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March 2024
Revised June 2024

TO: Property Owner's Association of Lake Hayward
ATTN: Wolf Koste
FROM: George Knoecklein, Owner, Principal Limnologist
Re: Summary of water quality and aquatic plant monitoring at Lake Hayward in 2023

Introduction

In 2023, POALH volunteers conducted water quality monitoring biweekly from May through October at two sampling stations: Station 1 and Station 2. At each station, dissolved oxygen and temperature profiles were recorded, along with water clarity and weather condition. Water samples were collected from Station 1 once per month for nutrient analyses.

NEAR staff visited the lake twice in November 2023 to conduct water quality monitoring and inspect the watershed.

Nutrient Goals

Some of the water quality data included in this summary is assessed using the CT DEEP categorization of lakes, which is primarily based on the amount of phosphorus in surface waters during summer conditions (**Table 1**). For Lake Hayward, the goal condition is oligo-mesotrophic, meaning surface water total phosphorus less than 15 ppb, surface water total nitrogen less than 300 ppb, and water clarity (Secchi depth) greater than 4 meters.

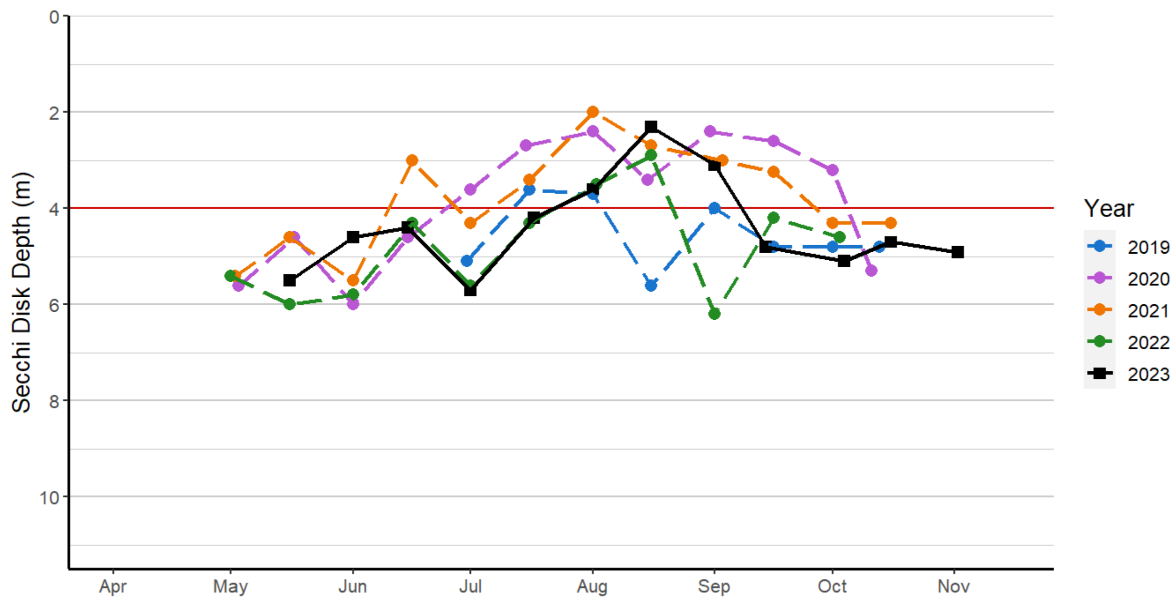
Table 1. Parameters and defining ranges for trophic states of lakes in Connecticut.

Category	Total Phosphorus (ppb)	Total Nitrogen (ppb)	Secchi Depth (ppb)
Oligotrophic	0 -- 10	2 -- 200	6 +
Oligo-mesotrophic	10 -- 15	200 -- 300	4 -- 6
Mesotrophic	15 -- 25	300 -- 500	3 -- 4
Meso-eutrophic	25 -- 30	500 -- 600	2 -- 3
Eutrophic	30 -- 50	600 -- 1000	1 -- 2
Highly Eutrophic	50 +	1000 +	0 -- 1

Water Clarity

The Secchi disk measurements in 2023 were better than the 4-meter threshold on all dates except August 1st, August 16th, and September 1st (**Figure 1**). During this period, the anoxic boundary ascended into the bottom layer of the thermocline. In all months except August, clarity in 2023 was similar to 2022 and better than 2020 and 2021.

Figure 1. Lake Hayward water clarity measured at Station 1, 2019 – 2023.



Water Temperature

The first sampling event of 2023 occurred in mid-May. By this time, the lake was already thermally stratified at both sampling stations (**Figure 2**, **Figure 3**). The water column remained stratified until fall mixing occurred in October.

The surface water at Station 1 warmed to a maximum temperature of 27.6°C in July. Station 2 reached 27.1°C at the surface on the same date but was slightly warmer at 1 meter below the surface and several meters deeper. This phenomenon occurred on multiple occasions. At Station 2, the shallower of the two sampling locations, the water column was mixed, with uniform temperature from top to bottom. Due to the deeper depth at Station 1, the water column here did not reach a fully mixed state until mid-October.

Figure 2. 2023 Lake Hayward Station 1 water temperature isopleth.

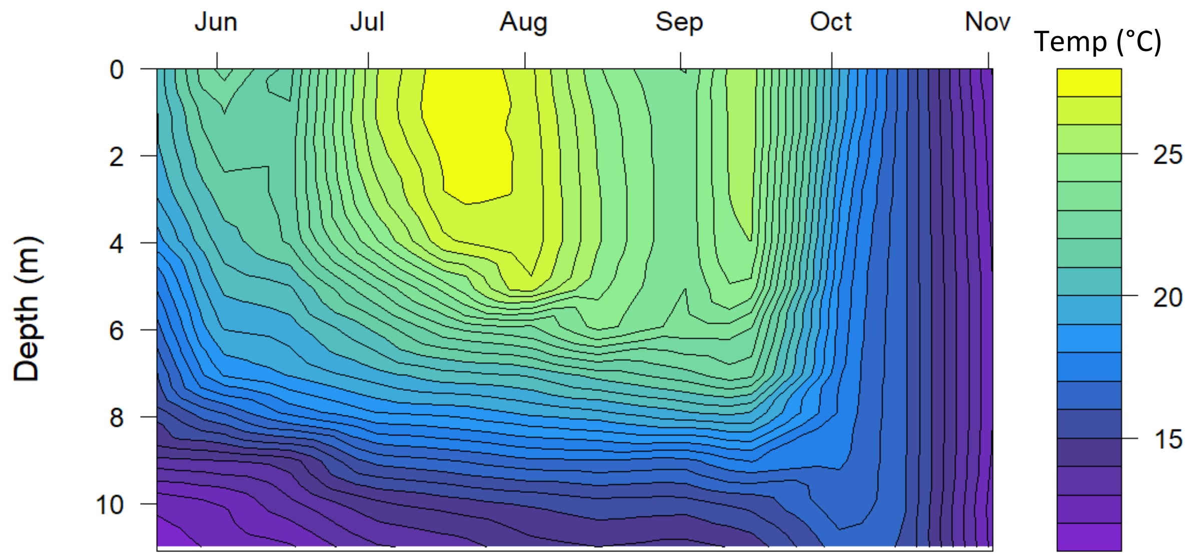
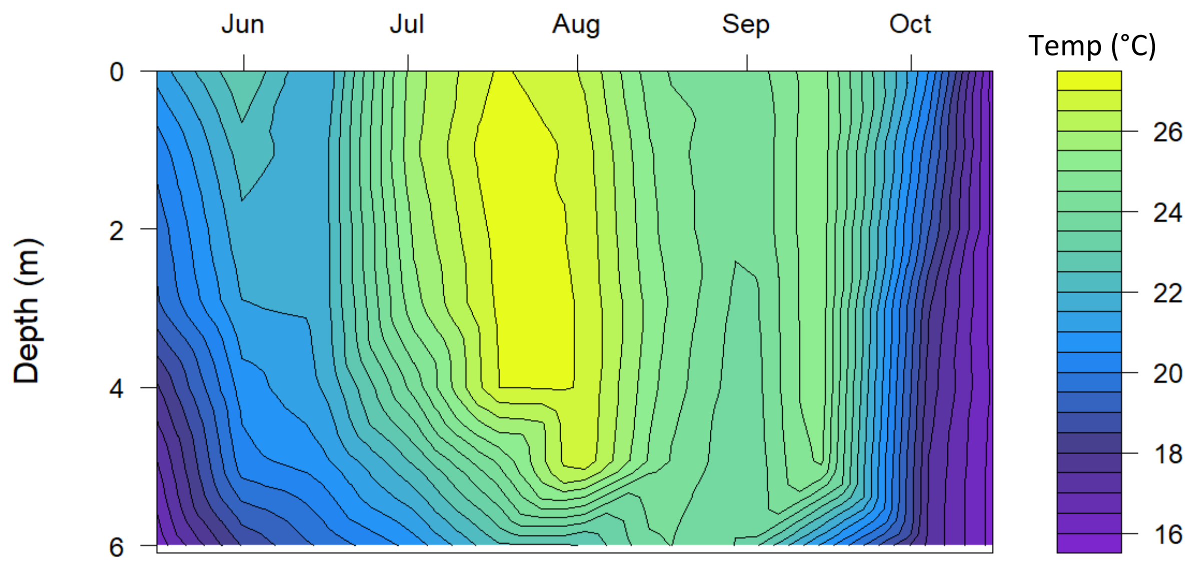


Figure 3. 2023 Lake Hayward Station 2 water temperature isopleth.



Dissolved Oxygen

During the first sampling event in mid-May, dissolved oxygen at Station 1 was reduced below 4 meters, and the bottom half meter of water was anoxic (<1mg/L of dissolved oxygen) (**Figure 4**). The anoxic boundary rose in the water column until reaching a maximum height of 5.5 meters from the surface (5.5 meters from the lake bottom) in mid-July (**Figure 5**). The anoxic boundary remained between ~5.5 and 7 meters from the surface until mid-September. This represents a considerable dissolved oxygen demand in the lake's bottom water. The lake began to quickly turnover in late September or early October. By mid-October, the water column was fully mixed.

At Station 2, the bottom half meter of water was anoxic from mid-July to early August, after which DO at the very bottom increased slightly (**Figure 6**). The water column at Station 2 had nearly reached thermal uniformity by mid-September, though the mixing of the oxygen-depleted bottom water throughout the water column did cause slightly reduced DO throughout. By early October, dissolved oxygen concentration had increased at all depths.

Figure 4. 2023 Lake Hayward Station 1 dissolved oxygen isopleth.

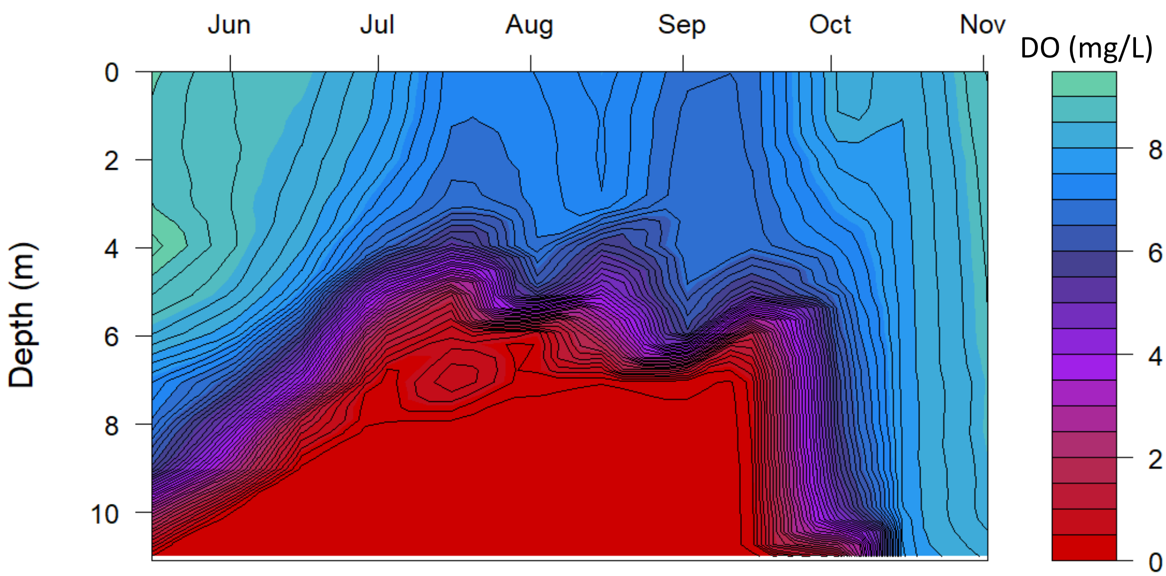


Figure 5. Lake Hayward Station 1 anoxic boundary depths, 2019 – 2023.

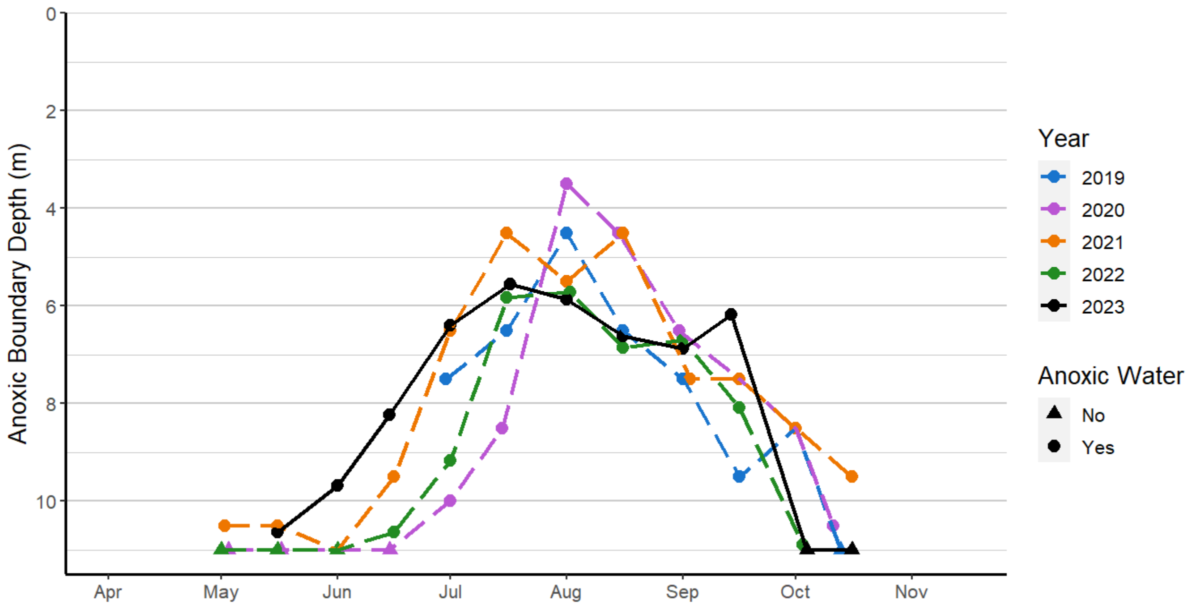
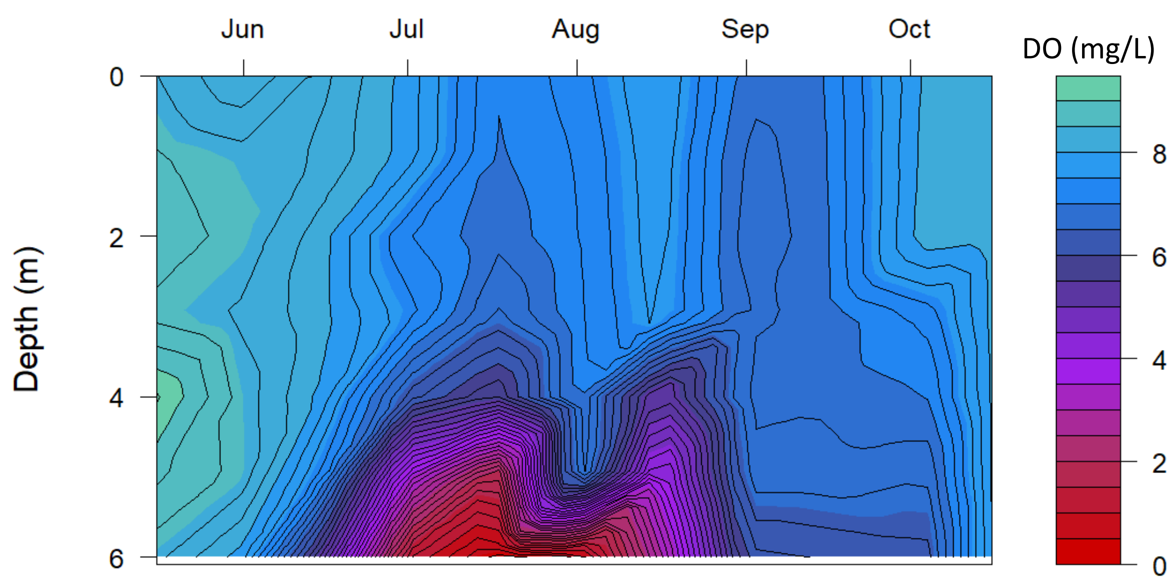


Figure 6. 2023 Lake Hayward Station 2 dissolved oxygen isopleth.



Nutrients

Total Phosphorus Concentration

Total phosphorus (TP) in surface water should remain below 15ppb for the entire sampling season. In 2023, surface water TP remained below this threshold on all sampling dates except for August 1st (**Figure 7**). TP in the middle sampling depths (6m and 8m) also remained low. In the bottom water (10m), TP was elevated during the first sampling event in mid-May. TP then dropped to low levels in June, before increasing again in July. From August through November, TP in the bottom water remained low. In recent years, the TP in the bottom water spiked in the mid- to late season in conjunction with anoxic conditions and internal loading (**Figure 8**). This was not observed in 2023, despite the presence of a large volume of anoxic water.

Figure 7. 2023 Station 1 total phosphorus concentrations.

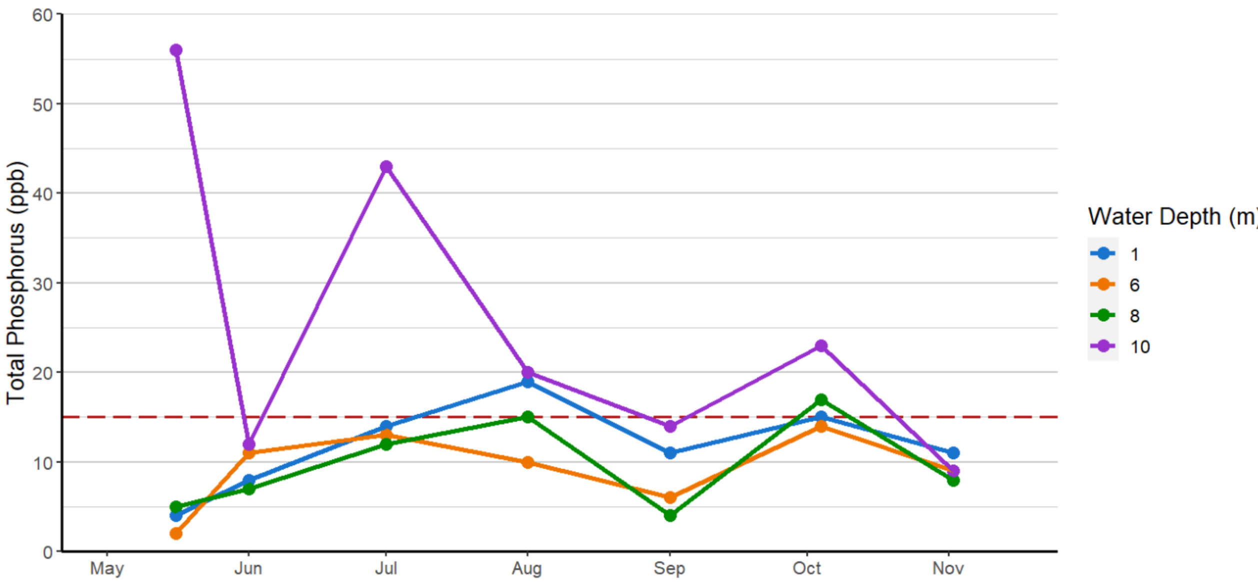
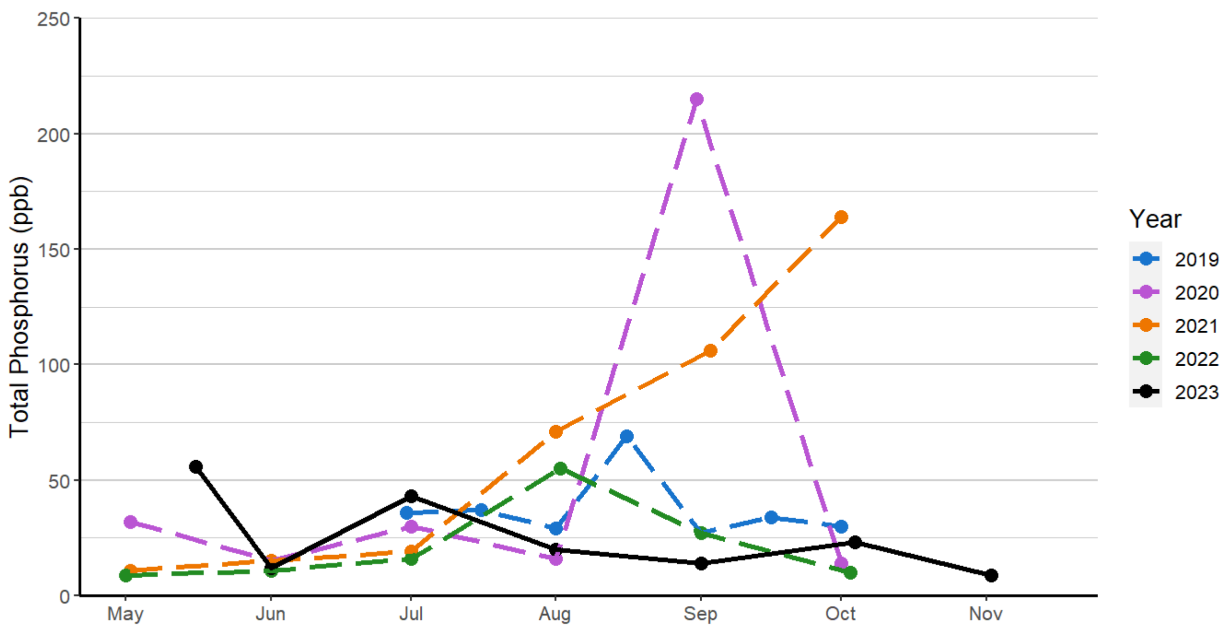


Figure 8. Bottom water total phosphorus concentrations, 2019 – 2023.



Total Phosphorus Mass

The total mass of phosphorus (P) in Lake Hayward is the product of the concentration of phosphorus in the water and the volume of water represented by the samples. The total mass of phosphorus (and nitrogen) in 2023 is compared to a similar study conducted by NEAR in 2000. In both 2000 and 2023, the water in Lake Hayward was sampled at 5 depths to obtain an accurate representation of the water column.

The total mass of phosphorus in the lake during 2000 varied between a low of 10 kgP in April to a high of 21 kgP in late September (**Figure 9**). Increases in P appear to be loading to the 1- and 3-meter water layers, as P mass at 5, 7, and 9 meters showed very little change over the season. This suggests that the lake was receiving approximately 10 kgP over a 5-month period, April to September, mostly from groundwater. A full year of loading may have supplied close to 20kgP/year.

In 2023, the mass of P in the lake was similar in April, at near 10kgP, but rapidly increased to 40 kgP by August 1st, twice the amount of phosphorus in the lake compared to 2000 (**Figure 10**). The kgP remained above 20kg for the remainder of the season. The largest changes occurred at 1m, with some changes occurring at 6 meters. The 8- and 10-meter layers showed very little change in TP mass.

In 2023, the lake gained ~30kgP during the months of April through August, as opposed to 10kgP in this same period in 2000. The greatest gain occurred in the top several meters of the lake, with ~10kgP in 2000, and ~25kP in 2023. Increases in bottom P have not been directly implicated in the increased P in upper layers. Increased P in the bottom layers in August 2000 did not translate to increased P in the 1- and 3-meter layers. In August 2023, P in deeper water decreased while P dramatically increased in the upper water.

Figure 9. Phosphorus mass as kg in Lake Hayward during 2000.

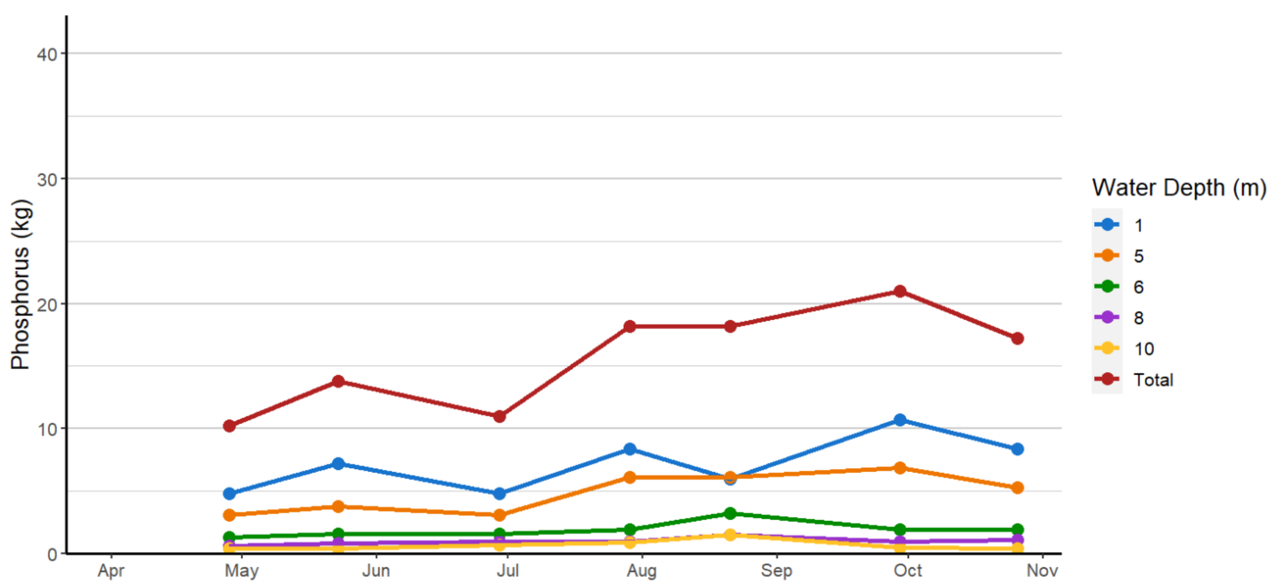
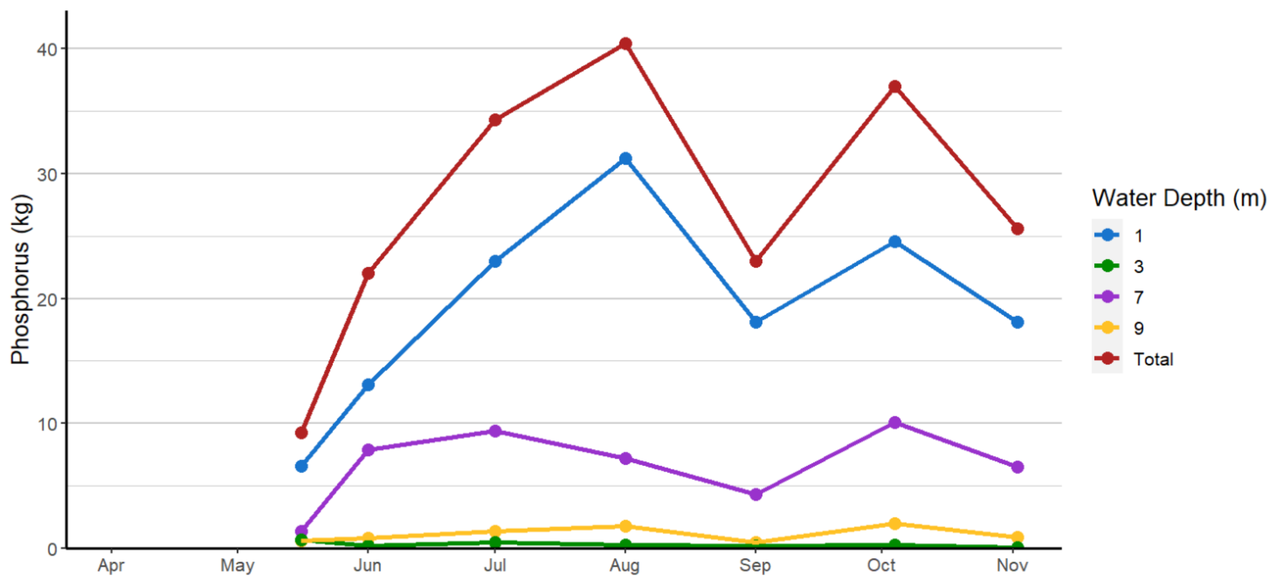


Figure 10. Phosphorus as total mass in kg in Lake Hayward during 2023.



Total Nitrogen Concentration

Total nitrogen (TN) in the surface water remained below the 300ppb threshold from May through July (**Figure 11**). TN rose steadily from July onward, reaching a maximum concentration of 400ppb in November. On this sampling date, the TN concentrations at all four sampling depths fell within a 30ppb range due to fall turnover, meaning the elevated nutrients that had been trapped in the anoxic bottom water mixed evenly throughout the water column. 400ppb is the highest surface water TN concentration recorded in the lake in the last five years (**Figure 12**). This is because bottom water TN concentrations were also unusually high compared to prior years (**Figure 13**). TN in the bottom water reached a maximum concentration of 2,359pbb in September. This is the highest in-lake TN concentration we have on record for Lake Hayward. This is indicative of increased internal loading of nutrients from the bottom sediments during anoxic conditions. Anoxia persisted in the deep spot for 4.5 months, and 4 to 5 meters of water was anoxic for 2.5 months, meaning anoxic water covered a large area of the lake bottom, and all the sediment that was exposed to anoxic water was releasing nutrients. While the anoxic boundary has reached higher in the water column in prior years, in 2023 the anoxic water began rising earlier in the season and remained high in the water column later into the season compared to prior years. This allowed for a longer period of internal loading.

Figure 11. 2023 total nitrogen concentrations.

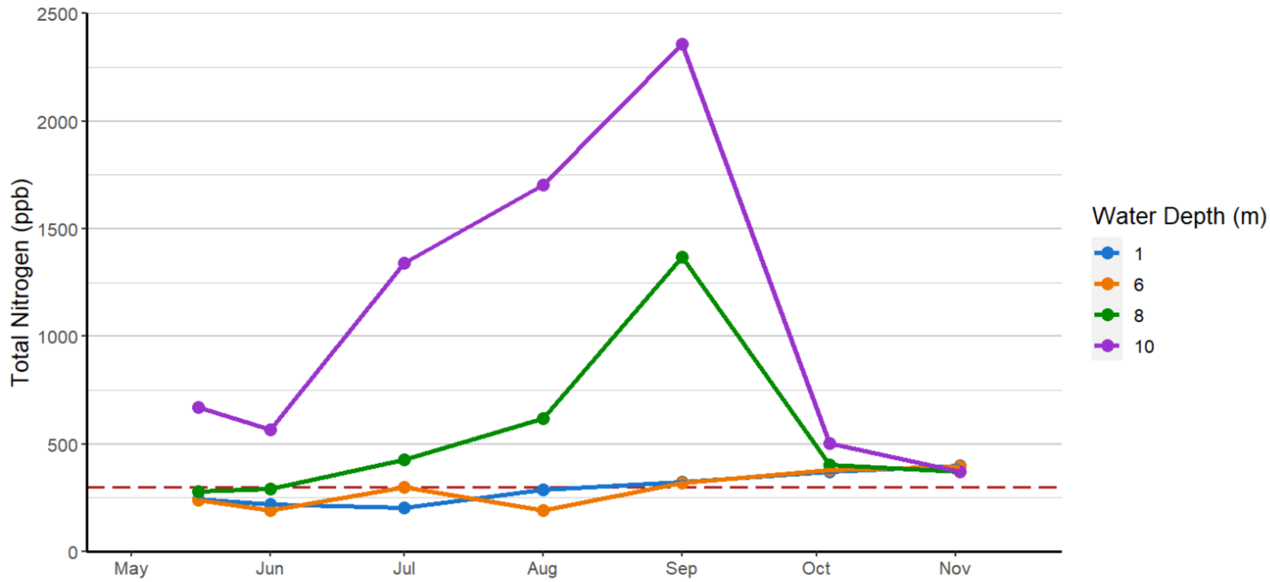


Figure 12. Surface water total nitrogen concentrations, 2019 – 2023.

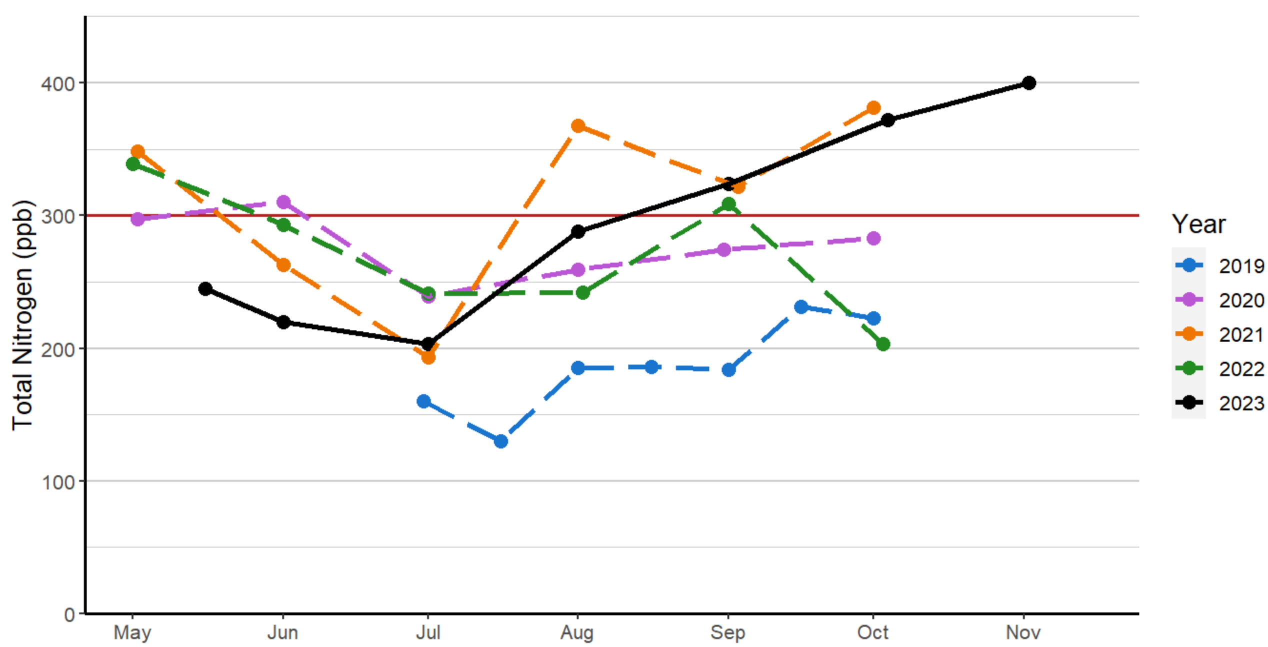
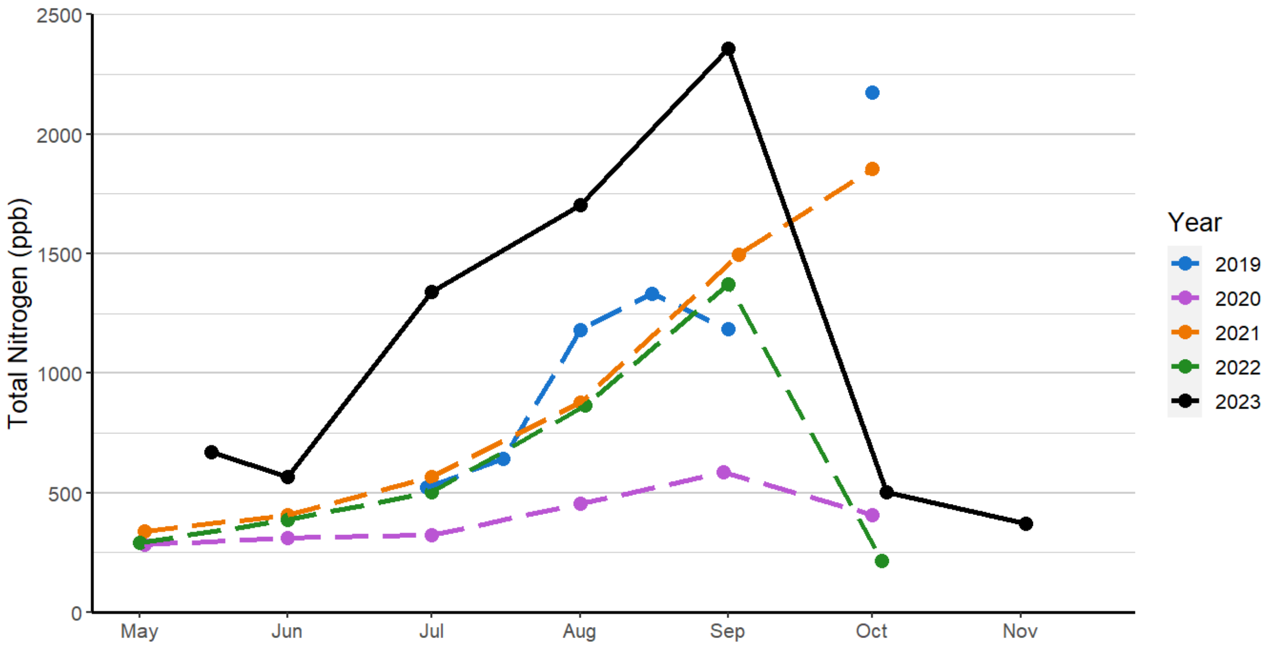


Figure 13. Bottom water total nitrogen concentrations, 2019 – 2023.



Total Nitrogen Mass

The total mass of nitrogen (N) in the lake during 2000 varied between a low of 400kgN in July to 900kgN in late June (**Figure 14**). Increases in N appear to be loading to the 1- and 3-meter water layers, as N mass at 5, 7, and 9 meters showed very little change over the season. In 2000, the lake lost a total of 200kgN between April and October.

In 2023, the mass of N in the lake was 600kg N in April, but instead of declining as in 2000, kgN slowly increased to end the season at 1000kgN (**Figure 15**). N began increasing in July and remained above 20kg for the remainder of the season. The largest changes occurred at 1 meter, with some changes occurring at 6 meters. The 8- and 10-meter layers showed very little change in N mass.

The lake appeared to lose 200kgN in 2000 but gained almost 400kgN in 2023. The gain occurred as a steady increase in surface water N, with minimal change in the bottom water.

Figure 14. Total nitrogen as kg in Lake Hayward 2000.

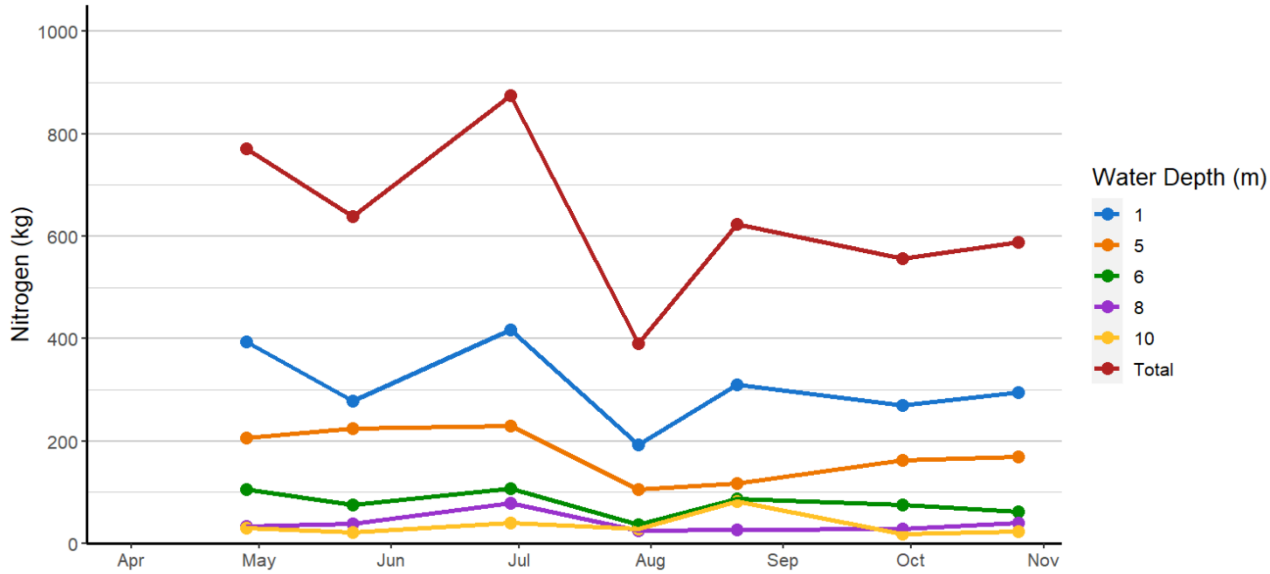
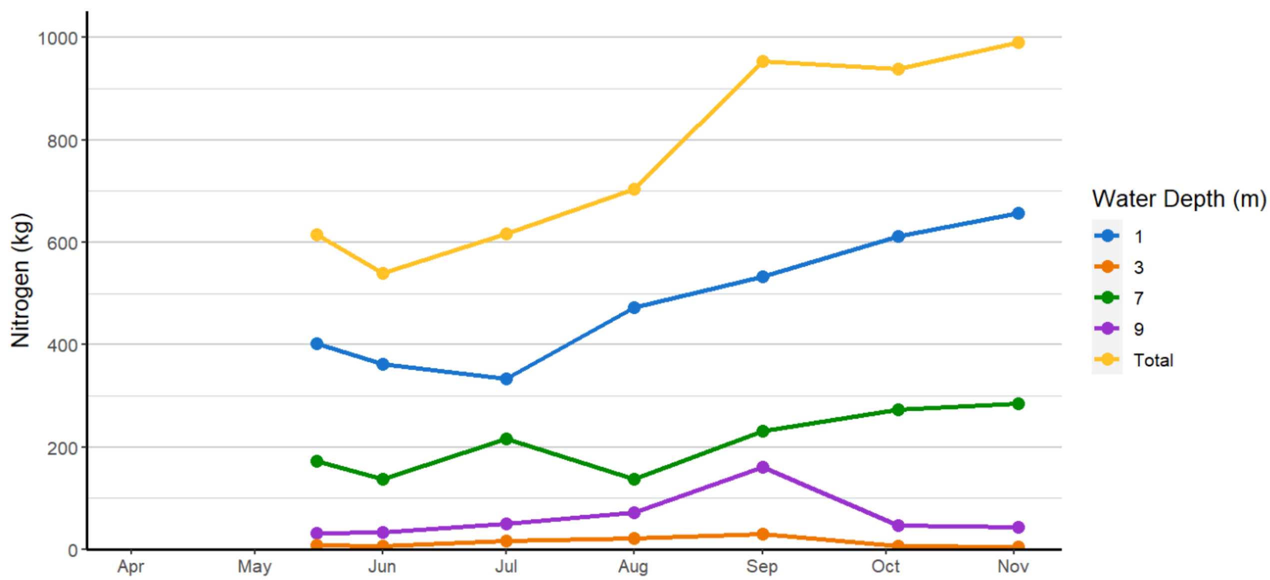


Figure 15. Total nitrogen as kg in Lake Hayward 2023.



Stream Nutrient Concentrations

The inlet concentrations for phosphorus and nitrogen testing between 2021 and 2023 are given in (**Tables 2 & 3**). The tables show that specific drains are contributing very high concentrations of each. Inlets W1, W2, W3, and W6 had highest average phosphorus concentrations, although all inlets had excess phosphorus, the TP goal is <20ppb. Inlets W2, W3, and E6 had highest average nitrogen concentrations, although all inlets except W1 and W5 had excessive nitrogen, TN goal is <400.

Table 2. Total phosphorus concentrations at the lake's inlets 2021-2023.
Salmon=>100ppb, yellow=75-99ppb, green=50-74ppb, and blue=20-49ppb.

Total Phosphorus ppb	2021									2022								2023		Mean	Max
	26-Mar	16-Apr	25-Apr	4-May	29-May	14-Jun	3-Jul	9-Jul	22-Aug	1-Apr	8-Apr	19-Apr	2-May	7-Jun	22-Aug	23-Aug	6-Sep	16-Jul	25-Sep	ppb	ppb
W1 (total area 65 ac)	44	119		84	203	192	74	183	229				40	94			98			124	229
W1-Lookout									203	50	61		39	122			116			99	203
W2 (total area 49ac)																					
W2-USD (Drains to W2)				35	20	183	20	365	356									128		158	365
W2-BBO (Drains to W2-USD)																224	66	160		150	224
W2-U (Drains to W2-BBO)	11	15								19	39			14		147	77	141		58	147
W2-U HFLD31 (Drains to W2-U)									268					8				135		137	268
W2-HFDUSDS (Drains to W2-USD)									645	106	147						242	208		270	645
W2.5																		219			
W3 (total area 63ac)	19	26		43	40	140	42	150	198				8	42	70		86			72	198
W3 LNGWD (Drains to W3)														55			118			87	118
W3-BCLFUSD (Drains to W3 LNGWD))												114	34				123			90	123
W4 (total area 22ac?)																		30	53	42	53
W5 (total area 22ac?)																			33	33	33
W6 (total area 23ac)	35					251		66												117	251
E1 (total area 135ac)																		44		44	44
E3 (total area 189 ac)														12			47			30	47
E5 (total area 160ac)	10	9		18	31	96	18	76	69					9	55		42			39	96
E6 (total area 104ac)	6	10	138	19	16	164	10	37	39					13	53		31			45	164
N1 (total area 432ac)														28			37			33	37

Table 3. Total nitrogen concentrations at the lake's inlets 2021-2023.
Salmon=>2000ppb, yellow=1000-1999ppb, green=750-999ppb, and blue=600-749ppb.

Total Nitrogen ppb	2021									2022								2023		Mean	Max
	26-Mar	16-Apr	25-Apr	4-May	29-May	14-Jun	3-Jul	9-Jul	22-Aug	1-Apr	8-Apr	19-Apr	2-May	7-Jun	22-Aug	23-Aug	6-Sep	16-Jul	25-Sep	ppb	ppb
W1 (total area 65 ac)	351	381		308	270	471	300	397	519				330	347			761			403	761
W1-Lookout									438	310	308		295	364			625			390	625
W2 (total area 49ac)																					
W2-USD (Drains to W2)				2951		2525	3069	1409	2927									2058		2490	3069
W2-BBO (Drains to W2-USD)																2283	4017	5510		3937	5510
W2-U (Drains to W2-BBO)	3945	3711								3981	3728			3658		2216	4138	5990		3921	5990
W2-U HFLD31 (Drains to W2-U)									3882					3788				4370		4013	4370
W2-HFDUSDS (Drains to W2-USD)									1131	416	404						2914	994		1172	2914
W2.5																		996		996	996
W3 (total area 63ac)	974	921		863	1160	1164	928	1376	2089				893	1049	1184		2225			1236	2225
W3 LNGWD (Drains to W3)														104			1133			619	1133
W3-BCLFUSD (Drains to W3 LNGWD))												915	222				1677			938	1677
W4 (total area 22ac?)																		966	737	852	966
W5 (total area 22ac?)																			315	315	315
W6 (total area 23ac)	224			117		1017		450												452	1017
E1 (total area 135ac)																		645		645	645
E3 (total area 189 ac)														738			762			750	762
E5 (total area 160ac)	1311	959		674	624	1390	636	857	1035					839	1625		840			981	1625
E6 (total area 104ac)	842	590	654	501	583	1069	588	624	948					286	2095		734			793	2095
N1 (total area 432ac)														600			607			604	607

W-2 subbasin

The subbasin with the highest nutrient levels was W2, draining approximately 49 acres. Along with the W2 site, which flows directly into the lake, there are 5 sampling locations within the subbasin, beginning at a culvert near the lake, W2-USD. This site collects water from two principal sources: a stream that runs between Hilltop Road and Town Road, and culverted water from catch basins at the base of Hilltop Road. The stream has three collection sites, W2-BBO, W2-U, and W2-HFLD31.

The water culverted from the base of Hilltop Road is collected at its head waters approximately 200 feet up hill on Hilltop Road at W2-HFDUSDS. On July 16th, following a 2.5” rain event within the prior 24 hours, these 5 sites were sampled, along with three additional subbasin inlets, E1, W2.5, and W4/5. The water samples were analyzed for concentrations of total phosphorus, total nitrogen, nitrate-nitrogen, and ammonia-nitrogen (**Table 4**).

The nitrate concentrations for the samples in the W2 stream series; HFLD31 => U => BBO => USD (**Map 1**) shows a very clear progression of decreasing concentrations from the highest of 5,977ppb at HFLD31 and lowest of 1,293ppb at USD. The total nitrogen at these sites was almost all in the form of nitrate, suggesting an inorganic form. Nitrate is readily taken up by plants, moss attached algae, etc., that are growing in the water channel, so a decreasing concentration of nitrate away from HFLD31 points to the source being somewhere upstream of HFLD31. These are extremely high nitrate concentrations. Ammonia was low at all sites but present nonetheless, suggesting a source of ammonia upstream. Phosphorus was high at all sites. The highest TP was found at W2-HFLDUSDS, a site that drains a large hay field to the south and west. The high TP at this site elevated the TP found at W2-USD. TP increased in the stream series HFLD31 => U => BBO, from 138 to 160ppb, but decreased => W2-USD to lowest TP of 128pp (still an excessive concentration!).

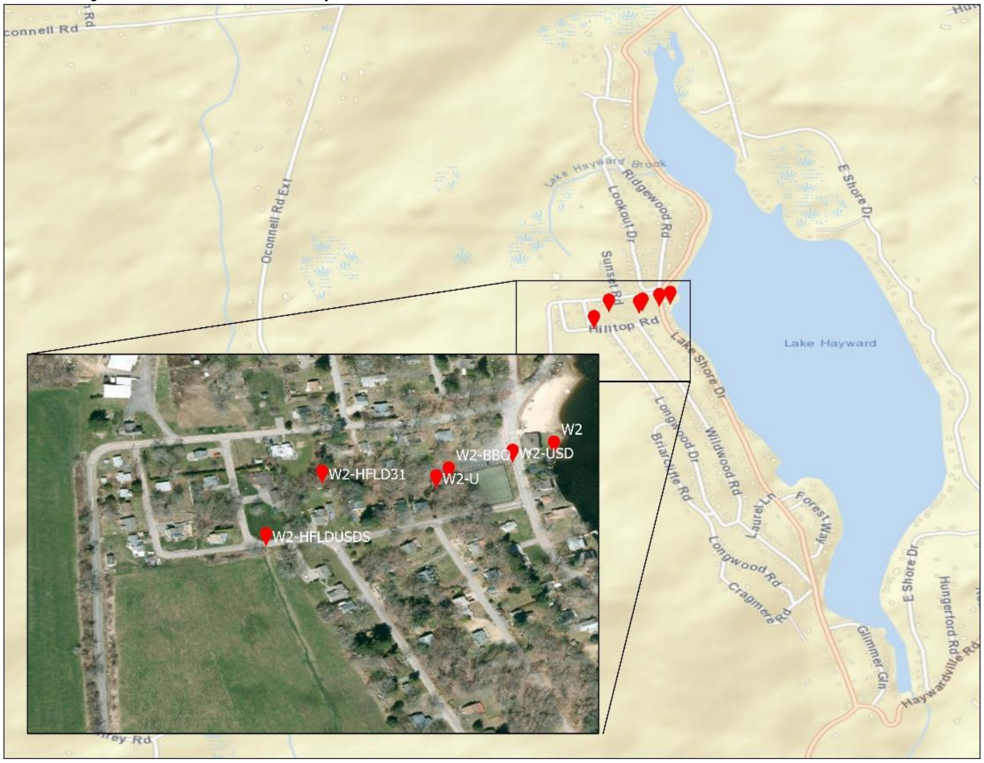
The other inlet samples collected following the rain event contained lower concentrations than those from the W2 subbasin, but they were still elevated above acceptable levels. W4/5N and W2.5 had total nitrogen concentrations close to 1,000 ppb, while W2.5 had the highest TP concentration of all the samples, at 219ppb.

Table 4. Nitrate and Ammonia nitrogen concentrations (ppb) from select inlets on July 16th and September 25th, 2023.

Basin Identifier	Nitrate ppb	Total Nitrogen ppb	Percent Nitrate	Ammonia ppb	Percent Ammonia	Total Phosphorus ppb
	7-16-2023					
E1	72	645	11	13	2.0	44
W2-USD (drains to lake)	1,293	2,058	63	31	1.5	128
W2-BBO (drains to W2-USD)	4,723	5,510	86	42	0.8	160
W2-U (drains to W2-BBO)	5,397	5,990	90	38	0.6	141
W2-HFLD31 (drains to W2-U)	5,977*	4,370*	>90?	53	1.2	135
W2-HFLDUSDS (drains to W2-USD)	14	994	1.4	42	4.2	208
W2.5	392	996	39	20	2.0	219
W4/5N	726	966	75	16	1.6	30
	9-25-23					
W4/5N	514	737	70	18	2.4	53
W4/5LSD	104	315	33	<5	<1	33

*Laboratory couldn’t rectify this inequality.

Map 1. Locations of stormwater samples with excessive nutrient concentrations.



Mass Loading

The average, or mean, concentrations listed in tables above can be converted into a mass quantity, by multiplying the concentration-micrograms per liter, by the water flow-cubic meters per year (**Table 5**). The estimated water flow is calculated by assuming half the annual rainfall of 47 inches, is converted into runoff from the area of the drainage basin. The estimates will vary based on changing volume of water flow and the concentration, the estimated mass increases as either the concentration or the water flow increase. The accuracy of these estimates can be increased by 1-collecting more base flow samples at regular intervals and more samples from high storm flows, and 2-use real time water flow rates as opposed to estimates. The total annual rainfall in CT during 2023 was 64.97, 18 inches, or 38% more than normal, indicating that all the loading estimates in **Table 5** were roughly 38% higher in 2023. Three factors from a higher annual rainfall will cause higher loading, 1) the large volume of water running off the land, 2) a larger fraction of the rainfall becomes runoff, often near 100%, during intense storms, and 3) the higher intensity storms cause high velocity in all streams, culverts, channels, etc., which causes more erosion.

The estimated total load to the lake of TN is 2,619 kgN/yr and of TP is 156 kgP/yr. Based on 2023 rainfall of 65inches the annual loading could have been roughly 3,614 kgN/yr, and 215 kgP/yr. The TN loading of 2600 – 3600 kgN/yr are close to the total estimated mass of N in the lake last year with a peak mass of about 400 kgN last summer, the phosphorus estimates of ~156 kgP/yr are closer aligned with lake mass increase of about 40 kgP in the summer.

Table 5. Total nitrogen and total phosphorus kg/y loading estimates and average concentrations at the lake's inlets.

Basin Identifier	Area (acres)	kgN/yr	Avg N (ppb)	kgP/yr	Avg P (ppb)
N1	461	675	604	36	33
E1	207	324	645	22	44
E2	456			33	
E3	189	344	750	14	30
E4	26				
E5	160	381	981	15	39
E6	104	200	793	11	45
E7	27				
W1	65	64	403	19	124
W2	49	296	2,490	19	158
W3	63	189	1,236	11	72
W4	44	91	852	4	43
W5	15	11	315	1	33
W6	23	44	793	3	45
Total	**1,302**	**2,619**		**156**	

Phytoplankton

The phytoplankton groups known as Chrysophytes, Diatoms, Greens, and Cyanobacteria were present in Lake Hayward in 2023 (**Figure 16, Figure 17**). Non-Cyanobacteria numbers were low in all samples collected in 2023, with July having highest cell numbers at ~12,000 cells/mL when the Chrysophyte: Dinobyron was dominant.

Cyanobacteria cell numbers were much higher, with a maximum density of ~90,000 cells/mL in June when the tiny (~20µmx0.5µm) filament, Raphidiopsis, typically found in deep water of the thermocline, was numerous. Microsystis was present at cell numbers between 20,000-30,000 cells/mL during June, July, and August. Cell numbers over 20,000 begin to affect water transparency and will provide suitable material to cause either pop-up blooms and or surface wispy-bits. Cyanobacteria and phytoplankton are generally very susceptible to the radiation of direct sunlight such that cells trapped at the surface die quickly. Wispy-bits are collections of massive colonies of overbuoyant cells that have become trapped by the surface tension of the lake surface. Cells become overbuoyant because buoyancy structures are only constructed in the dark in deepest water and must be sufficient to compensate for the high density of that water at that depth. These cells end up accelerating with increasing lift as they ascend because the water continually becomes less dense as the cells rise.

Figure 16. Non-cyanobacteria groups and counts during 2023.

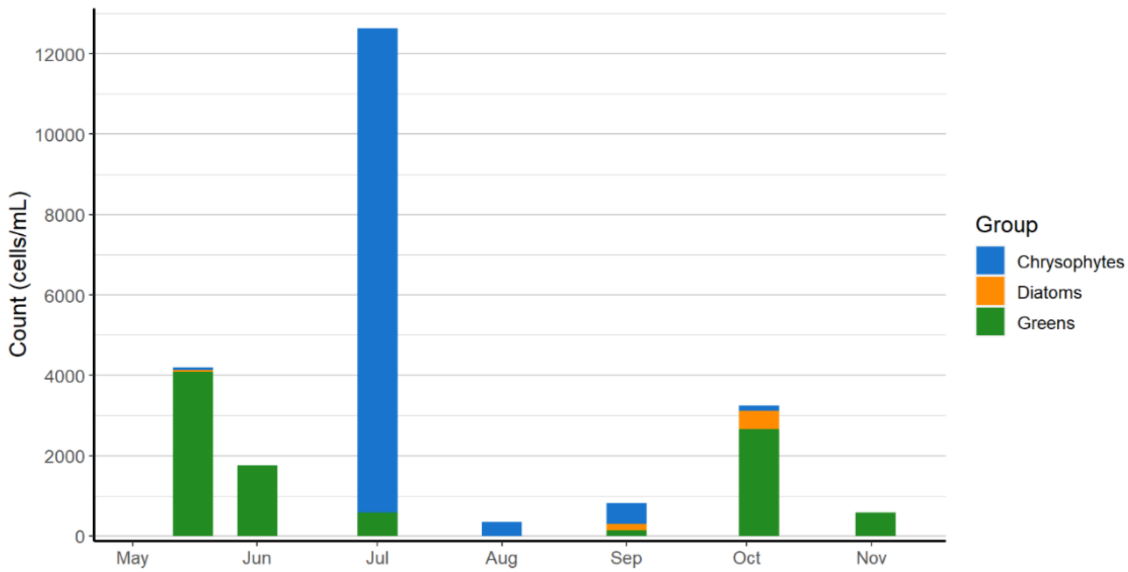
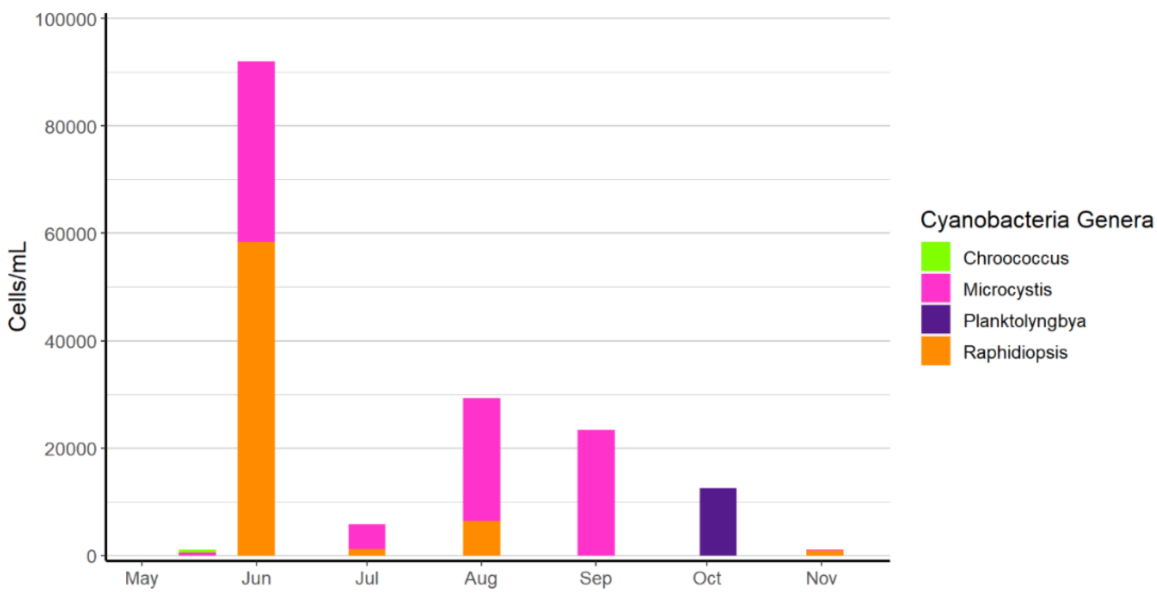


Figure 17. Cyanobacteria groups and counts during 2023.



Recommendations for 2024

Monitoring Plan

The data in **Tables 2 & 3** show that subbasins W1, W2, and W3 have extraordinarily high concentrations of phosphorus and nitrogen. In 2024, the priority should be to collect samples from the mouth of the W1, W2, and W3 subbasin inlets (where the inlet enters the lake), once per week from April through November. These samples will be analyzed for concentrations of total phosphorus, total nitrogen, and nitrate nitrogen. The POALH should purchase a Global Water Flow Probe to measure water flow at these inlets during each sampling event. This will allow us to calculate the mass of nutrients entering the lake from these subbasins.

Additionally, during one heavy rain event in 2024 (at least 1" of rainfall in a 24-hour period) all inlets that flow directly into the lake should be sampled at the mouth of the inlet on the same day. These samples will be analyzed for concentrations of total phosphorus and total nitrogen.

In-lake water quality monitoring should be conducted bi-weekly from April through November. One of the goals of water quality monitoring is to capture lake conditions during spring and fall mixing. By May, the water column was already heavily stratified, with anoxic bottom water. Sampling should begin in early April when the water column is isothermal. Water samples do not need to be collected from the 6-meter depth in 2024. Samples should be collected from 1, 9, and 11 meters. Additionally, water quality monitoring does not need to be conducted at Station 2.

Watershed Improvements

The bioretention basin in the W2 subbasin needs to be reexamined and corrected to improve its detention capability. There should be a 6-8" increase in the capability of the basin to hold water to allow for infiltration.

Any manure piles in the hayfields should be surrounded by a silt fence or hay bales to reduce runoff. There are many programs available to aid in improving environmental practices on farmland. Information about programs available through the US Department of Agriculture (USDA) and the Natural Resources Conservation Service (NRCS) can be found at the following links:

- https://www.nrcs.usda.gov/programs-initiatives/ama-agricultural-management-assistance/connecticut/connecticut-agricultural
- https://www.nrcs.usda.gov/programs-initiatives/csp-conservation-stewardship-program/connecticut/connecticut-conservation
- https://www.fsa.usda.gov/state-offices/Connecticut/news-releases/2023/usda-offers-connecticut-producers-many-conservation-choices-with-continuous-crp-

Nitrate nitrogen concentration during the July 2023 storm was extremely high at the upper reach of the W2 stream (HFLD31 => U => BBO => USD). The total nitrogen was nearly all in the form of nitrate, with little organic nitrogen present, suggesting the nitrate was an inorganic form. This indicates that adding nitrate to the testing regimen will be important going forward.

Ammonia nitrogen was low at all sites during July 2023, indicating ammonia testing isn't warranted at this point.

The Connecticut Department of Energy and Environmental Protection (DEEP) offers grant funding through the Section 319 Clean Water Act to help municipalities implement watershed improvements. To obtain grant funding, the municipality must first produce a 9-Element Watershed Based Plan, which involves identifying problem areas within the watershed and proposing improvements. At this time, we suggest focusing on the potential issues we identified in the W2 subbasin, discussed above, but the POALH may wish to consider preparing a 9-Element WBP in the coming years to obtain funds for other watershed improvements.

More information about 319 grant funding can be found at the link below:

- https://portal.ct.gov/DEEP/Business-and-Financial-Assistance/Grants-Financial-Assistance/Clean-Water-Act-Section-319-Nonpoint-Source-Grants

The Property Owners Association of Lake Hayward should look to their Rules and Regulations to enforce the maintenance of septic systems in the community. There is specific language under the heading “Environmental” item #2 in that document pertaining to the required maintenance of these systems.

Current Lake Hayward sampling stations. Water quality monitoring only needs to be conducted at Station 1 (Wpt 955) in 2024.