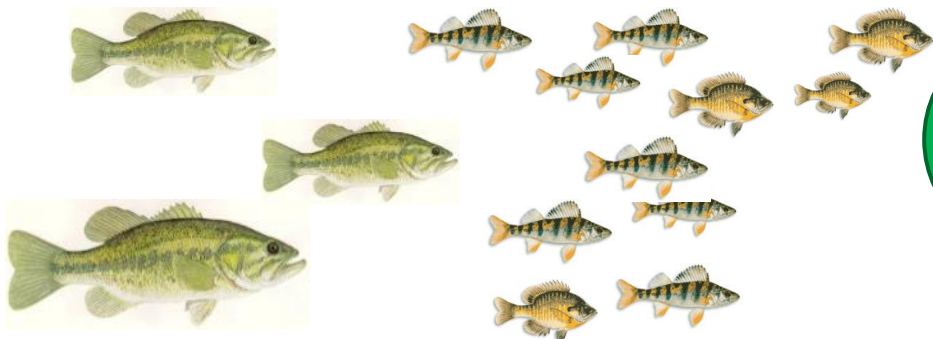


Oligotrophic

Eutrophic

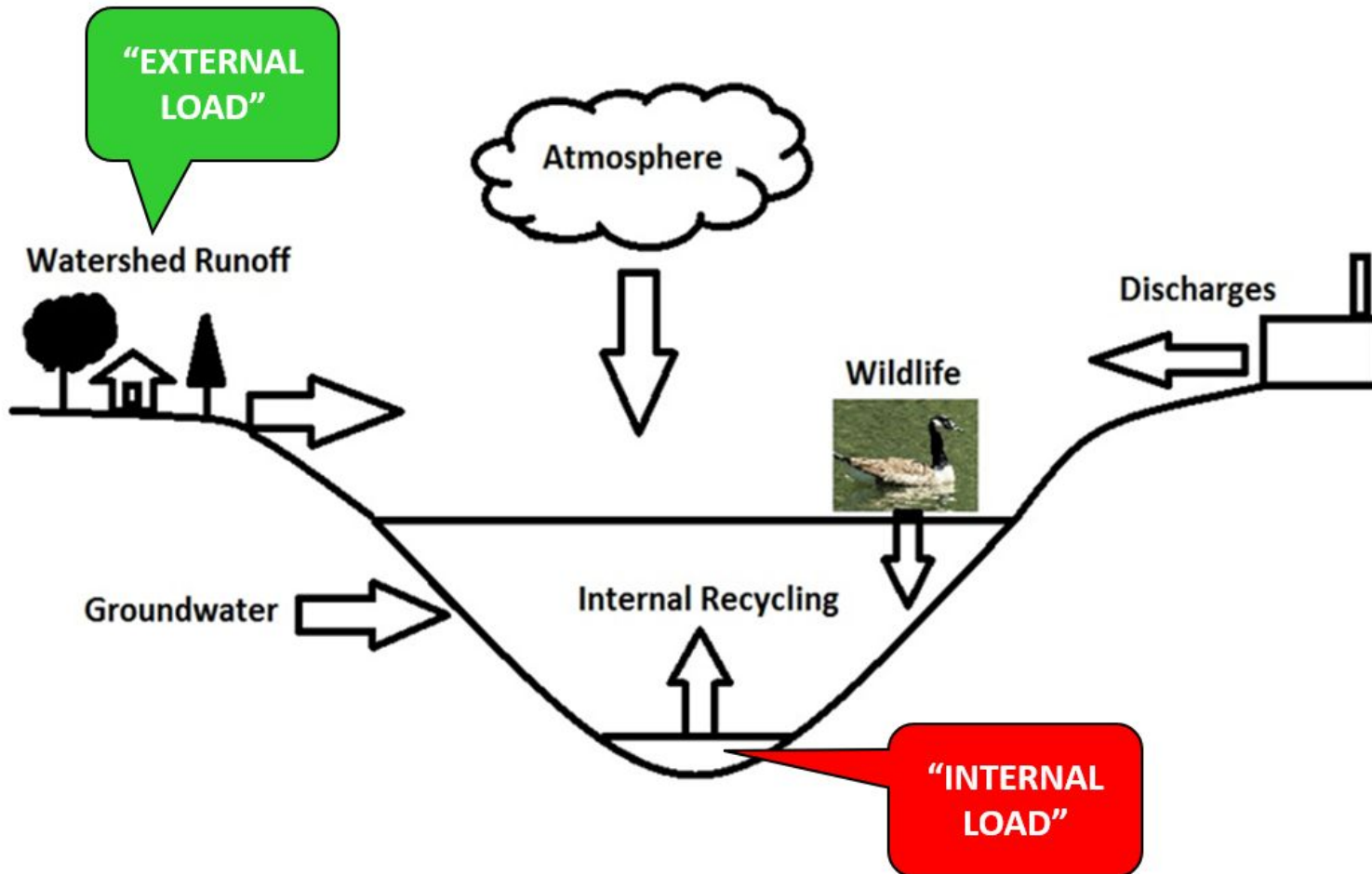


Low
Nutrients



High
Nutrients

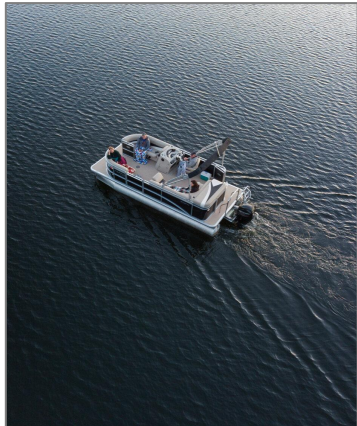
Sources of P



Tools for Lake Restoration



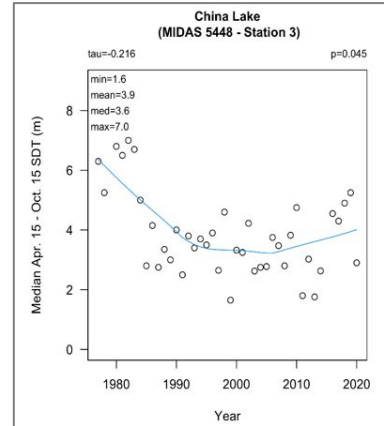
Watershed Survey



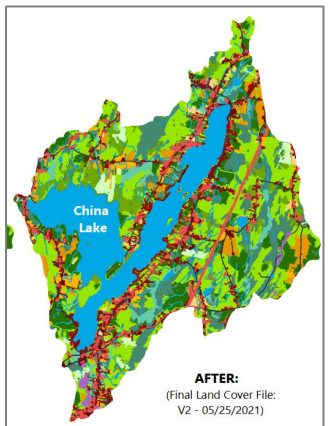
Water Quality Monitoring



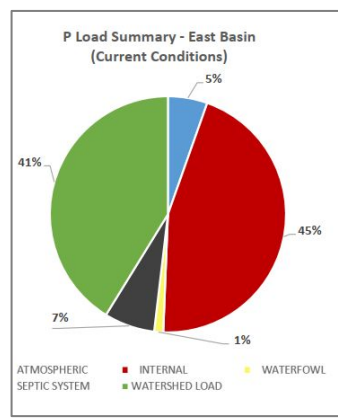
Sediment Sampling & Analysis



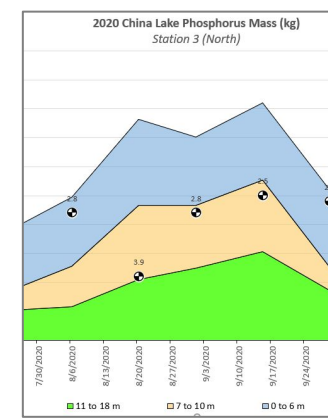
Water Quality Analysis



Land-Cover Update



Watershed Modeling



Internal Loading Analysis

China Lake WBMP (2022 - 2031)	
Category	Cost
A. Internal P Load	\$ 1,445,465
B. External P Load	\$ 1,175,000
C. New Sources of NPS	\$ 55,500
D. Education/Outreach	\$ 67,350
E. Local Capacity	\$ 169,000
F. Monitoring/Assessment	\$ 258,400
Total	\$ 3,170,715

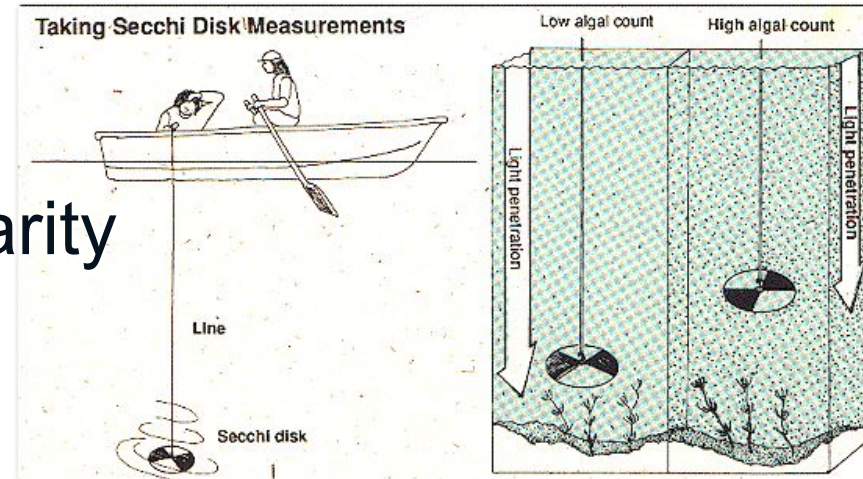
Watershed Management Plan

How Do We Measure Water Quality?



Secchi Disc

Measures Water Clarity



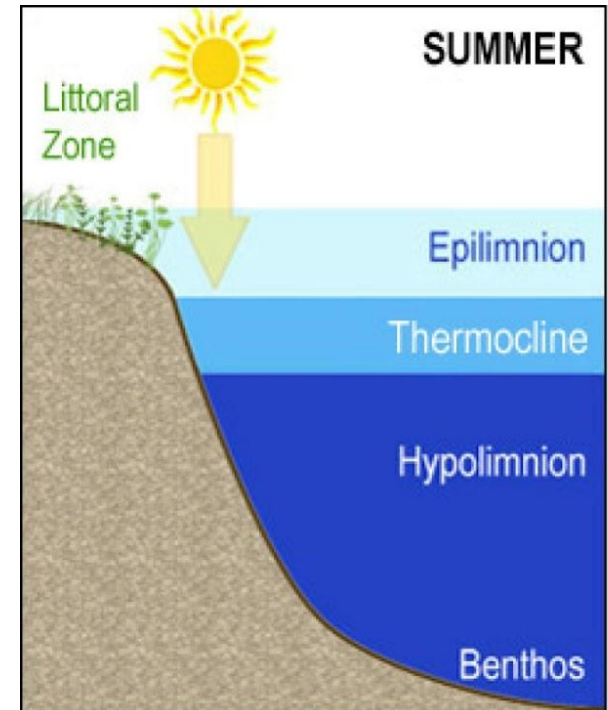
Water Column Readings

Dissolved Oxygen & Temperature

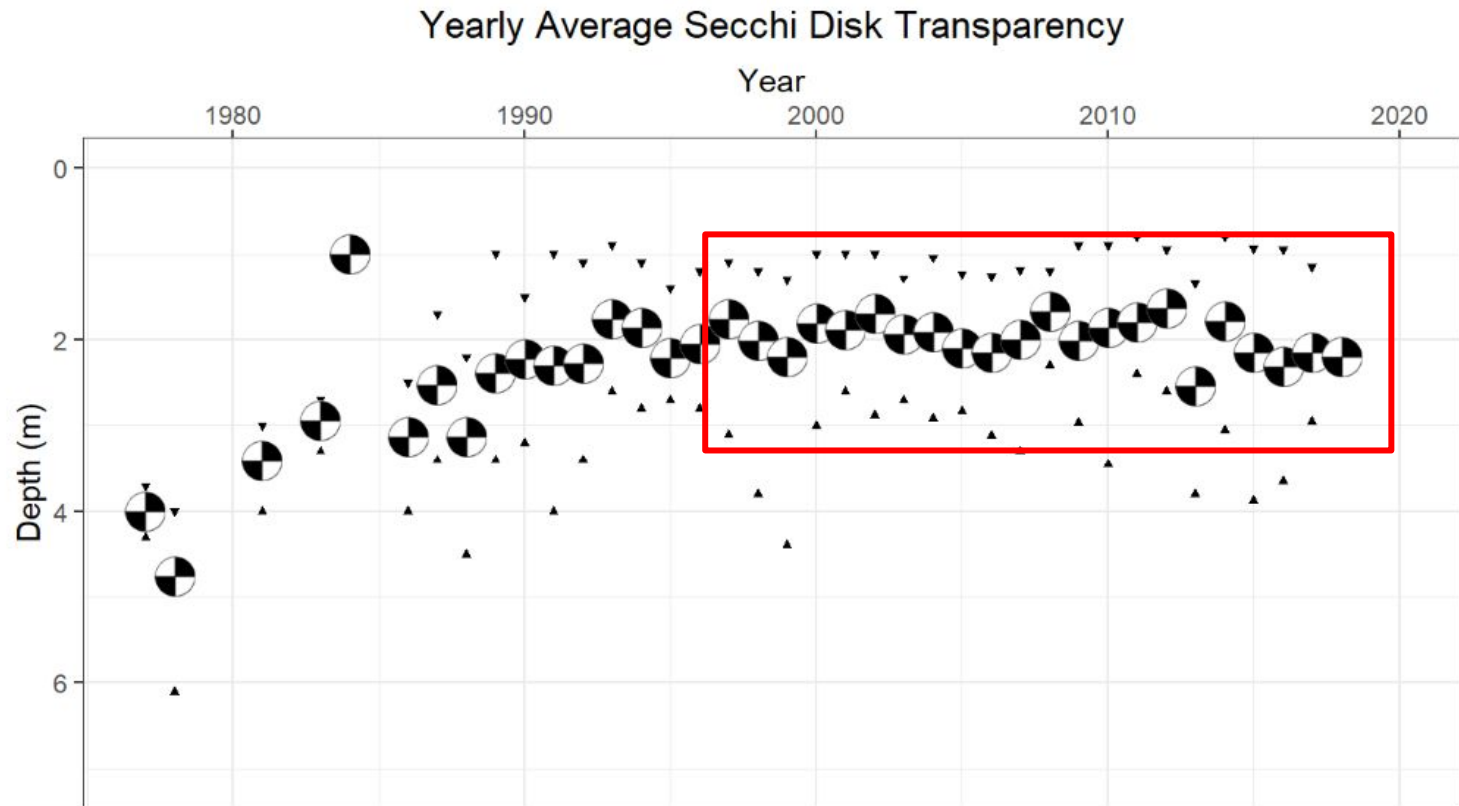


Water Samples

Total Phosphorus & Chlorophyll-a



Water Clarity



Unity Pond 1977 – 2019 (0.8 m – 6.1 m)

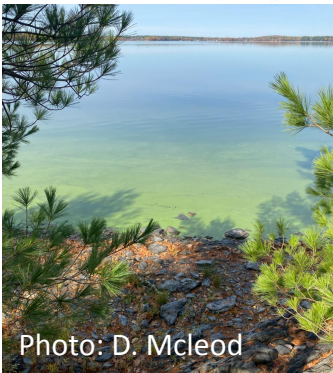


Photo: D. Mcleod

Water Clarity

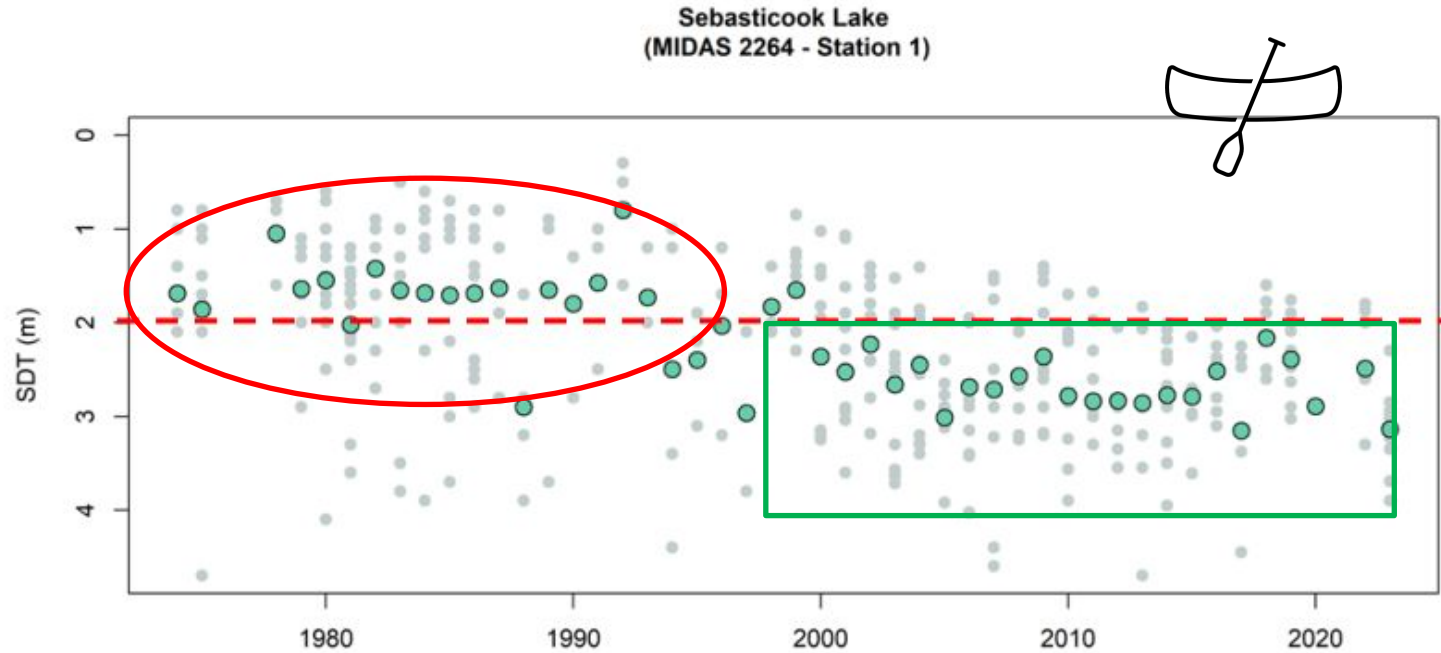
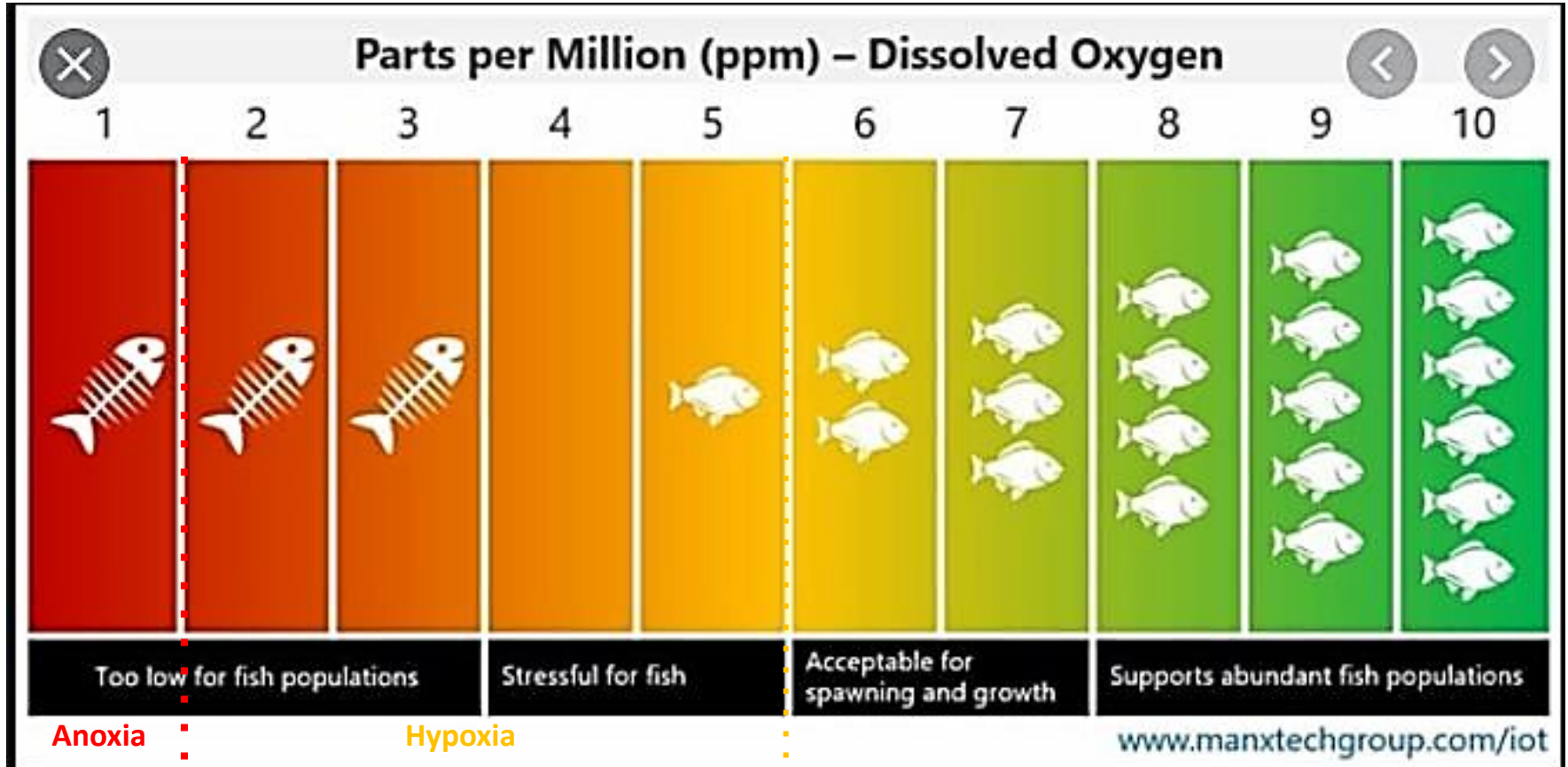


Figure 11. Historical water clarity readings in Sebasticook Lake 1974 – 2023. (Green circles indicate the average SDT reading for each year and gray circles represent the range in actual readings collected each year. SDT readings above the red line indicate algal bloom conditions.)

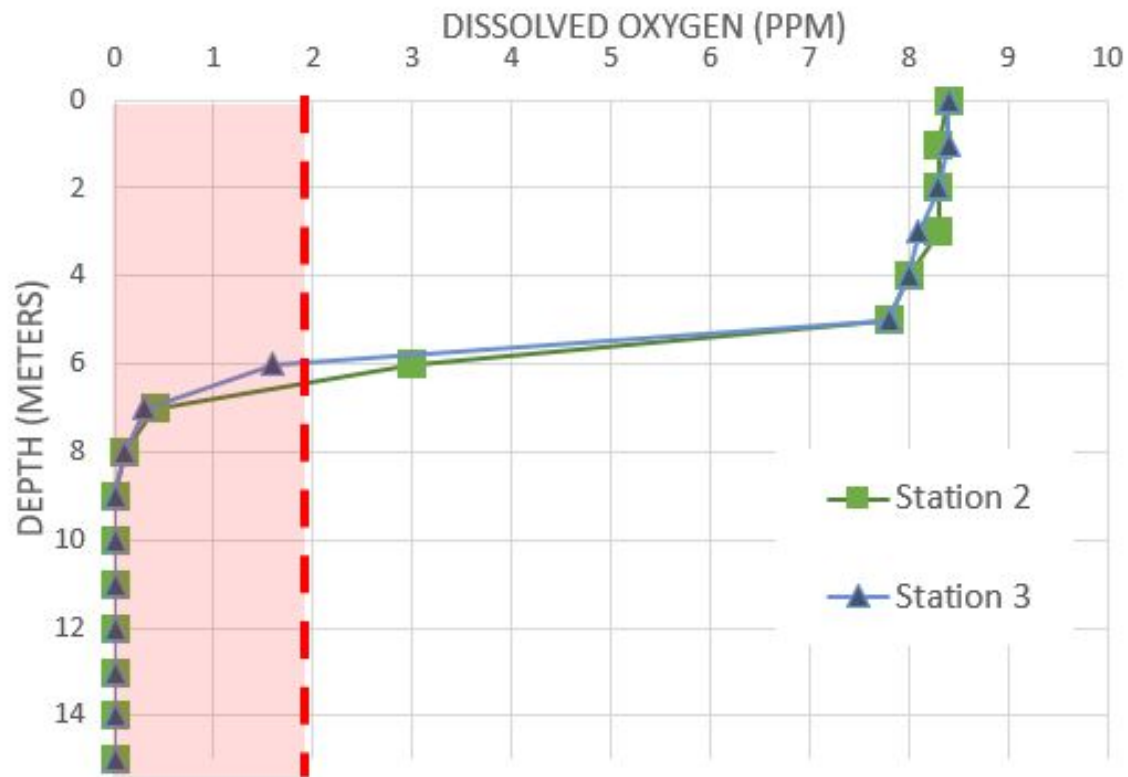
Anoxia



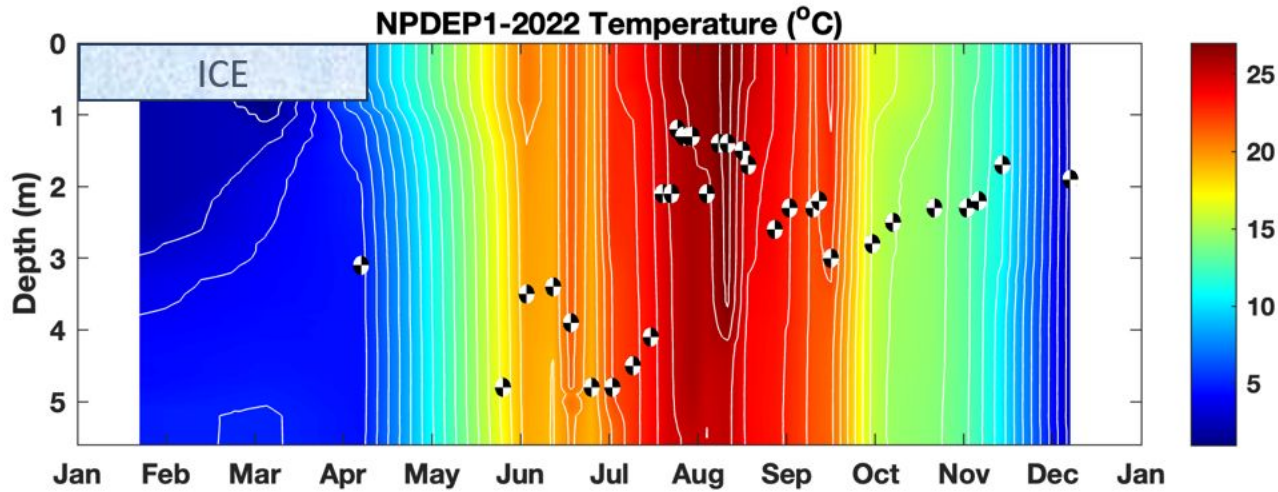
Anoxia occurs in the absence of dissolved oxygen, or very low concentrations, in a water body like a lake.

DO Profiles

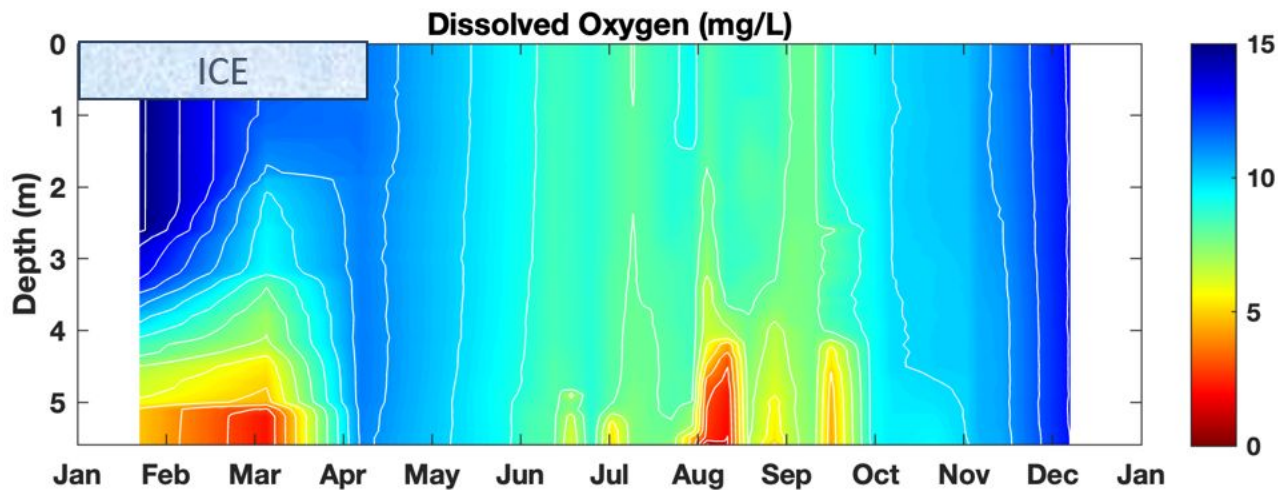
DISSOLVED OXYGEN PROFILES CHINA LAKE, STATIONS 2 & 3 AUGUST 20, 2021



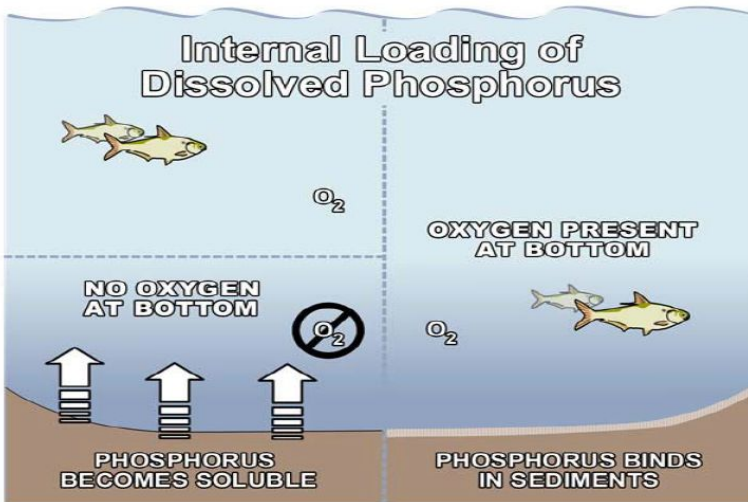
“Heat Maps”



North Pond, Smithfield, ME.
Photo Credit: Alexander Wall



DO & Internal P Loading



- ❖ Low levels of DO results in release of phosphorus from the lake's sediment

- ❖ Increase in P provides food for algae and results in annual algal blooms



Anabaena spiroides from a lake in New Hampshire USA

- ❖ Biologically-mediated internal P loading (less understood & harder to document)

Lakes Susceptible to Internal P Release

* *Added to the DEP NPS Priority Watersheds List*

- ❖ Lakes with Al:Fe ratios less than 3 (Al:Fe < 3:1)
- ❖ Al:P ratios less than 25 (Al:P < 25:1)
- ❖ Lakes meeting both- added to list
- ❖ Lakes with low or border line Al:Fe ratios (BG > 40 ppb)

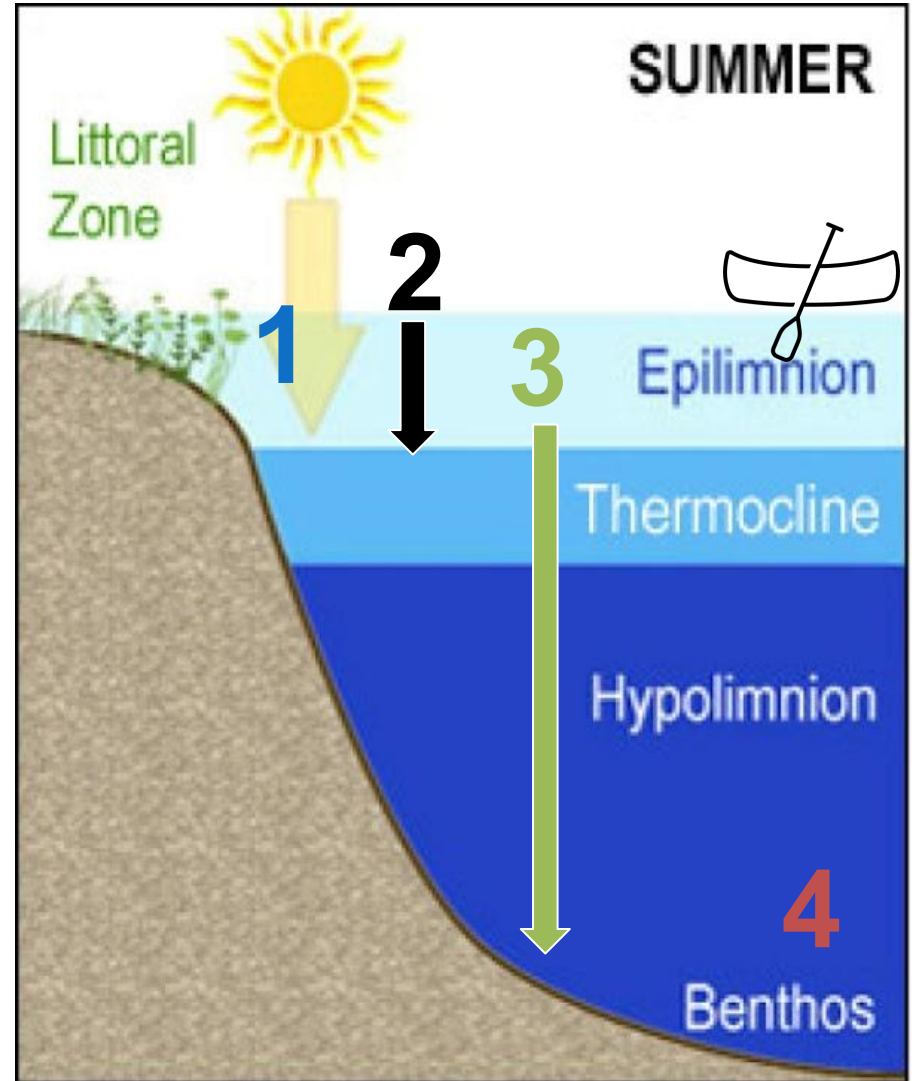


Lake sediment core

Lake	Town	Priority List Reasoning
Round Pond	Vinalhaven	Public Water System
Roxbury Pond	Roxbury	Watch List
Sabbathday Lake	New Gloucester	Sensitive
Salmon L (Ellis P)	Belgrade	Watch List, Sensitive – Sediment Chemistry
Salmon Stream Pond	Guilford	Public Water System
Sand Pond	Monmouth	Sensitive
Sawyer Pond	Greenville	Negative clarity trend
Sebago Lake (including Crooked River)	Sebago	Outstanding Water Quality, Public Water System
Sennebec Pond	Appleton	Sensitive – Sediment Chemistry
Shaker Pond	Alfred	Sensitive
Sheepscot Lake	Palermo	Fish Hatchery
Silver Lake	Bucksport	Public Water System
Spectacle Pond	Vassalboro	Sensitive
Square Lake	T16 R5 WELS	Watch List, Development Threat
Square Pond	Acton	Sensitive – Sediment Chemistry

Sampling Depths

1. **Surface Grab**
2. **Epilimnetic Core**
3. **Profile Grabs**
4. **Bottom Grabs**



Types of Data Needed

❖ Total Phosphorus Profiles

- Every meter (shallow lakes)
- Every other meter (deep lakes)
- Every two weeks from ice-off through turnover (ideal)



Photo: Georges Pond Association

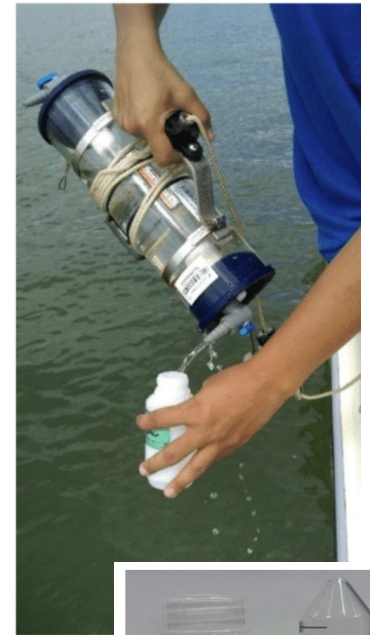
Sampling Equipment for P

1. Epilimnetic Core



Weighted core tubing for collecting phytoplankton and chlorophyll

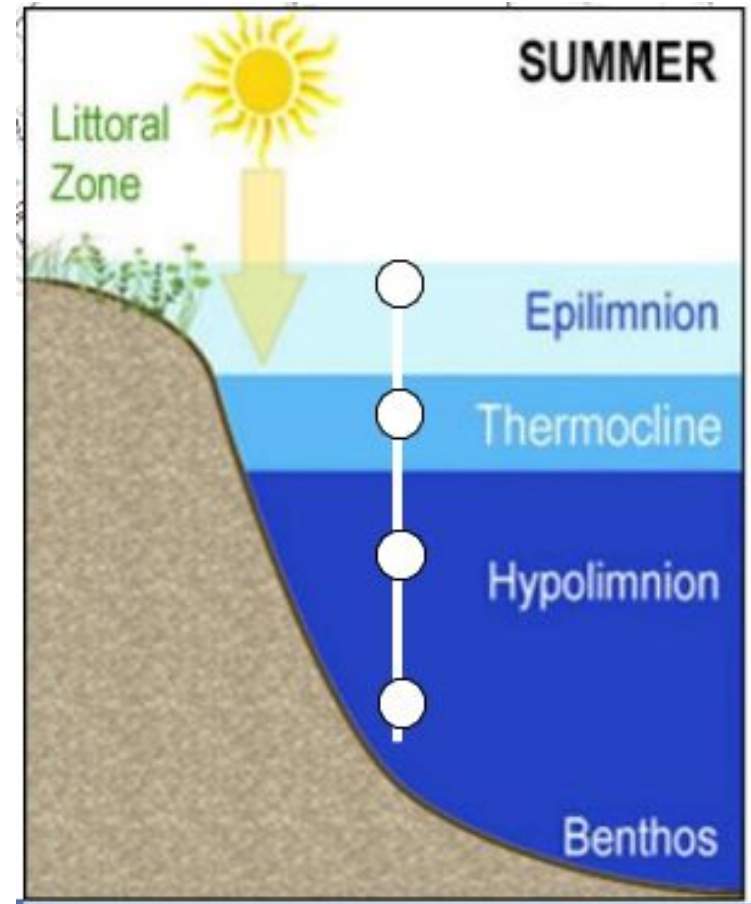
2. Profile Grabs



Erlenmeyer Flask (left) & transfer vial (right)

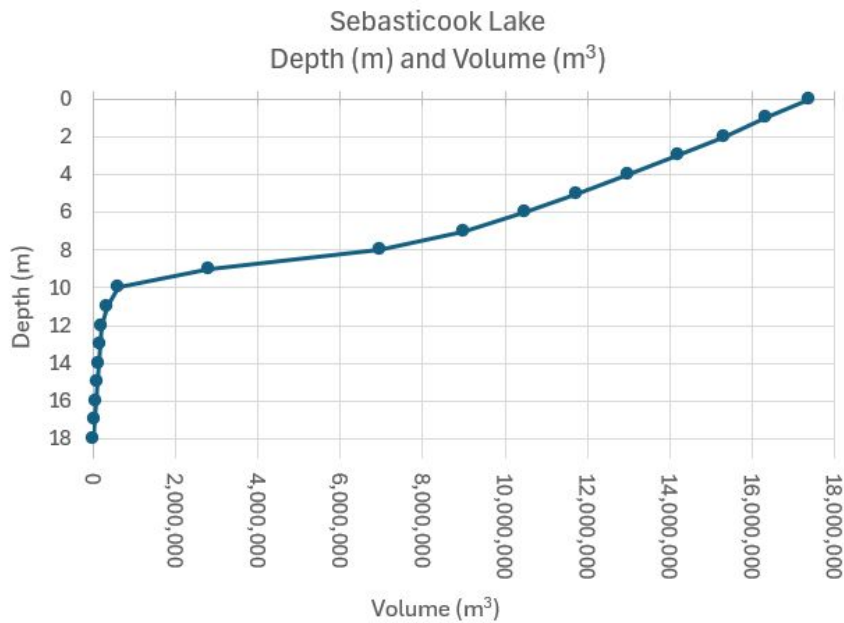
Other Useful Data

- ❖ Dissolved Oxygen & Temp Profiles
- ❖ Secchi disk transparency
- ❖ Precipitation
- ❖ Chlorophyll-a
- ❖ Phytoplankton
- ❖ Bathymetry

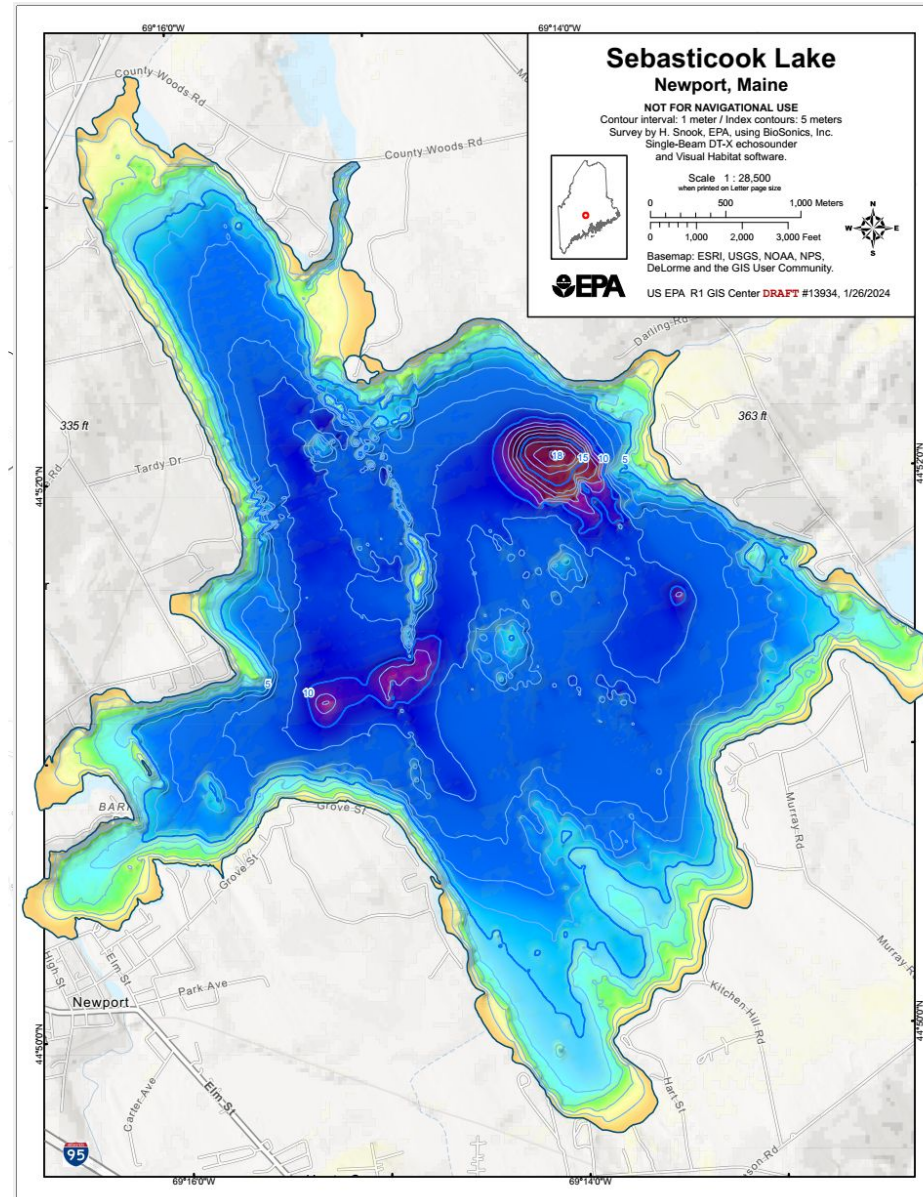


Bathymetry- Data Collection

❖ Bathymetric data



- Small volume below 10 m
- Important to understanding the extent of internal loading

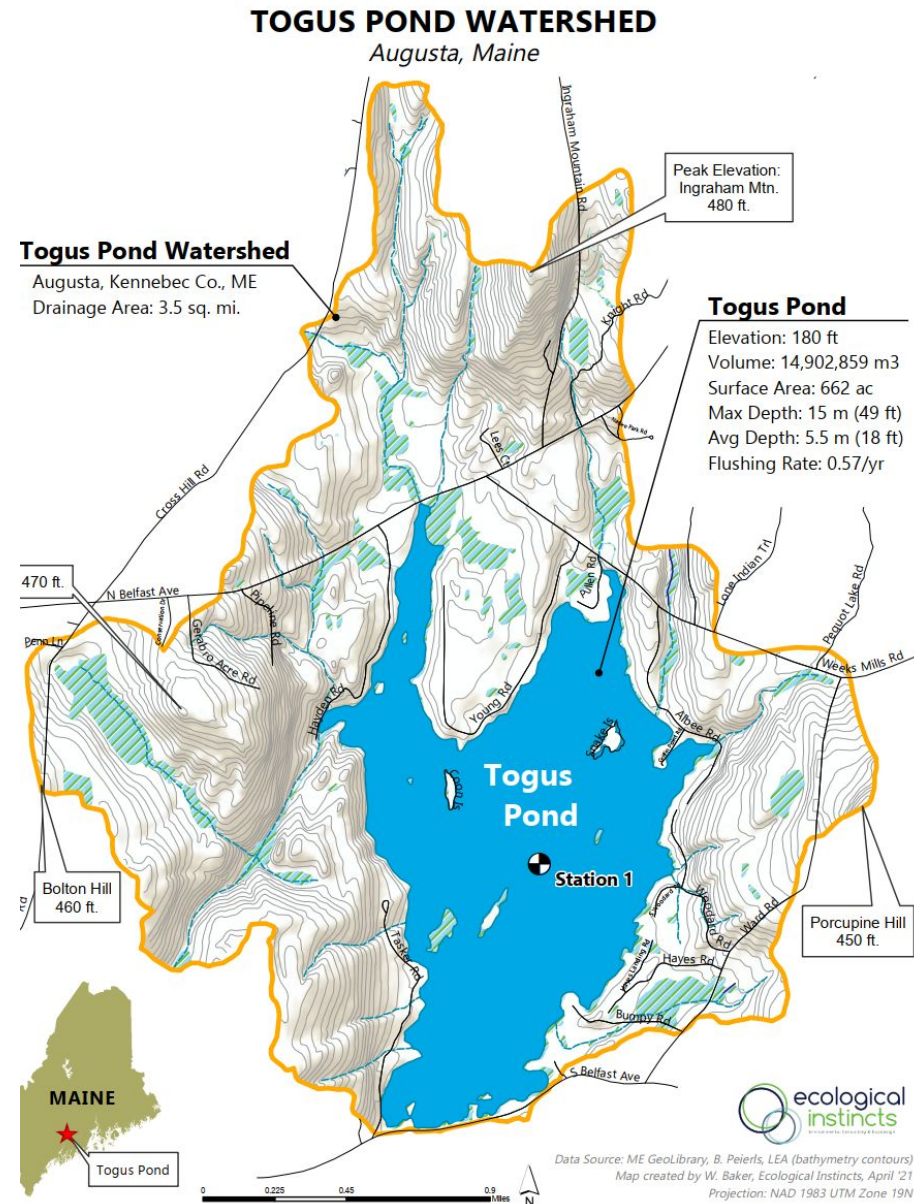


Example- Togus Pond

- ❖ Long history of algal blooms
- ❖ 3.5 sq. mi watershed
- ❖ 662 acres
- ❖ 0.57 flushes/yr



2018 Algal Bloom
Togus Pond



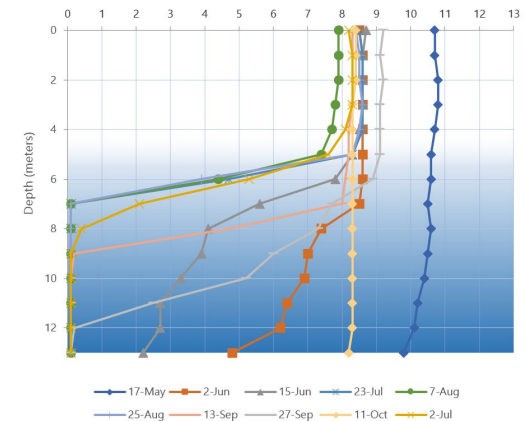
DO Profile- Togus Pond

Station 1 Temperature (T) in °C and Dissolved Oxygen (DO) in mg/l																					
Station 1	Depth (m)	17-May		2-Jun		15-Jun		2-Jul		23-Jul		7-Aug		25-Aug		13-Sep		27-Sep		11-Oct	
SDT (m)		2.30		4.31		4.83		4.20		4.68		3.40		3.84		3.99		4.47		2.48	
		T	DO	T	DO	T	DO	T	DO	T	DO	T	DO	T	DO	T	DO	T	DO	T	DO
	0	12.9	10.7	19.0	8.5	20.7	8.7	23.8	8.2	26.8	8.5	25.7	7.9	24.6	8.4	21.1	8.3	17.9	9.2	15.4	8.4
	1	12.7	10.7	19.0	8.6	20.6	8.6	23.7	8.3	26.0	8.6	25.7	7.9	24.6	8.5	21.1	8.3	17.9	9.1	15.4	8.4
	2	12.0	10.8	19.0	8.6	20.4	8.6	23.6	8.3	25.8	8.6	25.6	7.9	24.6	8.5	21.1	8.3	17.8	9.2	15.4	8.4
	3	11.8	10.8	19.0	8.6	20.4	8.6	23.5	8.3	25.6	8.6	25.6	7.8	24.5	8.6	21.1	8.3	17.6	9.1	15.4	8.3
	4	11.8	10.7	18.9	8.6	20.3	8.5	23.5	8.1	24.1	8.6	25.6	7.7	24.4	8.5	21.0	8.2	17.5	9.1	15.4	8.3
	5	11.7	10.6	18.9	8.6	20.0	8.3	23.0	7.6	23.5	8.3	25.5	7.4	24.3	8.3	21.0	8.2	17.5	9.1	15.4	8.3
	6	11.7	10.6	18.1	8.6	19.5	7.8	20.2	5.3	22.5	4.7	24.1	4.4	23.6	3.9	21.0	8.1	17.3	8.9	15.4	8.3
	7	11.7	10.5	13.7	8.5	16.3	5.6	17.4	2.1	18.5	0.1	20.1	0.1	21.4	0.1	21.0	8.0	16.8	7.7	15.4	8.3
	8	11.6	10.6	12.6	7.4	13.4	4.1	13.3	0.4	15.4	0.1	16.8	0.1	16.6	0.1	20.5	4.7	16.7	7.3	15.4	8.3
	9	11.6	10.5	12.4	7.0	12.8	3.9	13.3	0.1	13.5	0.1	14.0	0.1	14.3	0.1	18.5	0.2	16.5	6.0	15.4	8.3
	10	11.6	10.4	12.3	6.9	12.4	3.3	12.7	0.1	12.9	0.1	13.4	0.1	13.3	0.1	13.3	0.1	16.3	5.2	15.4	8.3
	11	11.5	10.2	12.2	6.4	12.1	2.7	12.3	0.1	12.6	0.1	12.9	0.1	12.8	0.1	12.7	0.1	15.5	2.5	15.4	8.3
	12	11.4	10.1	12.1	6.2	12.1	2.7	12.2	0.1	12.2	0.1	12.2	0.1	12.5	0.1	12.5	0.1	12.9	0.2	15.4	8.3
	13	11.2	9.8	11.9	4.8	12.0	2.1	12.0	0.1	12.0	0.1	12.1	0.1	12.2	0.1	12.1	0.1	11.9	0.1	15.4	8.2
	14	11.1	9.6	11.8	4.2	12.0	2.1	11.9	0.1	11.9	0.1	12.0	0.1	12.0	0.1	12.0	0.1	11.8	0.1	15.4	8.2
	15	mud				11.9	1.2	11.8	0.1	11.7	0.1	11.9	0.1	11.8	0.1	11.8	0.1	11.7	0.1	11.8	0.2

Overview:

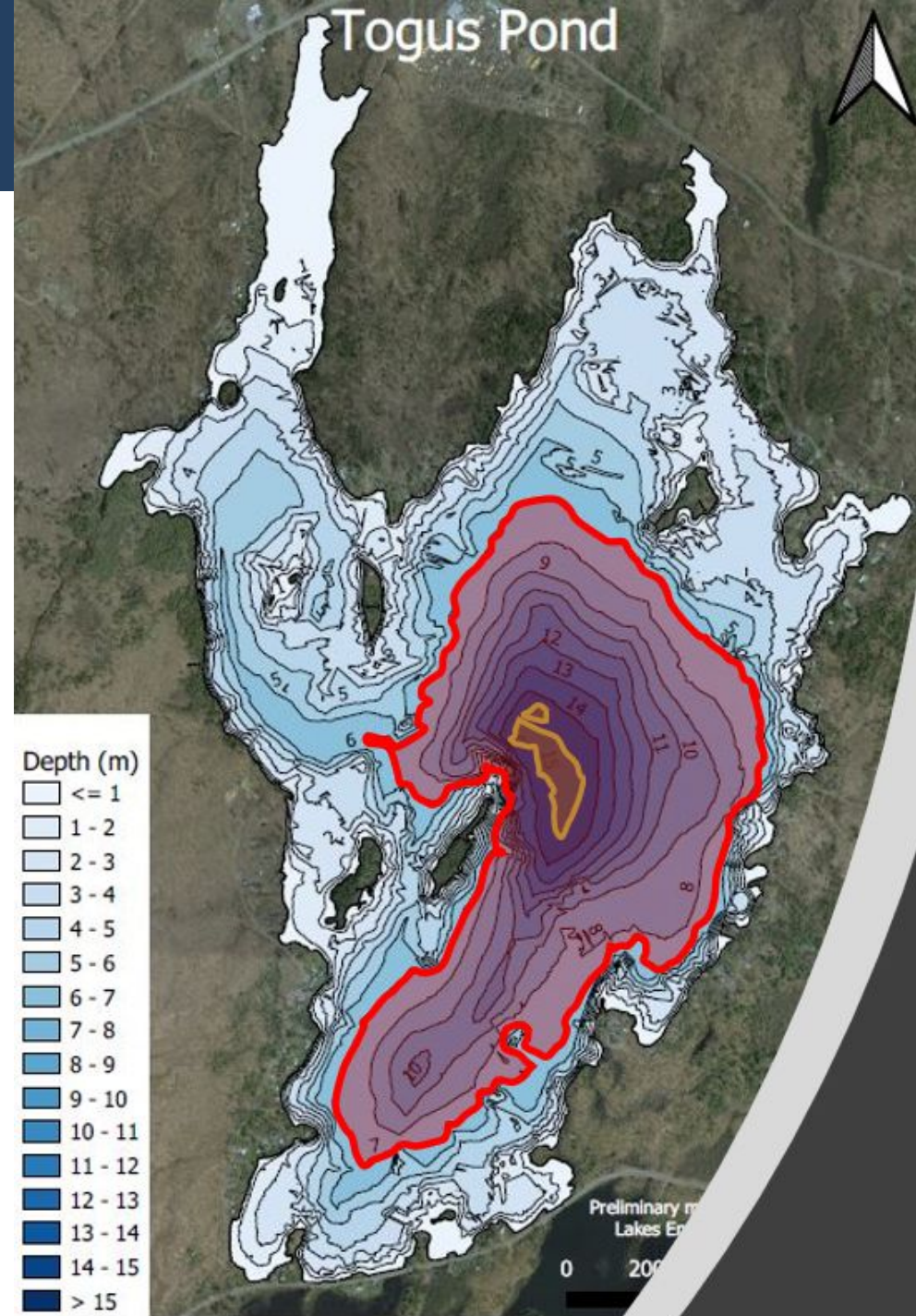
- ❑ Stratification sets up by early June
- ❑ Increasing water temperature peaks July 23
- ❑ Peak anoxia at 7m on July 23

2020 Dissolved Oxygen Profiles
Togus Pond, Station 1



Togus Pond

- ❖ Anoxia > 7 m
- ❖ Large area of lake sediments exposed to anoxia



DO & TP Profiles

Station 1 Temperature (T) in °C and Dissolved Oxygen (DO) in mg/l

Station 1	Depth (m)	17-May		2-Jun		15-Jun		2-Jul		23-Jul		7-Aug		25-Aug		13-Sep		27-Sep		11-Oct	
SDT (m)		2.30		4.31		4.83		4.20		4.68		3.40		3.84		3.99		4.47		2.48	
		T	DO	T	DO	T	DO	T	DO	T	DO	T	DO	T	DO	T	DO	T	DO	T	DO
	0	12.9	10.7	19.0	8.5	20.7	8.7	23.8	8.2	26.8	8.5	25.7	7.9	24.6	8.4	21.1	8.3	17.9	9.2	15.4	8.4
	1	12.7	10.7	19.0	8.6	20.6	8.6	23.7	8.3	26.0	8.6	25.7	7.9	24.6	8.5	21.1	8.3	17.9	9.1	15.4	8.4
	2	12.0	10.8	19.0	8.6	20.4	8.6	23.6	8.3	25.8	8.6	25.6	7.9	24.6	8.5	21.1	8.3	17.8	9.2	15.4	8.4
	3	11.8	10.8	19.0	8.6	20.4	8.6	23.5	8.3	25.6	8.6	25.6	7.8	24.5	8.6	21.1	8.3	17.6	9.1	15.4	8.3
	4	11.8	10.7	18.9	8.6	20.3	8.5	23.5	8.1	24.1	8.6	25.6	7.7	24.4	8.5	21.0	8.2	17.5	9.1	15.4	8.3
	5	11.7	10.6	18.9	8.6	20.0	8.3	23.0	7.6	23.5	8.3	25.5	7.4	24.3	8.3	21.0	8.2	17.5	9.1	15.4	8.3
	6	11.7	10.6	18.1	8.6	19.5	7.8	20.2	5.3	22.5	4.7	24.1	4.4	23.6	3.9	21.0	8.1	17.3	8.9	15.4	8.3
	7	11.7	10.5	13.7	8.5	16.3	5.6	17.4	2.1	18.5	0.1	20.1	0.1	21.4	0.1	21.0	8.0	16.8	7.7	15.4	8.3
	8	11.6	10.6	12.6	7.4	13.4	4.1	13.3	0.4	15.4	0.1	16.8	0.1	16.6	0.1	20.5	4.7	16.7	7.3	15.4	8.3
	9	11.6	10.5	12.4	7.0	12.8	3.9	13.5	0.1	13.5	0.1	14.0	0.1	14.3	0.1	18.5	0.2	16.5	6.0	15.4	8.3
	10	11.6	10.4	12.3	6.9	12.4	3.3	12.7	0.1	12.9	0.1	13.4	0.1	13.3	0.1	13.3	0.1	16.3	5.2	15.4	8.3
	11	11.5	10.2	12.2	6.4	12.1	2.7	12.3	0.1	12.6	0.1	12.9	0.1	12.8	0.1	12.7	0.1	15.5	2.5	15.4	8.3
	12	11.4	10.1	12.1	6.2	12.1	2.7	12.2	0.1	12.2	0.1	12.9	0.1	12.5	0.1	12.5	0.1	12.9	0.2	15.4	8.3
	13	11.2	9.8	11.9	4.8	12.0	2.2	12.0	0.1	12.0	0.1	12.1	0.1	12.2	0.1	12.1	0.1	11.9	0.1	15.4	8.2
	14	11.1	9.6	11.8	4.2	12.0	2.1	11.9	0.1	11.9	0.1	12.0	0.1	12.0	0.1	12.0	0.1	11.8	0.1	15.4	8.2

Station 1 Secchi Disk Transparency and Total Phosphorus Results

Station 1	Depth (m)	17-May-20	2-Jun-20	15-Jun-20	2-Jul-20	23-Jul-20	7-Aug-20	25-Aug-20	13-Sep-20	27-Sep-20	11-Oct-20
SDT (m)		2.30	4.31	4.83	4.20	4.68	3.40	3.84	3.99	4.47	2.48
Core Depth (m)				7		6.5					
Chl-a Result				4							
TP Core taken by DEP & DLM RESULTS are PPB											
	1	15	16	14	14	14	19	18	16	14	30
	3	13	14	16	13	16	18	18	17	14	28
	5	15	13	15	21	26	23	19	18	13	30
	7	14	18	20	15	20	28	31	17	36	27
	9	13	20	23	20	29	64	88	52	32	27
	11	18	20	30	34	94	145	180	180	97	23
	13	18	61	45	59	170	230	280	390	430	25
	15	-	-	61							
Ave TP		15	23	28	25	53	75	91	99	94	27

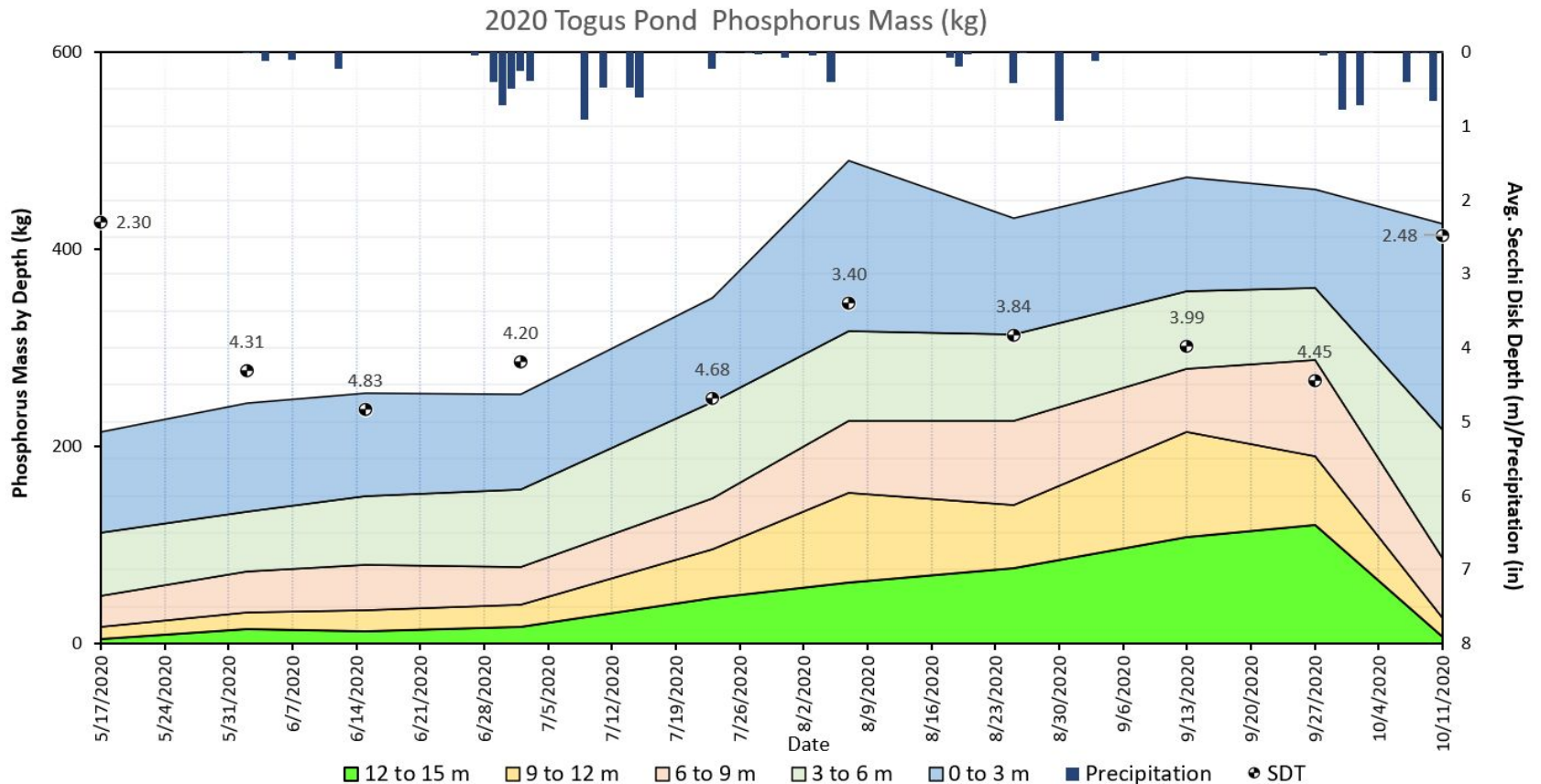
Calculate P Mass

1. Enter volume of each layer of water
2. Depth of layer
3. Date of sample collection
4. [TP] at corresponding depth
5. Calculate mass for depths with data & interpolated concentration
6. REPEAT for each date

Slice Volume (m ³)	Depth (m)	Date	Concentration of TP (ug/L)	Interpolated Concentration of TP (ug/L)	Mass of Phosphorus (kg)
0	0	5/17/2020		15.0	0
2584675	1	5/17/2020	15	15.0	38.77
2399425	2	5/17/2020		14.0	34.79
2127821	3	5/17/2020	13	13.0	28.73
1783372	4	5/17/2020		14.0	24.08
1476873	5	5/17/2020	15	15.0	21.41
1219993	6	5/17/2020		14.5	17.99
997172	7	5/17/2020	14	14.0	14.21
760407	8	5/17/2020		13.5	10.46
517350	9	5/17/2020	13	13.0	6.85
349153	10	5/17/2020		15.5	4.98
242752	11	5/17/2020	18	18.0	4.07
180935	12	5/17/2020		18.0	3.26
131331	13	5/17/2020	18	18.0	2.36
85472	14	5/17/2020		18.0	1.54
42727	15	5/17/2020		18.0	0.77
3402	15.5	5/17/2020		18.0	0.06
0	0	6/2/2020		16.0	0
2584675	1	6/2/2020	16	16.0	41.35
2399425	2	6/2/2020		15.0	37.19
2127821	3	6/2/2020	14	14.0	30.85
1783372	4	6/2/2020		13.5	24.52
1476873	5	6/2/2020	13	13.0	19.57
1219993	6	6/2/2020		15.5	17.38
997172	7	6/2/2020	18	18.0	16.70
760407	8	6/2/2020		19.0	14.07
517350	9	6/2/2020	20	20.0	10.09
349153	10	6/2/2020		20.0	6.98
242752	11	6/2/2020	20	20.0	4.86
180935	12	6/2/2020		40.5	5.47
131331	13	6/2/2020	61	61.0	6.67
85472	14	6/2/2020		61.0	5.21
42727	15	6/2/2020		61.0	2.61
3402	15.5	6/2/2020		61.0	0.21
0	0	6/15/2020		14.0	0
2584675	1	6/15/2020	14	14.0	36.19

P Mass- Togus Pond

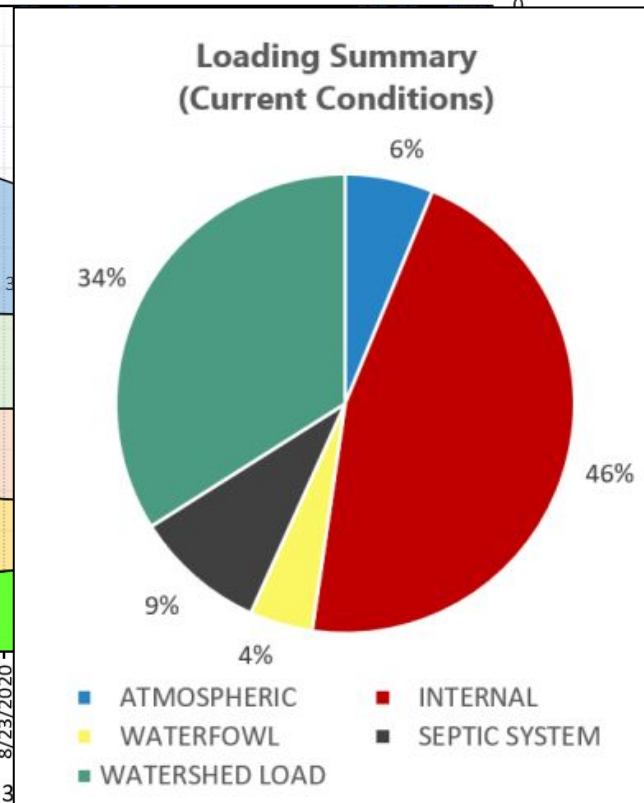
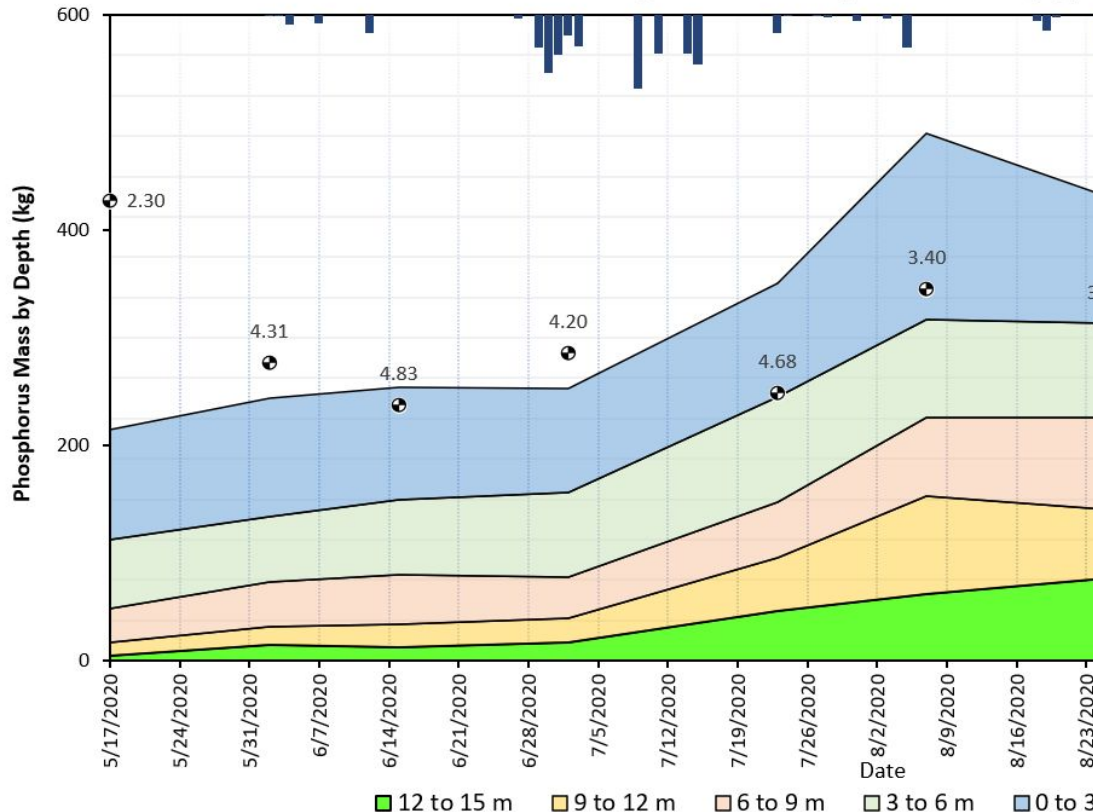
P Mass (kg) in each depth interval										
	5/17/2020	6/2/2020	6/15/2020	7/2/2020	7/23/2020	8/7/2020	8/25/2020	9/13/2020	9/27/2020	10/11/2020
0 to 3 m	102	109	104	97	105	172	118	116	100	209
3 to 6 m	63	61	70	79	98	91	87	79	73	130
6 to 9 m	32	41	46	39	52	73	86	64	98	61
9 to 12 m	12	17	21	22	49	91	64	107	69	19
12 to 15 m	5	15	12	17	46	62	76	108	121	7
Total by Date	214	244	254	253	351	490	432	473	461	426
										276



Calculate P Mass- Togus Pond

P Mass (kg) in each depth interval										
	5/17/2020	6/2/2020	6/15/2020	7/2/2020	7/23/2020	8/7/2020	8/25/2020	9/13/2020	9/27/2020	10/11/2020
0 to 3 m	102	109	104	97	105	172	118	116	100	209
3 to 6 m	63	61	70	79	98	91	87	79	73	130
6 to 9 m	32	41	46	39	52	73	86	64	98	61
9 to 12 m	12	17	21	22	49	91	64	107	69	19
12 to 15 m	5	15	12	17	46	62	76	108	121	7
Total by Date	214	244	254	253	351	490	432	473	461	426
										276

2020 Togus Pond Phosphorus Mass (kg)



Example- China Lake

- ❖ Public drinking water supply
- ❖ Algal blooms since 1980s
- ❖ 6.2 sq. mi watershed
- ❖ 3,939 acres
- ❖ 0.64 - 0.68 flushes/yr
- ❖ Unique bathymetry



China Lake. (Photo Credit: Elaine Philbrook, CLA.)

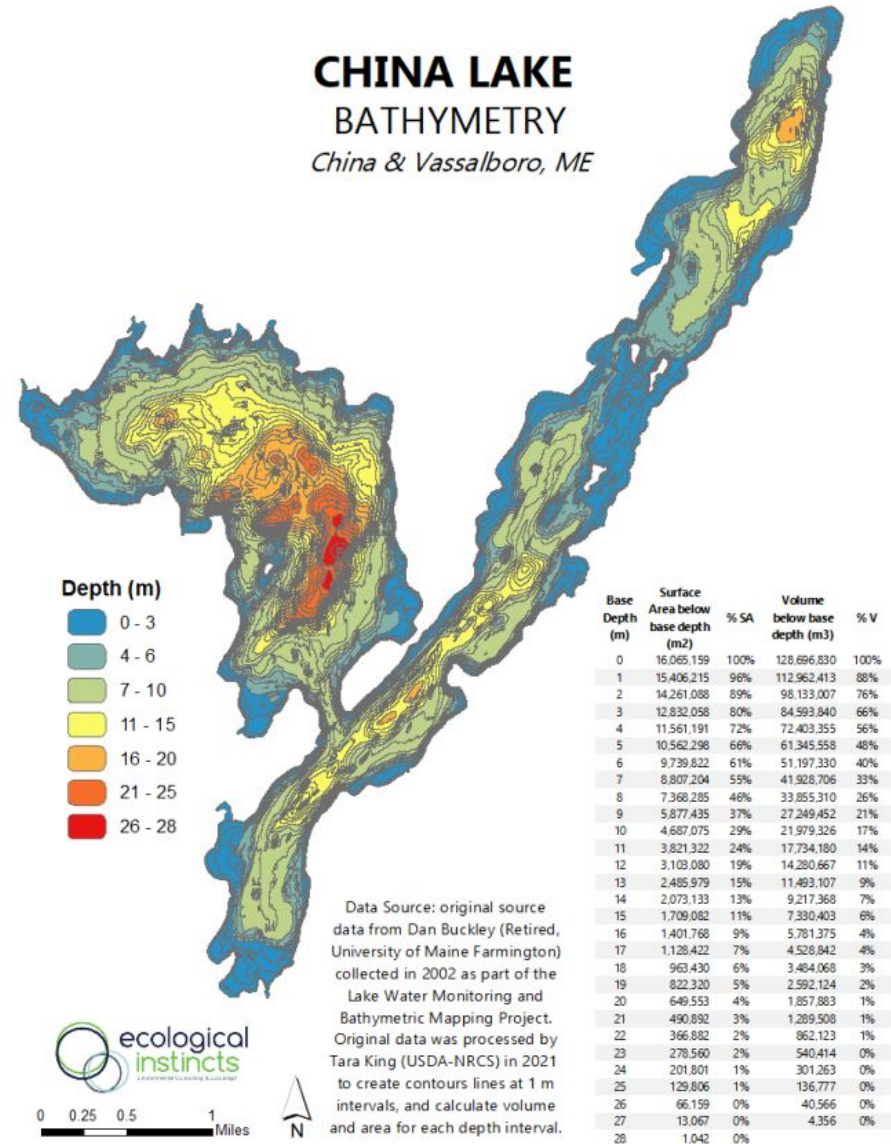
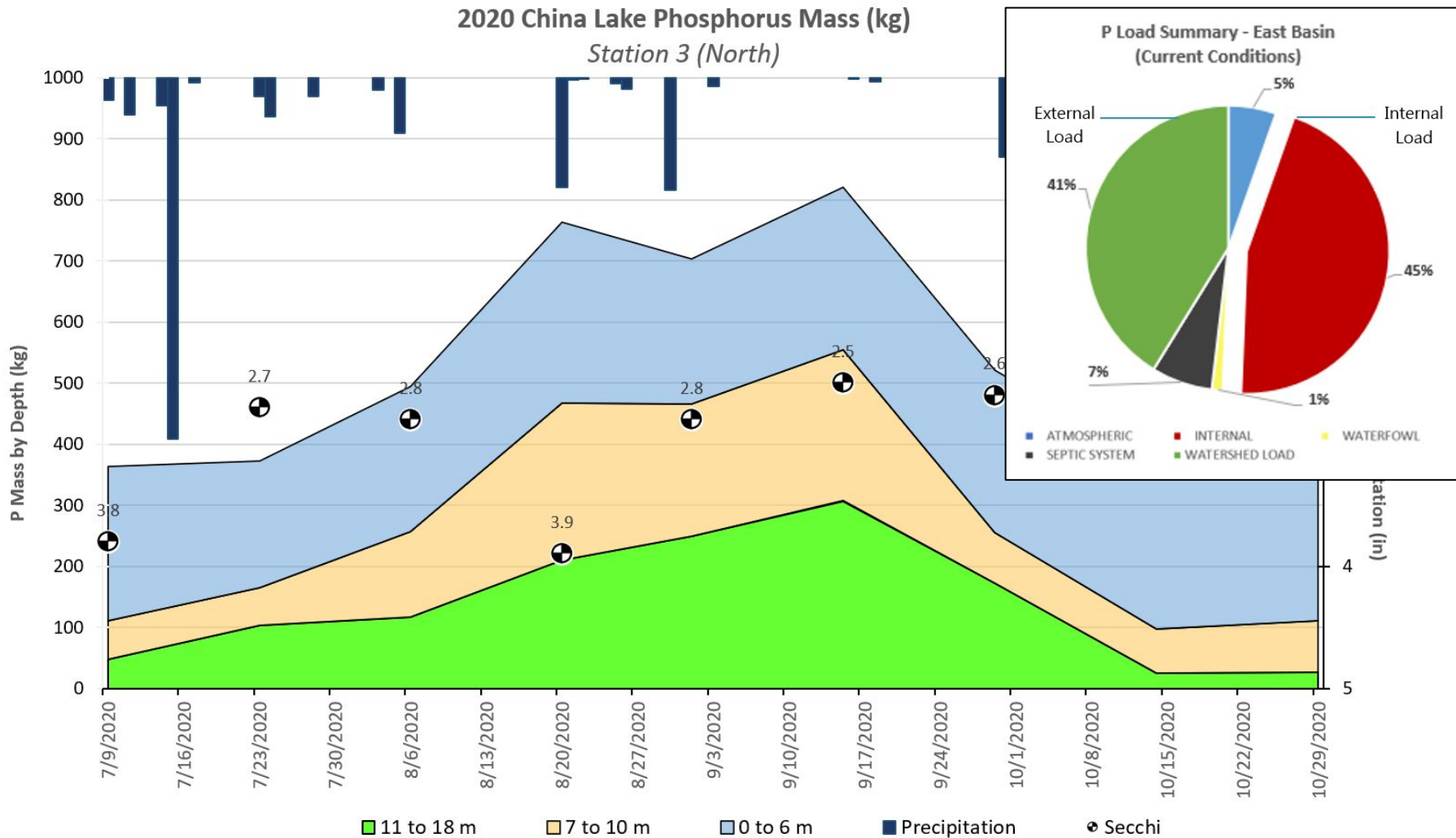


Figure 4. Bathymetric map for China Lake.

Example - China Lake

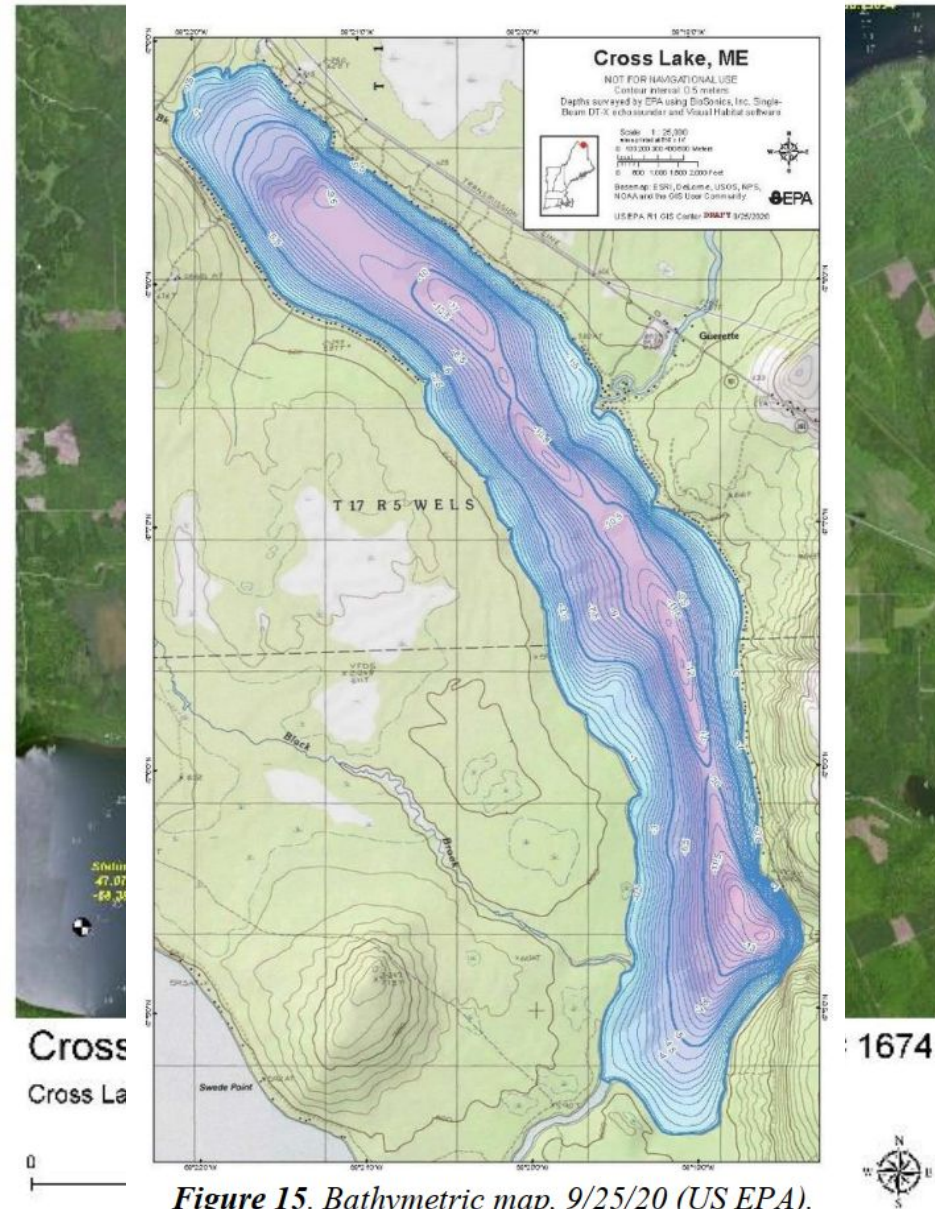


Example- Cross Lake

- ❖ Public drinking water supply
- ❖ Algal blooms since 1980s
- ❖ 58 sq. mi watershed
- ❖ 2,480 acres
- ❖ 3.5 flushes/yr

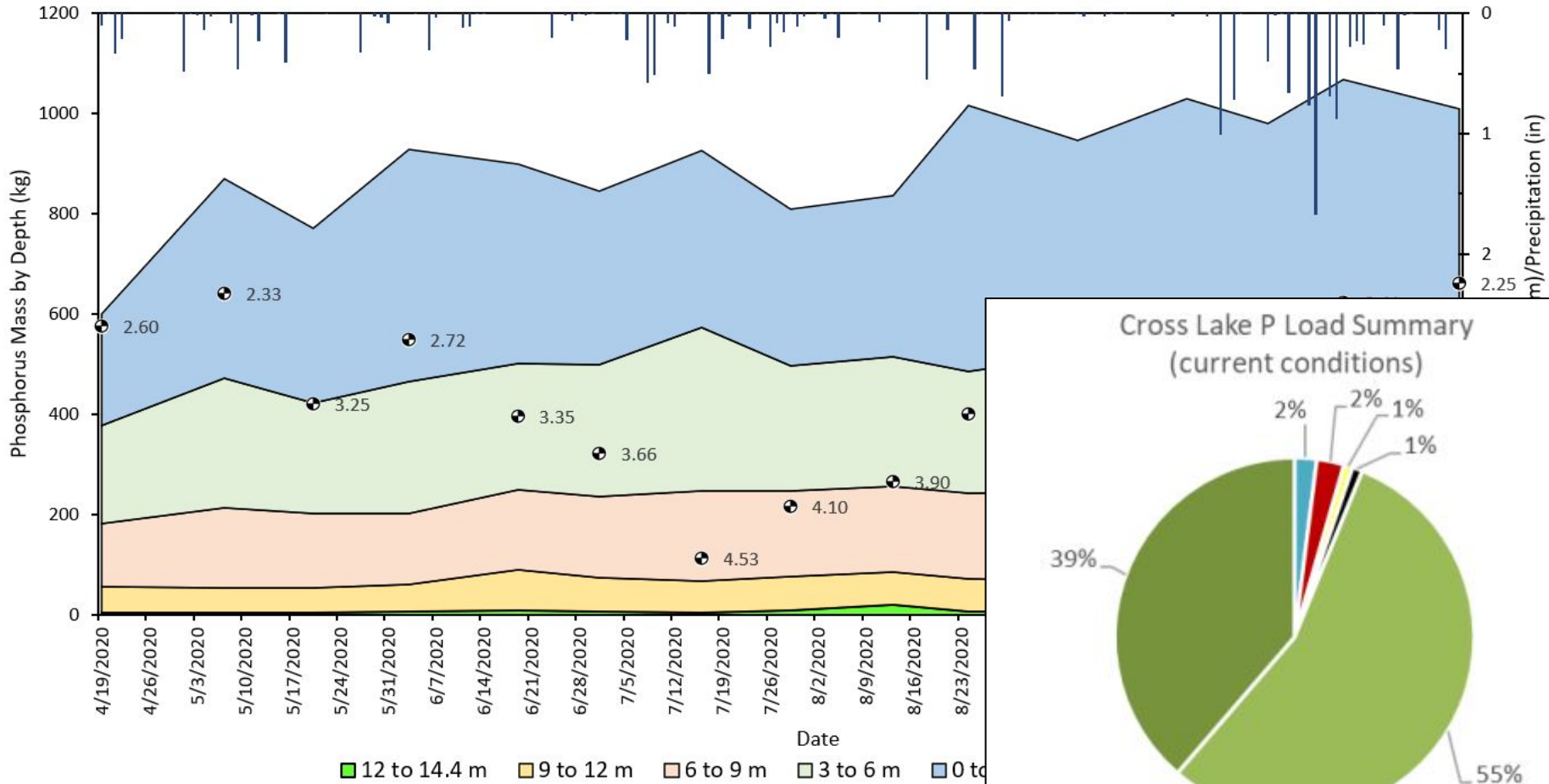


Cyanobacteria bloom on Cross Lake, September 20, 2019.

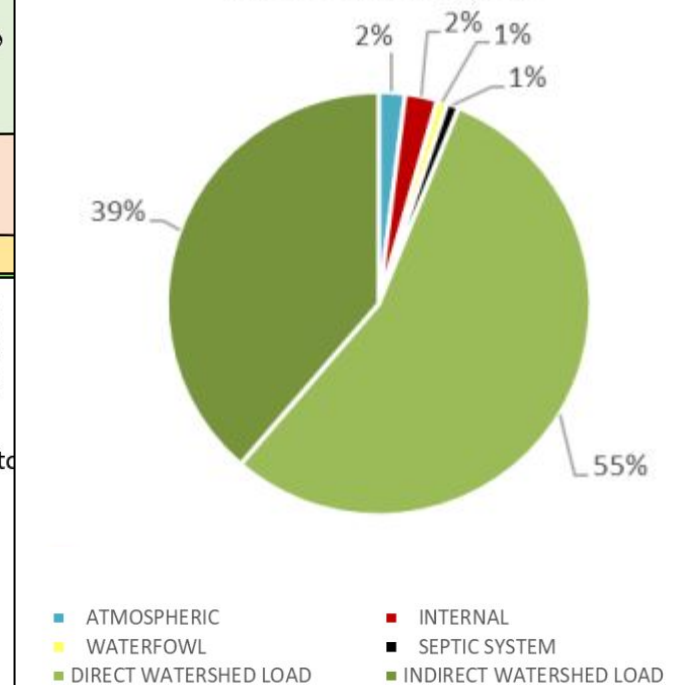


Cross Lake P Mass

2020 Cross Lake Phosphorus Mass (kg)



Cross Lake P Load Summary (current conditions)

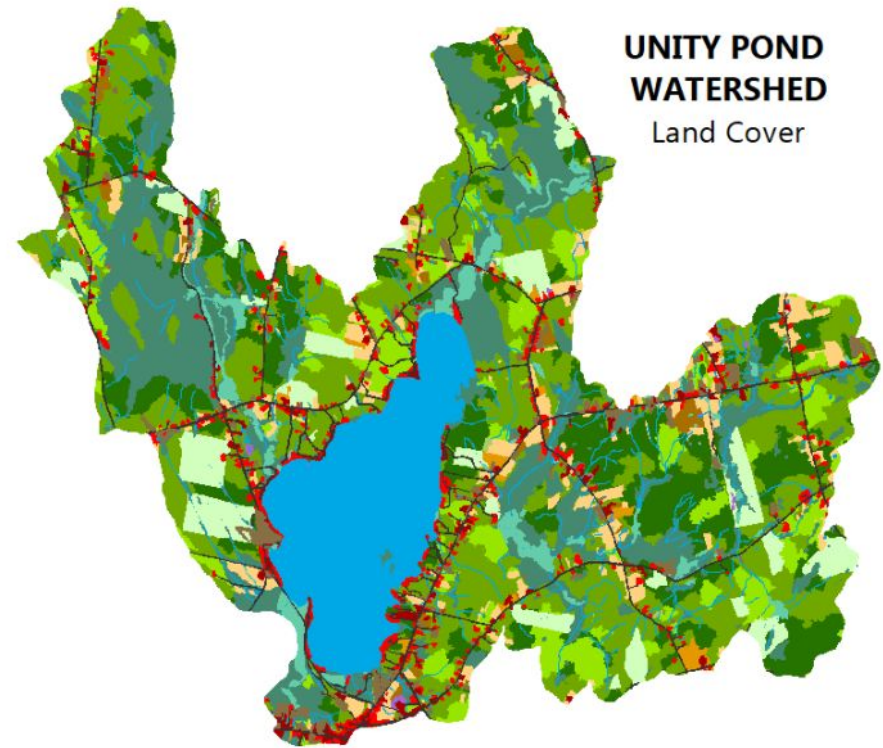


Example- Unity Pond

- ❖ Long history of algal blooms
- ❖ 30 sq. mi watershed
- ❖ 2,569 acres
- ❖ 1.28 flushes/yr
- ❖ Backflushing into lake from downstream watershed



A blue-green algae bloom on the shoreline of Unity Pond in 2021. Photo Credit: FOLW



UNITY POND
WATERSHED
Land Cover

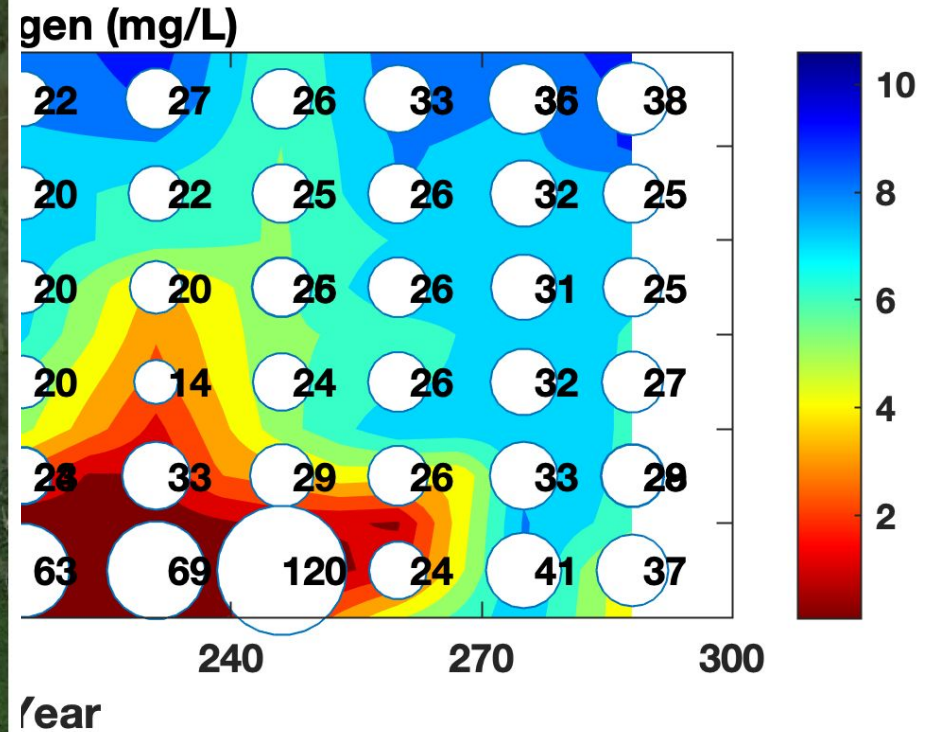
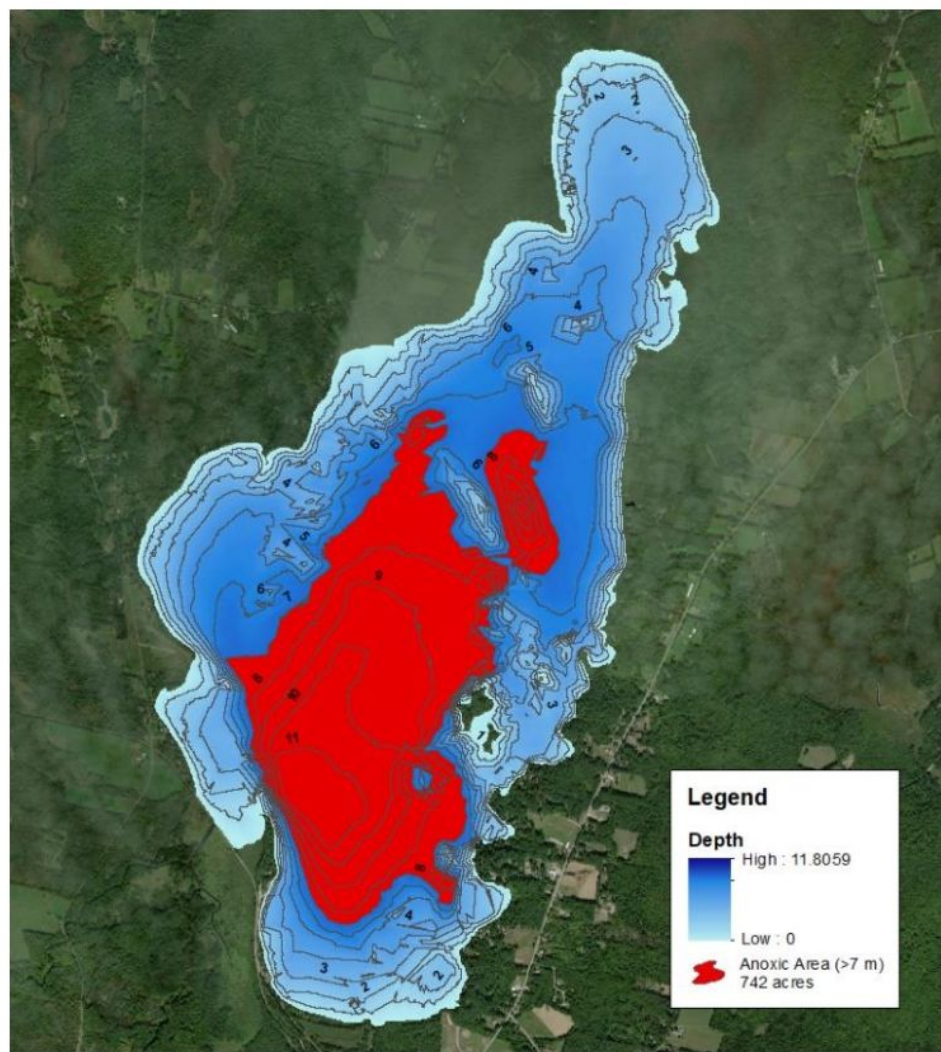


Source: ME Geolibary, NHDPlusHR, NWI,
Ecological Instincts
Projection: NAD 1983 UTM Zone 19N
K. Goodwin, Ecological Instincts - July 2021

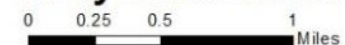


Figure 4. Land cover in the Unity Pond direct watershed.

Anoxia- Unity Pond



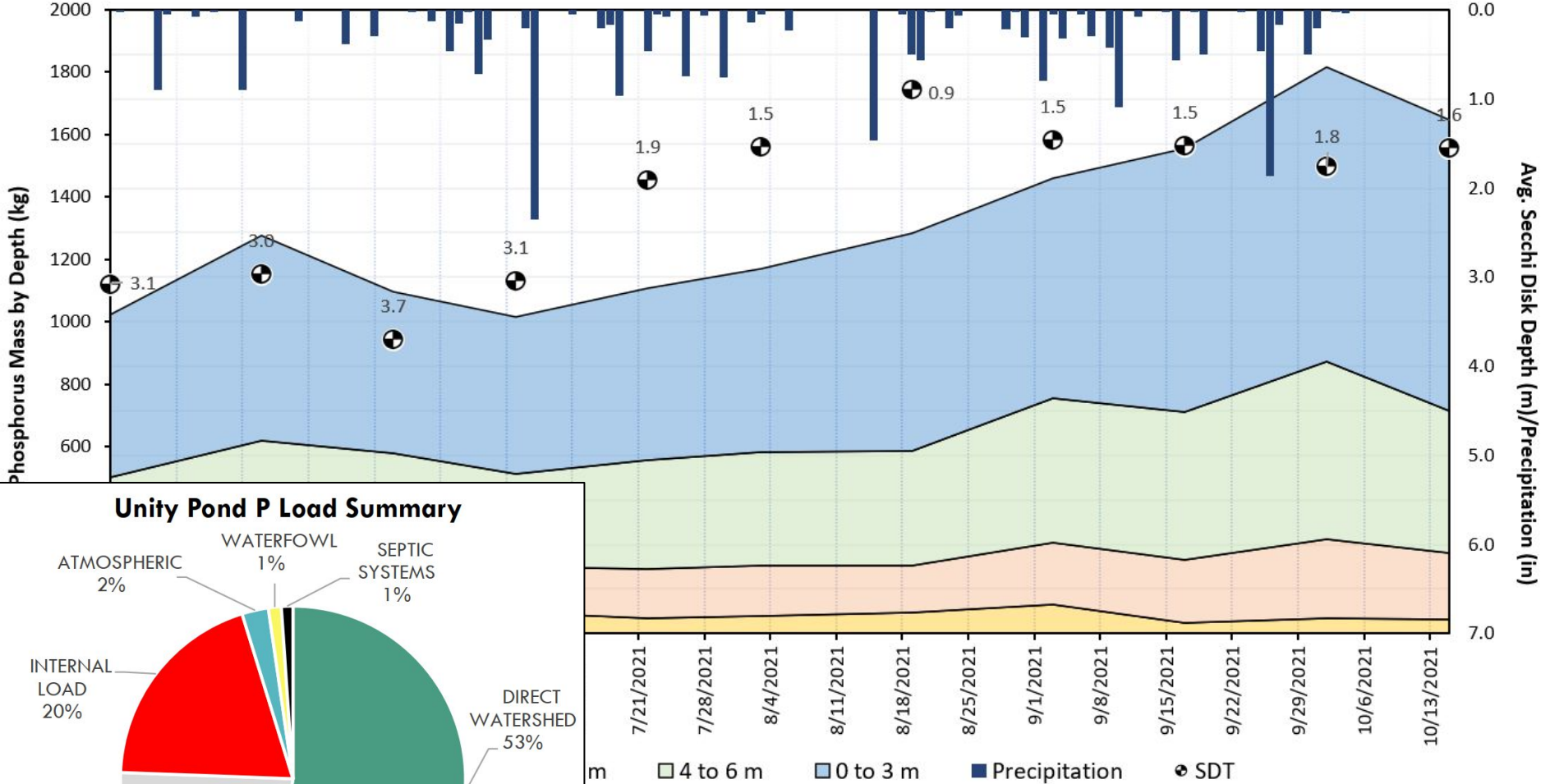
Unity Pond Anoxic Area



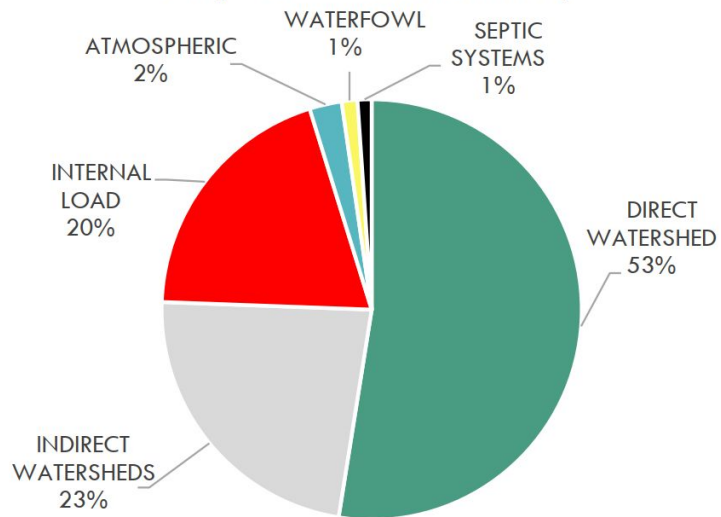
Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
 Data Source: 7 Lakes Alliance, Projection: NAD 1983 UTM Zone 19N, Created By: K. Goodwin, October 2022

Unity Pond P Mass

2021 Unity Pond Phosphorus Mass (kg)



Unity Pond P Load Summary



Example- Abrams Pond

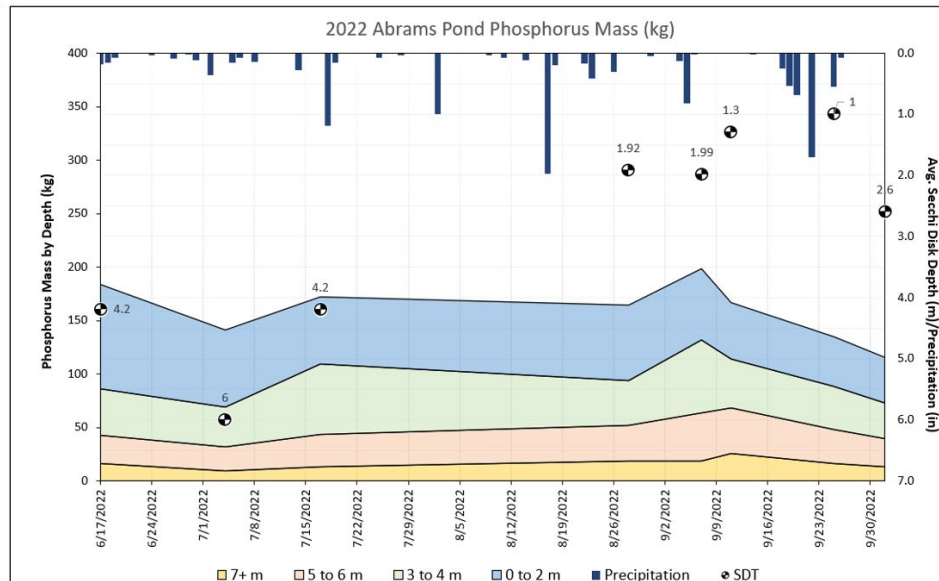
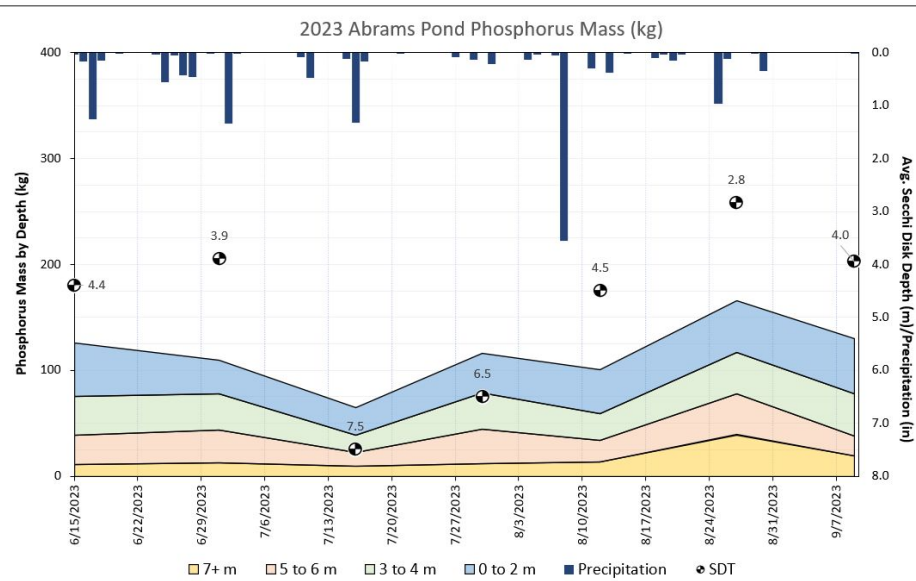
- ❖ Inconsistent blooms since 2012
- ❖ 1.4 sq. mi watershed
- ❖ 435 acres
- ❖ 0.41 flushes/yr
- ❖ 3 years P monitoring



Annual Variability- Abrams Pond

2023: Cool, wet (no bloom)

2022: Warm, dry (bloom)

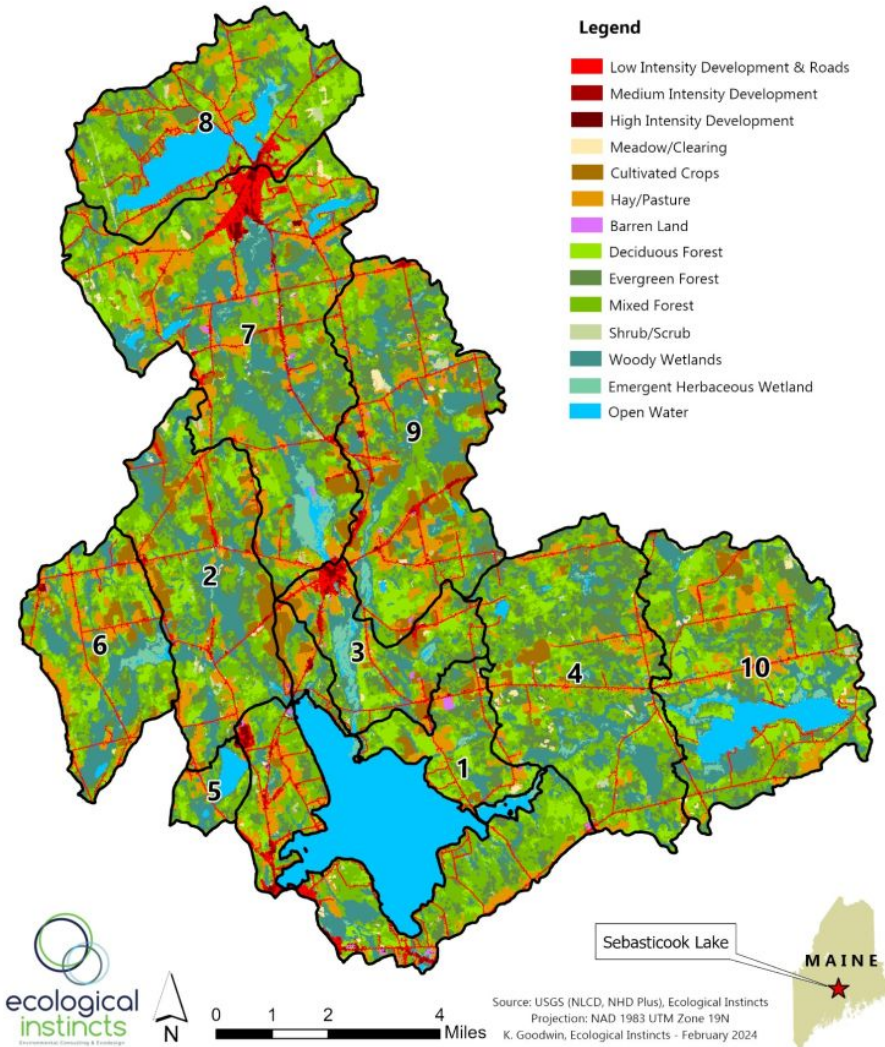


- ❖ High TP at surface in the spring
- ❖ Short periods of ephemeral anoxia
- ❖ Phytoplankton data suggest biologically mediated internal loading

Example - Sebasticook Lake

- ❖ 167 sq mi watershed
- ❖ 4,537 acres
- ❖ 1.47 flushes/yr
- ❖ Industrial & municipal wastewater discharges
- ❖ Only 6 of last 25 years without an algae bloom
- ❖ 40 years of drawdowns to remove internal P load

SEBASTICOOK LAKE WATERSHED
LAND COVER BY BASIN



Long-Term Changes: Sebasticook Lake

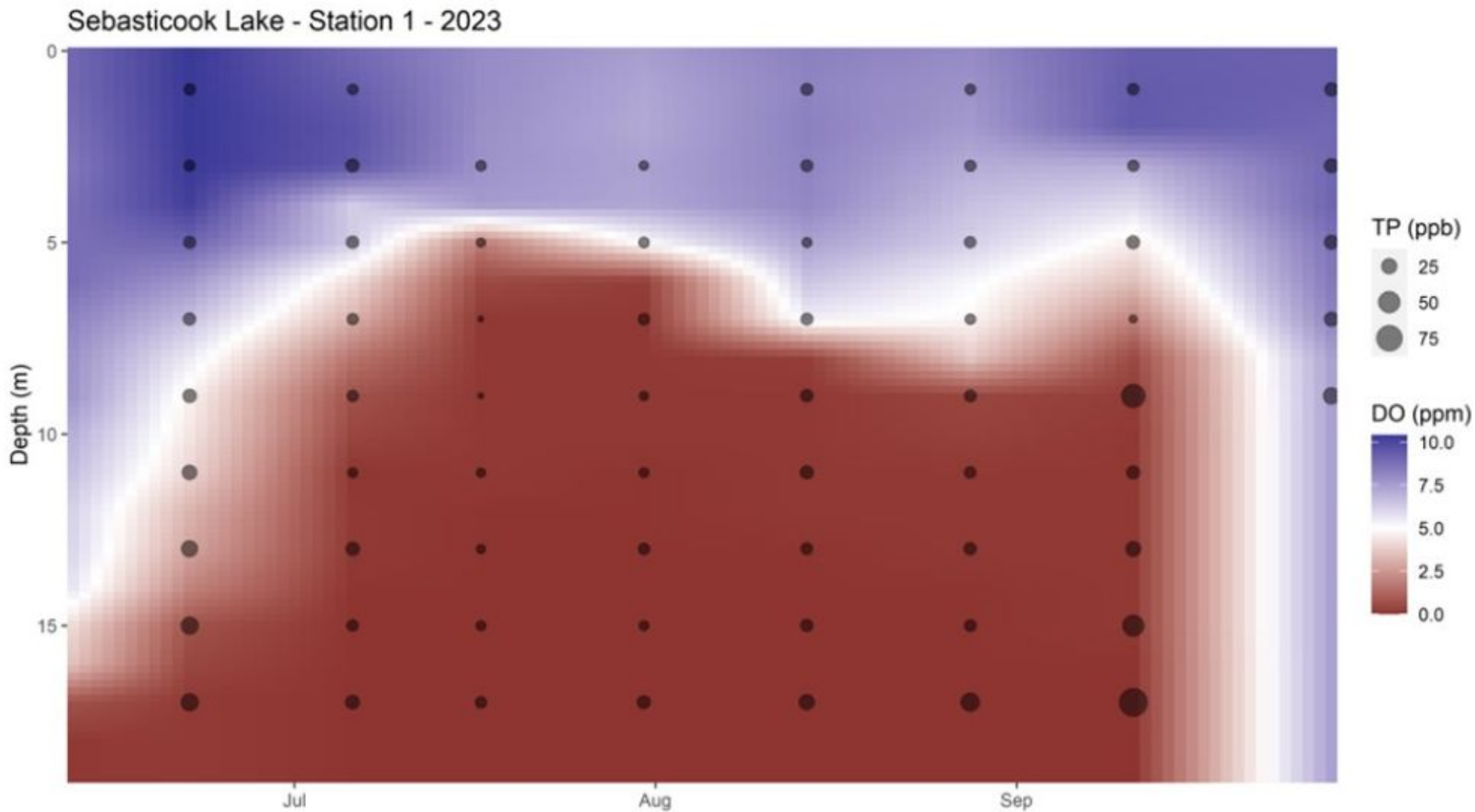
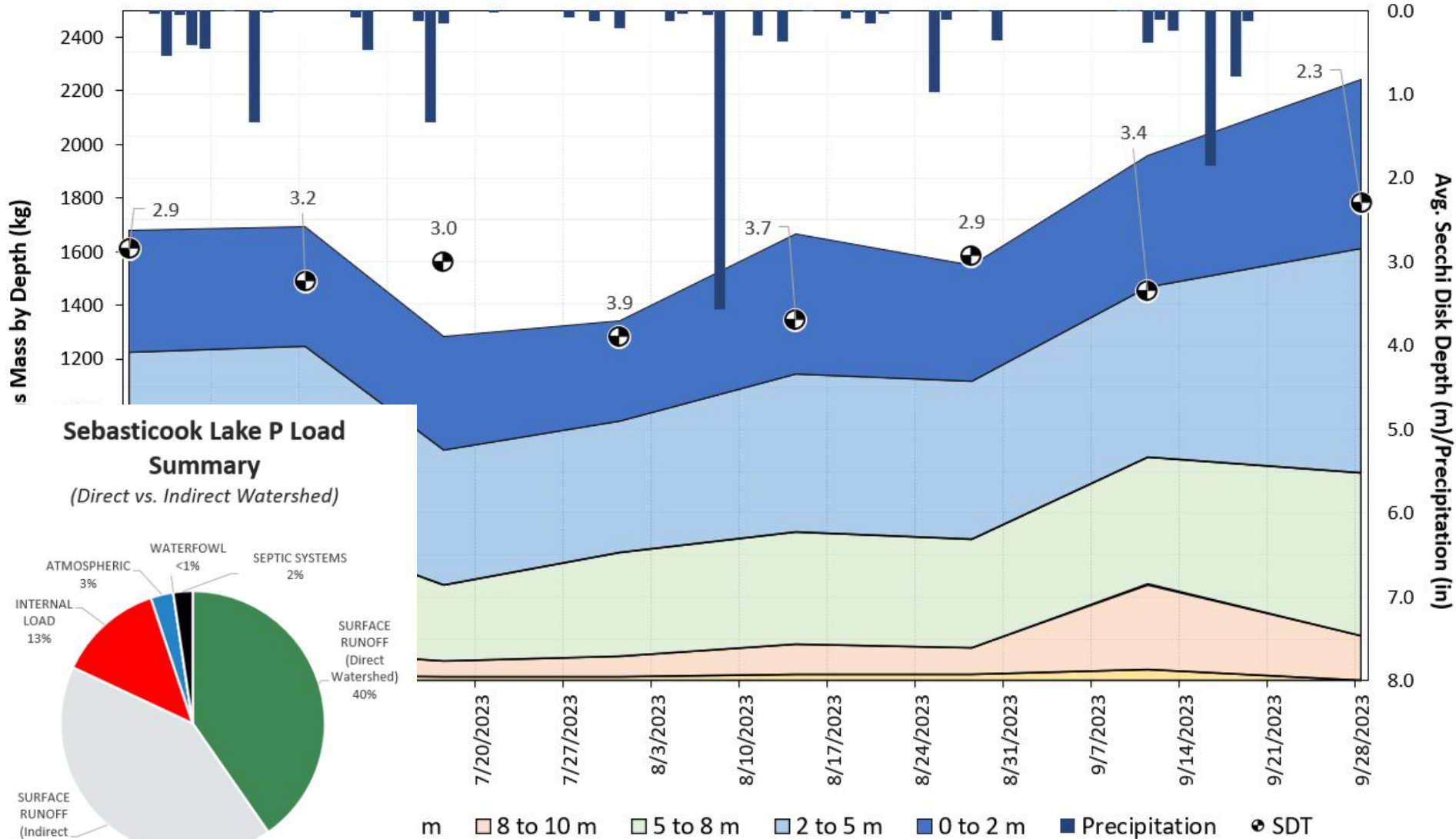


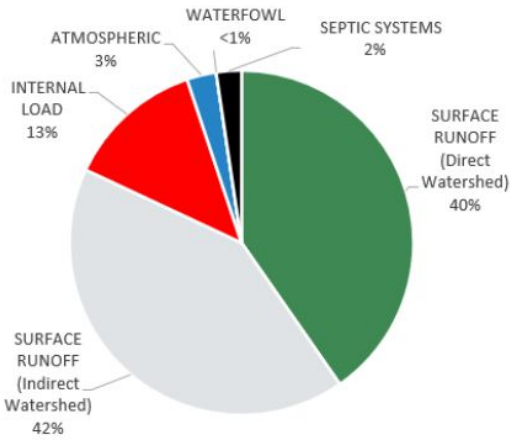
Figure 12. 2023 DO and TP concentrations by depth in Sebasticook Lake, Station 1. (Gray circles represent the concentration of TP at each depth in the water column, period of low DO are represented by dark red areas)

Long-Term Changes: Sebasticook Lake

2023 Sebasticook Lake Phosphorus Mass (kg)

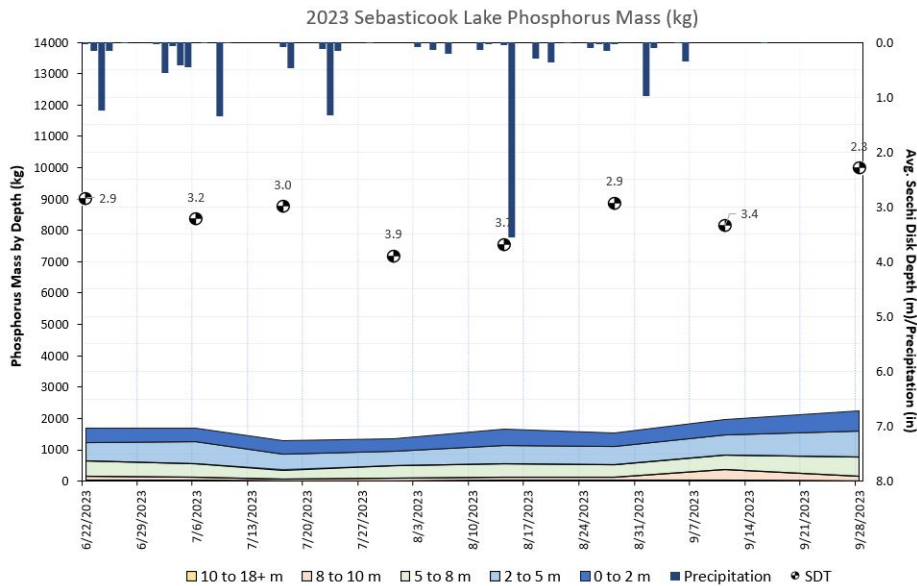


Sebasticook Lake P Load Summary
 (Direct vs. Indirect Watershed)

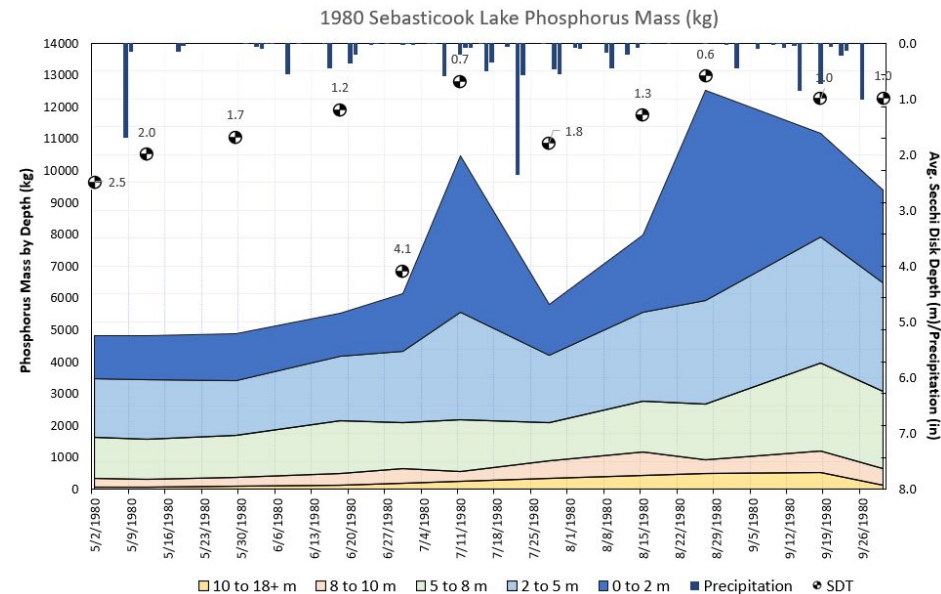


Long-Term Changes: Sebasticook Lake

2023: 40 years after drawdown



1980: Prior to drawdown



- ❖ Significant reduction in both watershed and internal loading
- ❖ Better? Yes, but....a new era of effort is needed to address persistent summertime algal blooms

Getting Started

1. Identify if internal loading is a potential factor (regular collection of DO/Temp profiles)
2. Raise funds to cover lab costs (\$45/P sample)
3. Recruit volunteers to help collect the data
4. Recruit technical staff to train volunteers & help with data analysis & interpretation
5. Start small- collect BG samples at bottom of lake



Sebasticook Lake, Newport

Questions/Discussion



Photo: Doug Miller, WLA