

Deep Creek Lake Water and Habitat Quality 2009–2024



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September 2026

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Executive Summary

An analysis of seasonal (May–September) Deep Creek Lake monitoring data from 2009–2024 revealed that surface water habitat and water quality remained good to fair for most indicators, years, and locations. The lake routinely exhibited intense summer stratification (layering), with an upper layer (epilimnion) that was favorable in terms of oxygen levels but unfavorably warm for some aquatic life, and deeper water that was cooler but severely oxygen-depleted, especially below 10 m (33 ft) depth.

Deep Creek watershed land use data (Claggett et al. 2025) indicated a net loss of 560 acres of forest and a net expansion of developed land (140 acres pervious, 108 acres impervious) between 2013/2014 and 2021/2022. Forest remained the primary land cover, and overall impervious surfaces remained relatively low at 4.4%. There were no substantial changes in cropland.

Spatial patterns in lake habitat and water quality were associated with differences in land use across the watershed in 2021/2022. The northwest sub-watershed and Cherry Creek sub-watershed were more forested (68.3% and 72.5%) and less agricultural (0.4% and 0.6% cropland), potentially contributing to better water quality in the northwest part of the lake. The southeast sub-watershed was most heavily agricultural (4.2% cropland) and least forested (51.4%), potentially contributing to worse water quality in the southeast part of the lake. Water quality was assessed in terms of the typical levels of nutrients (nitrogen and phosphorus), algae, cloudiness, and water clarity in similar lakes. A gradient from lower water quality at shallow nearshore tributary stations to intermediate water quality in intermediate-depth coves to higher water quality in the mainstem lake was apparent in both the northwest and southeast parts of the lake (Table ES.1).

Statistical models were used to evaluate changes (trends) in water quality indicators at specific monitoring stations. Trends analysis was mostly restricted to a specific subset of data (13 stations, 2009 to mid-2016), because of changes to the monitored stations and changes to the analytical laboratories that processed the collected samples starting in 2016. For other subsets of the data, a statistically robust trends analysis will become feasible if the current monitoring methods are maintained for 3–5 additional years of data collection. Statistically significant declines in water quality were detected at some but not all stations for most assessed indicators (surface water temperature; bottom water oxygen; surface and bottom acidity and conductivity, surface water levels of algae and related indicators: nitrogen, phosphorus, cloudiness, and water clarity). These declines were generally small, only rarely involved changes in assessment category (i.e., from good to fair or from fair to poor water quality), and do not necessarily indicate ongoing, longer-term trends.

Table ES.1. Summary of typical 2009–2024 Deep Creek Lake water quality.

Monitoring stations were grouped by sub-watershed (southeast, northwest including Cherry Creek) and by deep (>10.7 m, >35 ft) intermediate (3.0–10.7 m, 10–35 ft) or shallow (<3.0m, <10 ft) nominal bottom depth. Named tributary stations refer to Arrowhead Run (AWR0001), Cherry Creek (CCR0001), and Green Glade Run (GGR0003). NP: algal growth limited by both phosphorus and nitrogen. P: pure phosphorus-limitation. 20 °C = 68 °F.

Indicator	SE deep	SE inter- mediate	SE shallow	NW deep	NW inter- mediate	NW shallow
Temperature >20 °C (surface, peak summer)	common	common	common in coves, uncommon in tributaries	common	common	common in coves, uncommon in tributaries
Temperature >20 °C (bottom, peak summer)	rare	common	common in coves, uncommon by tributaries	rare	common	common in coves, uncommon by tributaries
Oxygen (surface, peak summer)	good	good	good	good	good	good
Oxygen (bottom, peak summer)	poor	good to poor	good	poor	good to poor	good
Acidity (surface)	good	good	good (often poor at GGR0003)	good	good	good (sometimes poor at CCR0001)
Conductivity	good	good	good	good	good	good (sometimes poor at AWR0001)
Algae (surface)	more good than fair	most fair, least poor	most fair, least poor	more good than fair	more good than fair	more good than fair
Nitrogen (surface)	more good than fair	more fair than good	most fair, least good	more good than fair	more good than fair	most fair, least good
Phosphorus (surface)	more good than fair	more good than fair	most fair, least poor	good	good	more good than fair
Nutrient limitation (surface)	more NP than P	more NP than P	more NP than P	more P than NP	more P than NP	more P than NP
Cloudiness (surface)	good	more good than fair	most poor, least good	good	good	most good, least poor
Water clarity (surface)	fair	more fair than poor	NA (too shallow)	more fair than good	more fair than good	NA (too shallow)

Introduction

Deep Creek Lake is a freshwater reservoir located in Garrett County (GC), the westernmost county of Maryland, near the town and county seat of Oakland. The unincorporated community of McHenry lies on the northernmost shore of the lake. Deep Creek Lake was created in 1925 by damming Deep Creek for hydroelectric power generation (DNR 2026a). With a surface area of approximately 3,700 acres (USGS 2012), Deep Creek Lake is the largest lake or reservoir entirely within the state of Maryland (DNR 2026a). The lake and its tributary streams are classified as “nontidal cold water and public water supply” (class III-P) and thus designated by the Code of Maryland Regulations as suitable for uses ranging from water contact sports to fishing to public water supply to propagation of self-sustaining trout populations (COMAR 26.08.02.02).

After the State of Maryland acquired Deep Creek Lake in 2000, a water quality monitoring plan and program were developed and regular field monitoring has been conducted since April 2009 (DNR 2026a). Monitoring fieldwork is funded by the Department of Natural Resources (DNR) Maryland Park Service, carried out by the DNR Resource Assessment Service, and involves measuring a suite of water quality indicators, primarily during the months of May to September. The previous DNR report on Deep Creek Lake water and habitat quality summarized monitoring efforts and data from 2009–2016 (DNR 2017). This report extends that time period to 2009–2024, with new and updated data, data analysis methods, and results. Due to multiple methodological changes to the monitoring program beginning in 2016, the full time period could not be assessed with the same methods.

Deep Creek watershed

The watershed draining into Deep Creek Lake (Figure 1) has the Maryland 8-digit watershed number 05020203 and consists of three parts or Maryland 12-digit sub-watersheds (DNR 2025). The southeast part of the lake (upstream of the narrow point at Glendale Road Bridge) is located in sub-watershed 050202030027, and the northwest part of the lake (downstream of Glendale Road Bridge) is in sub-watershed 050202030028. The smaller northern sub-watershed 050202030029 drains into the largest Deep Creek Lake tributary, Cherry Creek, before flowing into the northwest lake. The relative flow of 67 Deep Creek Lake tributary streams has been estimated using data from the National Hydrography Dataset for the Deep Creek Watershed draft characterization report (DNR and GC 2014). In that analysis, the tributaries contributing at least 5% of total flow were Cherry Creek (17.9%, Cherry Creek sub-watershed), Meadow Mountain Run (6.9%, northwest sub-watershed), North Glade Run (6.8%, southeast sub-watershed), and Red Run (6.6%, northwest sub-watershed). Note that the only water quality monitoring station in the Cherry Creek sub-watershed, CCR0001, was located

in close proximity to the northwest part of the lake and was treated as belonging to the northwest sub-watershed in this report.

Forest, cropland, and impervious developed land are of particular importance to watershed systems and management. The Deep Creek watershed management plan, adopted in 2016, recognized that a high level of forest cover is important for good stream and lake water quality; called for conservation and retention of forest cover; recognized that fertilizer and sediment inputs from cropland have negative effects on water quality and called for these impacts to be minimized; recognized negative effects of stormwater flow from impervious surfaces on the watershed system; and called for further study and implementation of best management practices in stormwater management (Deep Creek Watershed Plan Steering Committee 2016):

- Goal 4: Manage existing land uses to achieve the desired condition of the Deep Creek Lake and watershed
- Goal 8: Manage stormwater infrastructure to decrease pollution from both existing and proposed development to ensure healthy watershed conditions
- Goal 11: Maximize the retention of forest cover to protect high-value aquatic and terrestrial natural resources

Due to its proximity to the Chesapeake Bay watershed, high resolution land use information for the Deep Creek watershed was available from the Chesapeake Bay Land Use/Land Cover (LULC) Database (Claggett et al. 2025). For this report, the oldest (2013/2014) and newest (2021/2022) available LULC data were simplified from 56 categories to seven categories and used to characterize the Deep Creek Lake watershed (Figure 1, Tables 1 and 2). For a full description of the method for simplifying LULC data, see Appendix A.

While the majority of land in all three sub-watersheds was forest, there were important distinctions in land use. In terms of absolute area (Table 1) and proportional land use (Table 2), the Cherry Creek sub-watershed had by far the least developed land, while the northwest sub-watershed had the least agricultural land, and the southeast sub-watershed had the least forest but the most agricultural land. Over 85% of total cropland was located in the southeast sub-watershed.

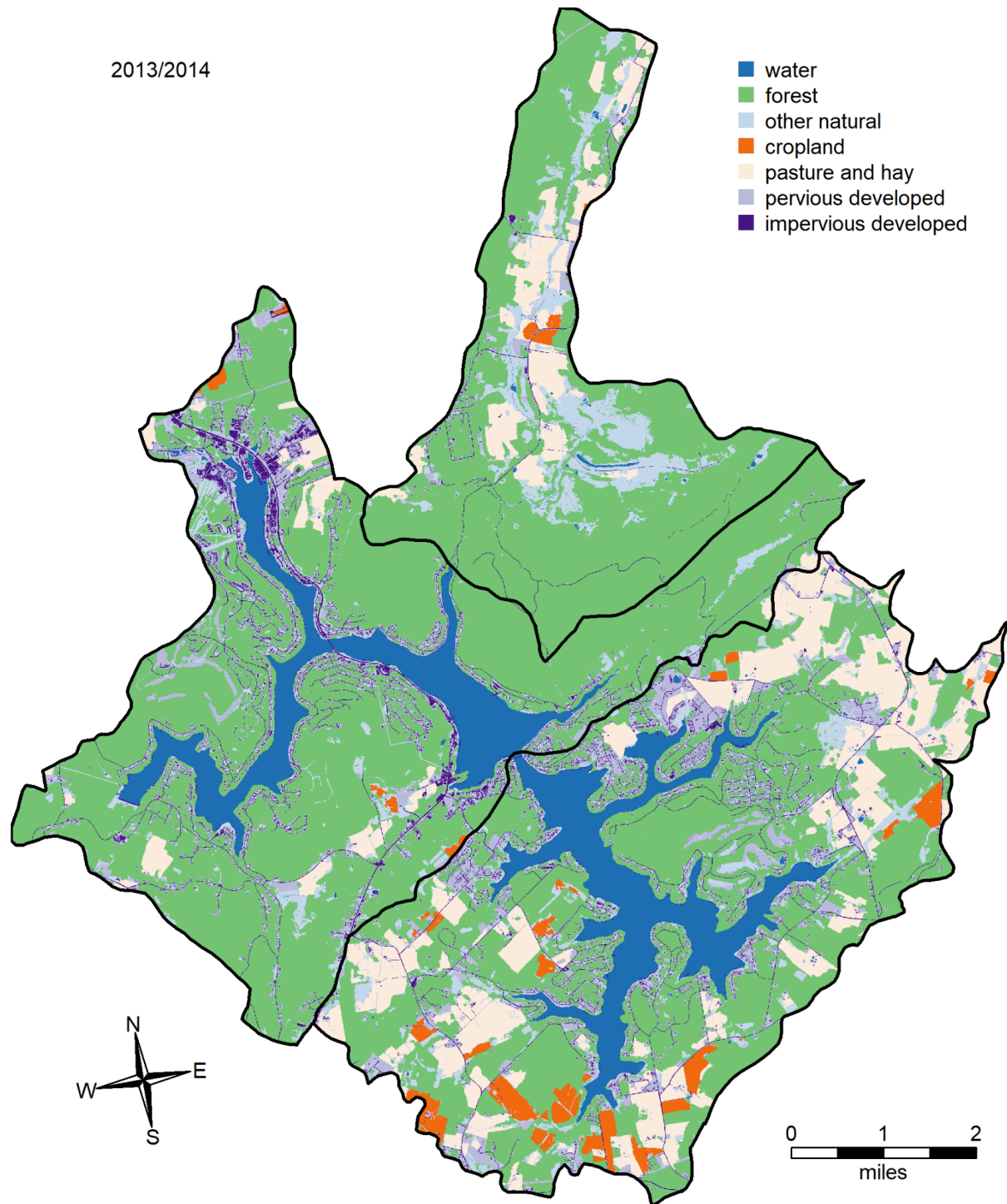


Figure 1. Deep Creek watershed land use in 2013/2014 and 2021/2022.

Tables 1–3 show the same land use patterns in tabular form. Colors indicate a simplified seven-category classification based on the Chesapeake Bay LULC Database (Claggett et al., 2025). Black outlines show the southeast, northwest, and Cherry Creek (north) sub-watersheds (DNR 2025). Map projection: USA Contiguous Albers Equal Area Conic USGS (Claggett et al. 2025).

2021/2022

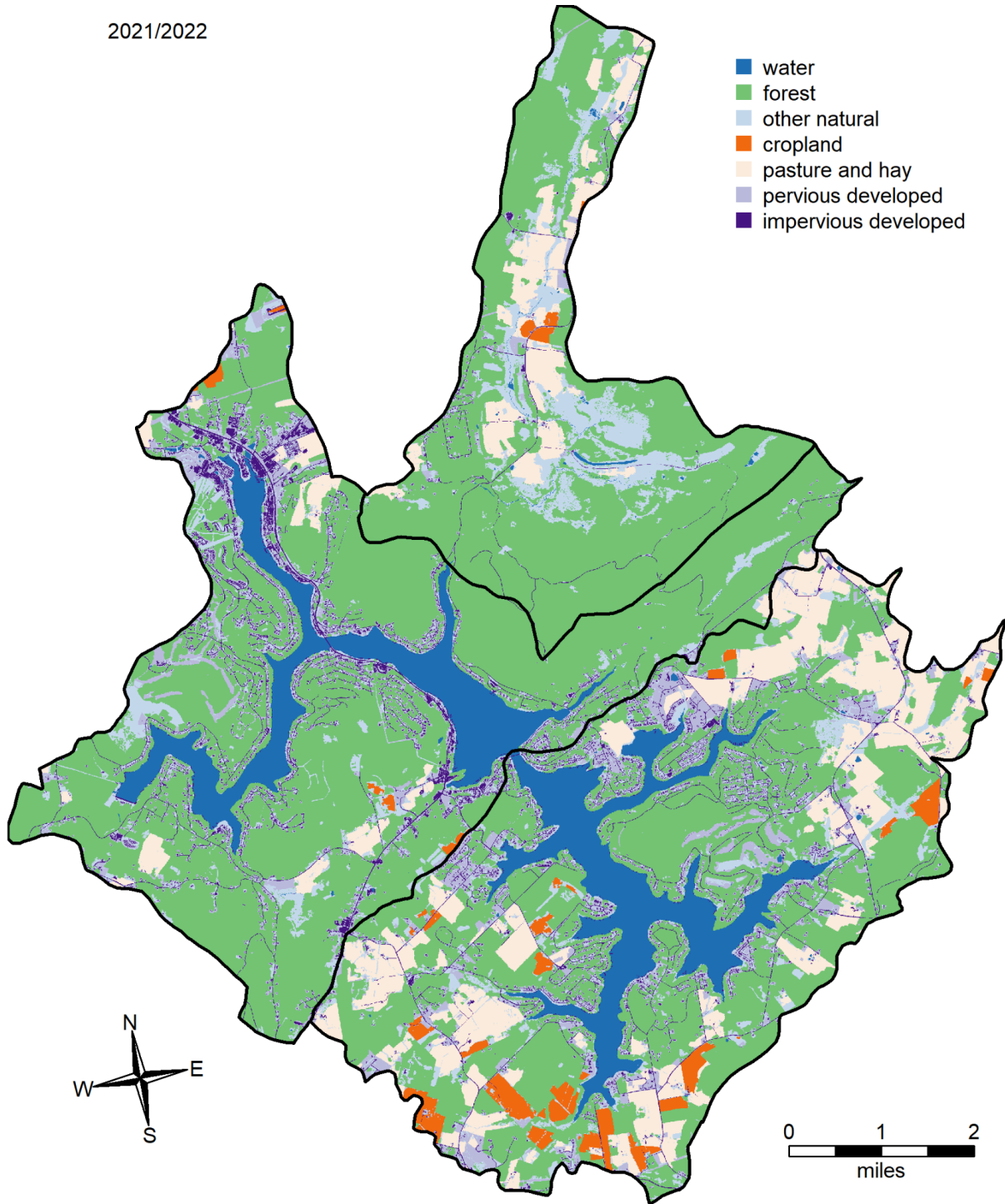


Figure 1, continued.

Table 1. Deep Creek watershed land use in 2021/2022.

Estimated acres of land in the southeast, northwest, and Cherry Creek (north) sub-watersheds.

Land use	Southeast	Northwest	Cherry Creek	Total
Water	2000	1758	44	3802
Forest	7770	10271	5375	23417
Other natural	1297	1087	1249	3633
Cropland	630	58	49	737
Pasture and hay	3056	448	929	4433
Pervious developed	1687	1411	172	3270
Impervious developed	668	885	92	1645
Total	17107	15918	7911	40936

Table 2. Proportion of Deep Creek watershed land use in 2021/2022.

Estimated for land use categories excluding water (Appendix A).

Land use	Southeast	Northwest	Cherry Creek	Overall
Forest	51.4%	72.5%	68.3%	63.1%
Other natural	8.6%	7.7%	15.9%	9.8%
Cropland	4.2%	0.4%	0.6%	2.0%
Pasture and hay	20.2%	3.2%	11.8%	11.9%
Pervious developed	11.2%	10.0%	2.2%	8.8%
Impervious developed	4.4%	6.2%	1.2%	4.4%

The main land use change between 2013/2014 and 2021/2022 was a net loss of forest (Table 3). In the southeast sub-watershed, net increases in developed land (69 acres pervious, 39 acres impervious) accounted for most of the net decrease in forest (-116 acres). In the northwest sub-watershed, a net increase in other natural land (147 acres) accounted for slightly over half of the forest lost (-281 acres), while a net increase in developed land (64 acres pervious, 63 acres impervious) accounted for slightly under half. In the Cherry Creek sub-watershed, a net increase in other natural land (144 acres) accounted for most of the decrease in forest (-163 acres). There were no major changes in cropland between 2013/2014 and 2021/2022. Note that forest includes wetlands forest, and other natural land includes other types of wetlands.

Table 3. Change in land use from 2013/2014 to 2021/2022.

Estimated acres of land in categories excluding water (Appendix A).

Land use	Southeast	Northwest	Cherry Creek	Total
Forest	-116	-281	-163	-560
Other natural	-8	147	144	283
Cropland	3	-2	0	2
Pasture and hay	10	6	4	20
Pervious developed	69	64	7	140
Impervious developed	39	63	6	108

Monitoring program and assessment methods

Monitoring data included measurements taken directly in the field (e.g., temperature) and measurements from laboratory analysis of water samples (e.g., nutrient concentrations). In general, field measurements were taken at regularly-spaced depths from the surface of the water column (typically measured at 0.5 m or 1.0 m depth) to the bottom (typically measured at 1.0 m above the bottom), whereas laboratory analysis was mostly focused on surface samples taken at 0.5 m (1 m = 3.3 ft). The dataset will be made available on the “Eyes on Deep Creek Lake” webpage (<https://eyesonthebay.dnr.maryland.gov/dcl/DeepCreekLake.cfm>). The dataset consisted primarily of regular monthly April to October measurements at specific lake, cove, and tributary stations monitored for periods of 5–8 years. Additional data from sampling during storm events was not included in this report. Overall, water samples for laboratory analysis were collected at less than half of stations. Beginning in 2016, multiple changes were made to the regularly monitored stations, the stations with water samples collected for laboratory analysis, and the laboratories contracted for chemical analysis. These changes were related to shifting priorities of the Maryland Park Service.

Stations and coverage

While sampling schedules changed over time, most effort was consistently allocated to the period from May 1 to September 30 (Table 4). Monitoring was conducted at >40 stations in some months and years, but laboratory analysis of water samples was only conducted for a subset of stations. For example, chlorophyll-*a* concentration measurements were available for up to 14 stations in some months and years (Table 5). In 2020, both field- and lab-work were negatively impacted by closures and restrictions related to the COVID-19 pandemic (Tables 4–5). Starting in 2022, laboratory measurements were conducted for six sites (per year) under continuous monitoring by autonomous instruments provided by the Deep Creek Watershed Foundation; discrete monthly laboratory samples collected at these locations are included in the analysis below but instrument-collected high frequency data are not included in this report.

Table 4. Deep Creek Lake water quality monitoring effort.

Numbers indicate unique stations with water quality data by month and year. Monitoring was most extensive and consistent during May to September (dark gray highlights) and adjacent months (April and October, light gray highlights). The regularly monitored stations varied from year to year, including a large change in mid-2016.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2009	0	0	0	18	19	19	19	19	19	18	19	4
2010	4	2	2	18	18	18	18	18	18	2	18	4
2011	4	2	2	18	18	18	18	18	18	2	18	4
2012	2	2	18	2	18	18	18	18	18	1	1	17
2013	1	1	1	17	17	17	17	17	17	1	1	3
2014	1	1	3	17	17	17	14	14	14	1	1	3
2015	3	1	1	1	14	14	14	14	14	21	8	8
2016	10	8	8	21	21	21	41	40	46	47	1	8
2017	1	1	1	43	43	43	43	43	41	43	3	3
2018	3	3	3	3	43	43	32	32	28	32	2	3
2019	3	3	3	32	31	32	35	32	32	32	3	3
2020	0	2	0	0	0	29	28	29	29	28	0	0
2021	0	0	0	29	29	29	29	29	29	29	0	0
2022	0	0	0	0	31	35	35	35	33	34	0	0
2023	0	0	0	0	34	34	34	34	34	31	0	0
2024	0	0	0	0	35	35	35	35	35	34	0	0

Table 5. Deep Creek Lake monitoring of algal levels.

Numbers indicate unique stations sampled for chlorophyll-a concentration analysis. Highlights as in Table 4. *: Monitoring scheduled for the end of September 2018 was delayed until October 1, but the resulting samples were included as nominal September samples for some data analyses. The regularly monitored stations varied from year to year, including a large change in mid-2016.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2009	0	0	0	0	14	13	14	14	14	13	14	0
2010	2	0	0	13	13	13	13	13	12	0	13	0
2011	2	0	0	13	13	13	13	13	13	0	13	0
2012	0	0	13	0	13	13	13	13	13	0	0	13
2013	0	0	0	13	13	13	13	13	13	0	0	0
2014	0	0	2	13	13	13	13	13	13	0	0	0
2015	2	0	0	0	13	13	13	13	13	13	0	0
2016	0	0	0	13	13	13	4	4	4	0	0	0
2017	0	0	0	4	4	4	4	4	4	4	0	0
2018	0	0	0	0	4	4	4	4	0*	4*	0	0
2019	0	0	0	11	12	11	12	12	12	0	0	0
2020	0	0	0	0	0	0	0	0	0	0	0	0
2021	0	0	0	12	12	12	12	12	12	12	0	0
2022	0	0	0	0	10	14	14	14	12	13	0	0
2023	0	0	0	0	14	14	14	14	14	11	0	0
2024	0	0	0	0	14	14	14	14	14	13	0	0

The distribution of the 25 most comprehensively monitored stations is shown in Figure 2 and Table 6. These stations include all those with laboratory analysis data over multiple growing seasons. Their spatial coverage includes 10 different coves (some with multiple stations), four different tributaries, and four stations along the mainstem (centerline) lake. For equivalent information on the 31 additional stations monitored for multiple years with field measurements only, and the 25 stations with data from a single growing season, see Appendix B. To describe spatial patterns in water quality, stations were grouped by sub-watershed, type (mainstem, cove, tributary), and nominal bottom depth in parts of this report. Note that station CCR0001 (Station 1 in Table 6) was grouped with the northwest sub-watershed. Also note that the true bottom depth at each station varied with changes in lake water level, which is managed at the dam (see DNR 2017 for more details on lake elevation).

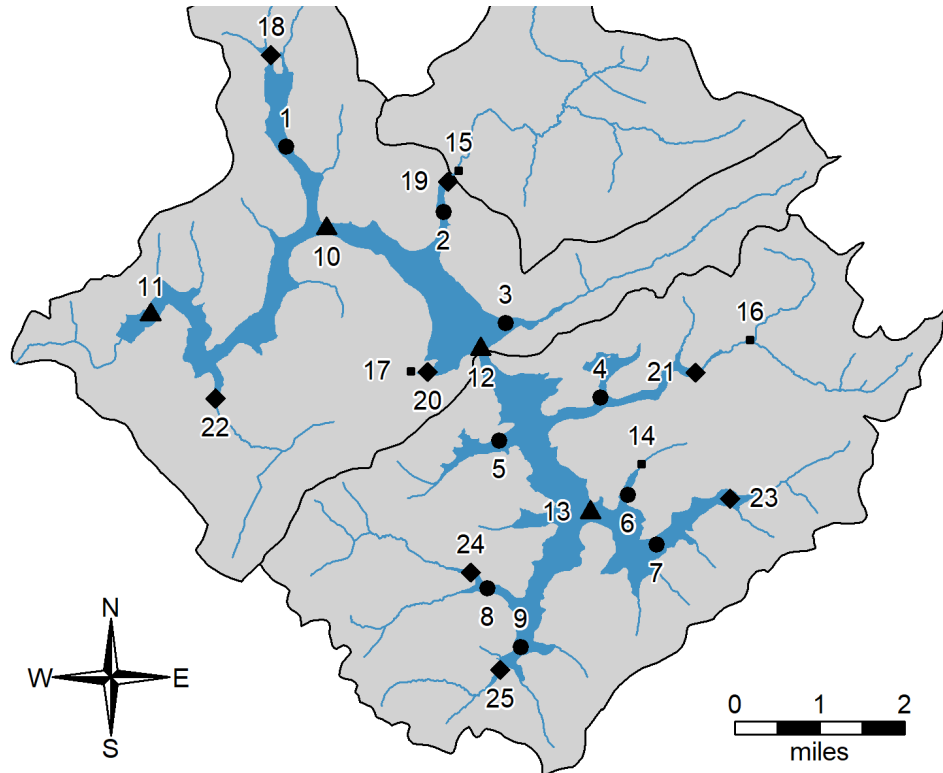


Figure 2. Selected water quality monitoring stations.

Table 6 provides the same data with additional details in tabular form. All 25 stations with May–September algal and nutrient level monitoring during multiple years in the 2009–2024 period are shown. Stations include deep mainstem lake stations (triangles) with >10.7 m (>35 ft) nominal bottom depth, intermediate cove stations (circles) with 3.0–10.7 m (10–35 ft) nominal depth, shallow cove stations (diamonds) with <3.0 m (<10 ft) nominal depth, and tributary stations (squares). Small symbols: depth <1.5 m (<5 ft). Nominal bottom depth was determined with reference to an elevation of 750 m (2462 ft, MGS 2016). Numbers: field “#” in Table 6. Gray areas with black outlines: 12-digit sub-watersheds (DNR 2025). Blue lines: National Hydrography Dataset streams (USGS 2012). Map projection: UTM zone 17N.

Table 6. Selected water quality monitoring stations.

Only stations with May–September algal and nutrient level monitoring during multiple years in the 2009–2024 period are included. #: numbers in Figure 2. 1 m = 3.3 ft.

#	Station	Waterbody	Type	Depth (m)	Longitude (°W)	Latitude (°N)	Years
1	MRC0011	Marsh Run Cove	Cove	3.0–10.7	79.35385	39.54194	2009–2016
2	CCC0008	Cherry Creek Cove	Cove	3.0–10.7	79.31935	39.53027	2009–2016
3	MMR0005	Meadow Mountain Run Cove	Cove	3.0–10.7	79.30613	39.51105	2009–2016
4	NGC0010	North Glade Run Cove	Cove	3.0–10.7	79.28550	39.49800	2009–2016
5	UDC0004	Hoop Pole Cove	Cove	3.0–10.7	79.30796	39.49097	2009–2016
6	PLV0004	Poland Run Cove	Cove	3.0–10.7	79.27980	39.48120	2009–2016
7	GGC0015	Green Glade Run Cove	Cove	3.0–10.7	79.27370	39.47269	2009–2016
8	PWC0004	Pawn Run Cove	Cove	3.0–10.7	79.31130	39.46568	2009–2016
9	DPR0119	Deep Creek Cove	Cove	3.0–10.7	79.30412	39.45550	2009–2016
10	DPR0056	Deep Creek Lake	Lake	>10.7	79.34528	39.52778	2009–2021
11	DPR0021	Deep Creek Lake	Lake	>10.7	79.38447	39.51355	2009–2021
12	DPR0082	Deep Creek Lake	Lake	>10.7	79.31167	39.50667	2009–2021
13	DPR0103	Deep Creek Lake	Lake	>10.7	79.28816	39.47838	2009–2021
14	PLD0001	Poland Run	Tributary	0–1.5	79.27661	39.48642	2009–2012, 2016
15	CCR0001	Cherry Creek	Tributary	0–1.5	79.31585	39.53723	2009–2017, 2019
16	NGR0003	North Glade Run	Tributary	0–1.5	79.25220	39.50732	2016–2019
17	AWR0001	Arrowhead Run	Tributary	0–1.5	79.32727	39.50311	2016–2019
18	MRC3	Marsh Run Cove	Cove	1.5–3.0	79.35688	39.55759	2019–2024
19	CCC3	Cherry Creek Cove	Cove	1.5–3.0	79.31815	39.53535	2019–2024
20	AWC3	Arrowhead Cove	Cove	1.5–3.0	79.32343	39.50287	2019–2024
21	NGC3	North Glade Run Cove	Cove	1.5–3.0	79.26435	39.50195	2019–2024
22	RRC3	Red Run Cove	Cove	1.5–3.0	79.37042	39.49904	2019–2024
23	GGC3	Green Glade Run Cove	Cove	1.5–3.0	79.25728	39.48026	2019–2024
24	PWC3	Pawn Run Cove	Cove	1.5–3.0	79.31472	39.46848	2019–2024
25	DCC3	Deep Creek Cove	Cove	1.5–3.0	79.30868	39.45167	2019–2024

Data analysis and presentation

Most data points represent a single sample collected per station, per day, per depth; for instances of replicate samples, data were aggregated using average (mean) values. Monthly averages were calculated from daily averages. Growing season median (middle) values were calculated from monthly values for May–September. Growing season medians were not calculated for stations with two or more missing monthly values. Data analysis was performed

using the software R versions 4.3.1–4.5.1 (R Core Team 2025) and SAS version 9.4 (SAS Institute 2025).

This report focuses on data from the May–September period and the adjacent months of April and October. Monitoring during other months was limited, especially after 2016 (Tables 4 and 5). Some additional results for November–March through 2016 were provided in the previous report (DNR 2017). Some data from September 2009, April 2019, and August 2021 were excluded from analysis, due to suspected measurement or data entry errors. In 2018, monitoring scheduled for the end of September 2018 was delayed until October 1, but the resulting measurements were included as nominal September data.

Benchmarks

To summarize and visualize the data, this report makes extensive use of simplified categories such as “good” water quality. For several key indicators, three-category benchmarks (good, fair, poor) were adopted from the 2022 National Lakes Survey (EPA 2024a, EPA2024b). These benchmarks were region-specific and based on historic samples of regional lakes considered least impacted by human activity (EPA 2024b). In this context, Deep Creek Lake falls in the Southern Appalachian region. Note that DNR monitoring of Deep Creek Lake went far beyond the sampling methodology used by the National Lakes Survey, which typically involved just one sample per lake and year, taken sometime between May and October near the surface at the deepest part of the lake. To compare different locations at Deep Creek Lake, National Lakes Survey benchmarks were used for all monitoring stations, including shallow nearshore stations and tributary stations. Consequently, references to “poor” water quality, for example, should be interpreted as “poor relative to surface water at the deepest part of the lake” (for National Lakes Survey benchmarks). Benchmarks for indicators not included in the 2022 National Lakes Survey were based on other sources (Table 7).

Table 7. Benchmarks for water quality assessment.

For six indicators, water quality was classified as good, fair (between good and poor), or poor. For conductivity and acidity (pH) water quality was classified as good or poor.

Indicator	Depth	Good range	Poor range	Unit	Source
Chlorophyll- <i>a</i>	Surface	<5.54	>13.1	µg/l	EPA 2024b
Conductivity	All	<300	>300	µS/cm	EPA 2011
Oxygen (dissolved)	All	>5	<3	mg/l	EPA 2024b, DNR 2017
pH	All	6.5–8.5	<6.5 or >8.5	none	EPA 2024a
Secchi depth	Surface	>4	<2	m	Carlson 1977
Total nitrogen	Surface	<0.266	>0.409	mg/l	EPA 2024b
Total phosphorus	Surface	<0.018	>0.033	mg/l	EPA 2024b
Turbidity	Surface	<2.83	>4.21	NTU	EPA 2024b

Seasonal cycles

The relative strength of seasonal cycles for each indicator was estimated using statistical models (generalized additive models) trained on a standardized subset of data (May–September, 2009–2015, cove and lake stations 1–13 in Table 6). Seasonality scores were defined as the degree to which seasonal models reproduced variability in the standardized subset and ranged from 0% (no seasonality) to 100% (purely seasonal). For example, surface water temperature is an indicator with a very strong seasonal pattern, and its seasonality score of 78% indicated that approximately 78% of May–September differences in lake surface temperature were seasonal in nature. See Appendix C for a more detailed description of the seasonality scores.

Trends analysis

Baytrends, a sophisticated statistical modeling tool developed specifically for water quality data analysis (Murphy et al. 2019, 2024), was used to evaluate changes over time (trends) for specific monitoring stations and indicators. Baytrends employs generalized additive models to account for seasonal patterns as well as year-to-year variability and longer-term trends. Due to multiple changes to the Deep Creek Lake water monitoring program starting in mid-2016, only data from nine cove stations and four mainstem lake stations (stations 1–13 in Table 6) were suitable for this analysis approach at present. For most stations and indicators, models were trained on data from April 2009 to June 2016 and used to compare growing season water quality in the baseline time period 2009/2010 to the later time period 2014/2015. For the four lake stations and some indicators measured in the field (water temperature, dissolved oxygen, and Secchi depth), the baseline period could instead be compared to 2023/2024. Differences unlikely to have arisen by random chance (model-estimated probability $p < 5\%$) were considered statistically significant changes. Models that did not indicate a good model fit (adjusted $r^2 < 0.30$) were considered inconclusive and were not used to assess water quality. For more details on model specifications, see Appendix D.

The two main challenges to assessing data after mid-2016 were changes to the monitored stations (such as different locations in the coves) and changes in the analytical laboratories that processed the collected samples. Given enough data (approximately five or more contiguous years), Baytrends can be used to estimate and potentially correct for the effects of different locations and/or laboratories. This means that newer data should become suitable for this analysis approach after some additional years of monitoring. Starting in 2025, laboratory analysis of water samples was resumed for some older cove stations but processed at the current laboratory, and the collection of samples for laboratory analysis was resumed at four mainstem lake stations (10–13 in Table 6). For these stations, using Baytrends may be feasible starting in 2029 if no additional changes in laboratory methods or station locations are made.

Habitat quality indicators

Deep Creek Lake provides habitat for a wide range of aquatic life, including popular gamefish species such as walleye and smallmouth bass (DNR 2022). While habitat requirements vary among species, temperature, dissolved oxygen concentration, acidity (pH), and conductivity are all important to habitat quality. Importantly, one of Deep Creek Lake's designated uses is growth and propagation of trout, which have upper thermal tolerance limits around 24 °C (for brook trout and rainbow trout, Eaton et al. 1995; 24 °C = 75 °F).

Temperature

With respect to environmental conditions for aquatic life in Deep Creek Lake, fall and spring temperatures are generally more favorable, whereas peak summer surface water temperatures often result in lower habitat quality. Consistent with the classification of Deep Creek Lake and its tributaries as "cold water," the desired species and communities tend to be more susceptible to warm water extremes. This is exacerbated by recent temperature increases, which have been measured throughout the state. Statewide Maryland air temperature data show that several years in the 2009–2024 period were among the warmest on record (NOAA 2025, Runkle et al. 2022). Additionally, warm water intensifies algal growth, which can result in low oxygen levels in deeper water, which in turn negatively affect fish and other aquatic life (see oxygen, below).

Surface water temperature

Deep Creek Lake surface water temperature (Figure 3) had a strong and predictable seasonal pattern, which explained the majority of differences among measurements (78% seasonality score).

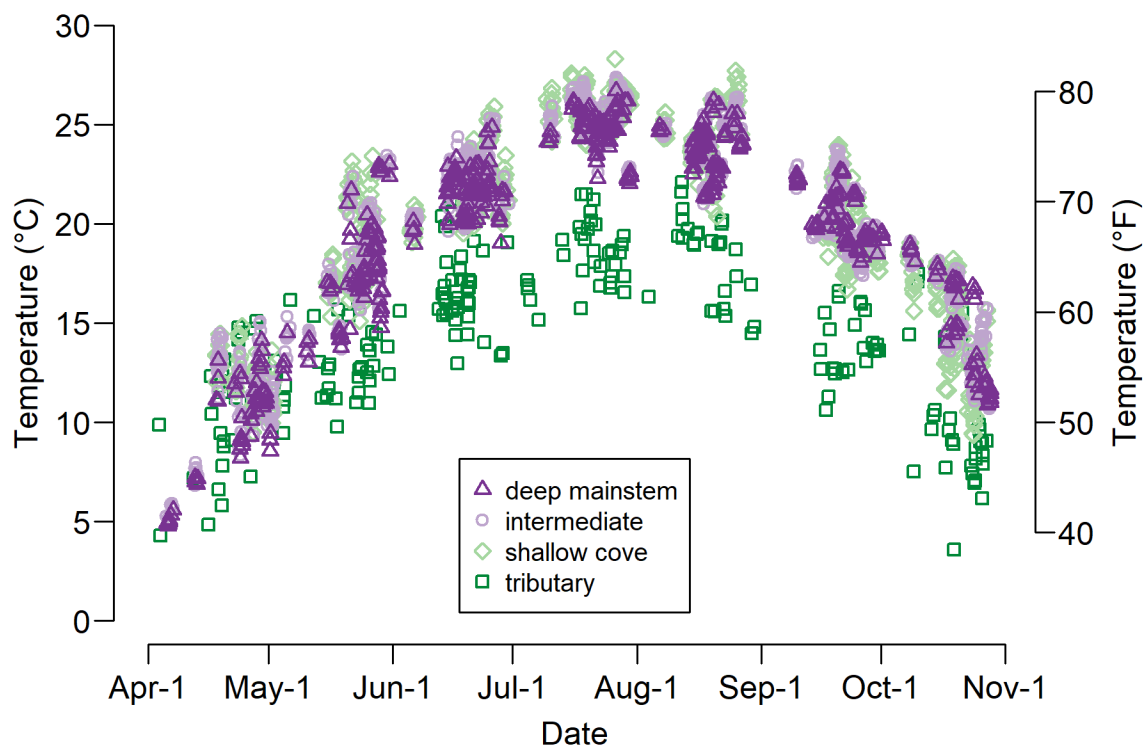


Figure 3. Seasonal cycle and variability in surface water temperature.

Stations were classified as deep mainstem (nominal bottom depth >10.7 m), intermediate (lake and cove stations, nominally 3.0–10.7 m), shallow cove (<3.0 m), and tributary. Non-tributary stations were somewhat similar, with pooled median (middle) temperatures increasing from around 12 °C in April to around 25 °C in July, before decreasing to around 15 °C in October. Median temperatures at tributary stations were cooler, increasing from around 11 °C in April to around 19 °C in August, before decreasing to around 9 °C in October. Most measurements were within 3 °C of median values for the time of year. Nominal bottom depth was determined with reference to an elevation of 750 m (MGS 2016). Data points were jittered (randomly, slightly shifted) and plotted in order from tributary (first) to mainstem (last), to reduce masking of some points by others. For temperatures in °F, see right axis. 1 m = 3.3 ft.

Lake surface water temperatures generally exceeded 20 °C (68 °F) from mid-June to mid-September. While this is high for designated cold waters, warming by the sun is considered natural and not a sufficient cause for listing Deep Creek Lake as impaired. Nevertheless, summer temperatures negatively affect at least one designated use category: DNR actively discourages catch and release trout fishing at water temperatures above 20 °C, due to the extreme stress to the fish (DNR 2026b).

Sub-surface temperature

Lakes often exhibit seasonal stratification, meaning that there are two or more distinct layers of water with different temperatures (and other properties) and with limited vertical mixing across layers. Only the top layer, or epilimnion, exchanges heat and oxygen with the atmosphere. By definition, the epilimnion is well-mixed, meaning it extends from the surface to the maximum depth where vertical mixing has recently occurred (e.g., due to a storm). In early spring, the Deep Creek Lake epilimnion typically extends all the way to the lake bottom (DNR 2017). Over the course of spring and summer, the lake absorbs more and more heat from the air, and its epilimnion becomes distinct from colder, deeper layers (DNR 2017). Temperature differences among layers have the effect of resisting mixing (more energy is needed to overcome layer boundaries). Consequently, deeper layers can be effectively cut off until the epilimnion cools to a point where mixing can break down the layered structure. Year by year variability in this pattern is shown in Figure 4 for four deep mainstem lake stations (stations 10–13 in Table 6). At shallow stations the water column was generally well-mixed throughout the year, resulting in similar temperatures at the bottom and surface. At intermediate-depth stations, bottom temperatures ranged between similar to the surface and similar to the deepest parts of the lake.

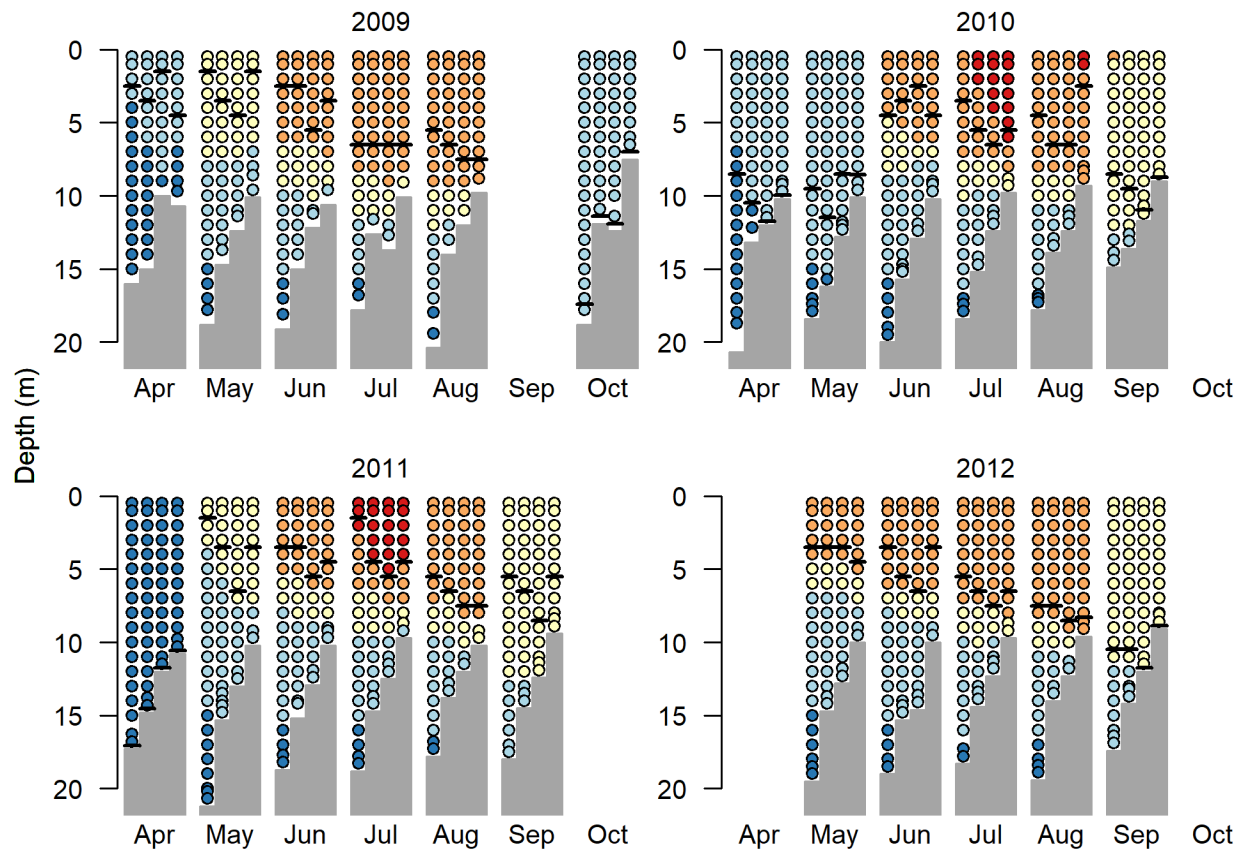


Figure 4. Vertical profiles of water temperature.

Blocks of points for each month and year represent measurements at four mainstem lake stations ordered from furthest downstream (left, bottom depth around 19 m) to furthest upstream (right, bottom depth around 10 m). Dark blue: $<10^{\circ}\text{C}$ ($<50^{\circ}\text{F}$); light blue: $10\text{--}15^{\circ}\text{C}$ ($50\text{--}59^{\circ}\text{F}$); yellow: $15\text{--}20^{\circ}\text{C}$ ($59\text{--}68^{\circ}\text{F}$), orange: $20\text{--}25^{\circ}\text{C}$ ($68\text{--}77^{\circ}\text{F}$), red $>25^{\circ}\text{C}$ ($>77^{\circ}\text{F}$). The depth of the well-mixed epilimnion layer is indicated by a thick black line. Gray areas indicate depths exceeding lake bottom depth. White areas indicate months that were not sampled. The May epilimnion was generally between 10°C and 20°C in temperature and $<10\text{ m}$ in depth, but in 2012 it was already warmer than 20°C and in 2018 it was still cooler than 10°C and deeper (15 m or near bottom at shallower stations). In 2011, 2016, 2020, and 2024 all four stations had July epilimnion temperatures above 25°C . In 2019 all four stations had August epilimnion temperatures above 25°C . In 2009, 2012, 2014, 2018, and 2023 peak temperatures were $<25^{\circ}\text{C}$. Epilimnion depth tended to increase between May and October, sometimes reaching $>15\text{ m}$ in October (e.g., 2009, 2015, 2018). Bottom water temperature at the deepest station (around 19 m), remained $<10^{\circ}\text{C}$ until at least July, and until October in some years (2015, 2016, 2018, 2022). At 15 m depth, temperature was consistently $<15^{\circ}\text{C}$, and at 10 m depth it was generally $<20^{\circ}\text{C}$ except for September in some years (2015, 2019, 2022, 2023, 2024). 1 m = 3.3 ft.

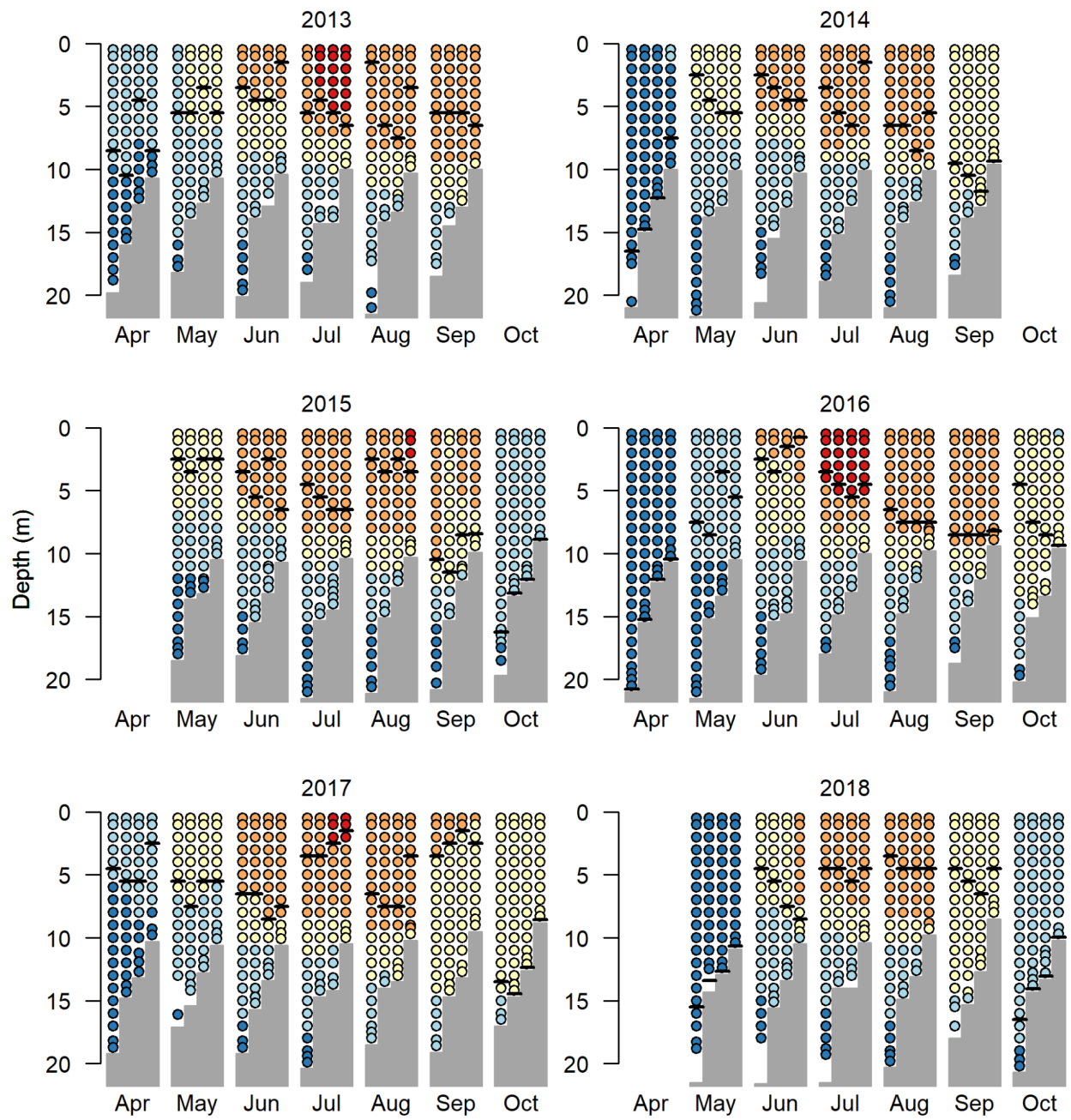


Figure 4, continued.

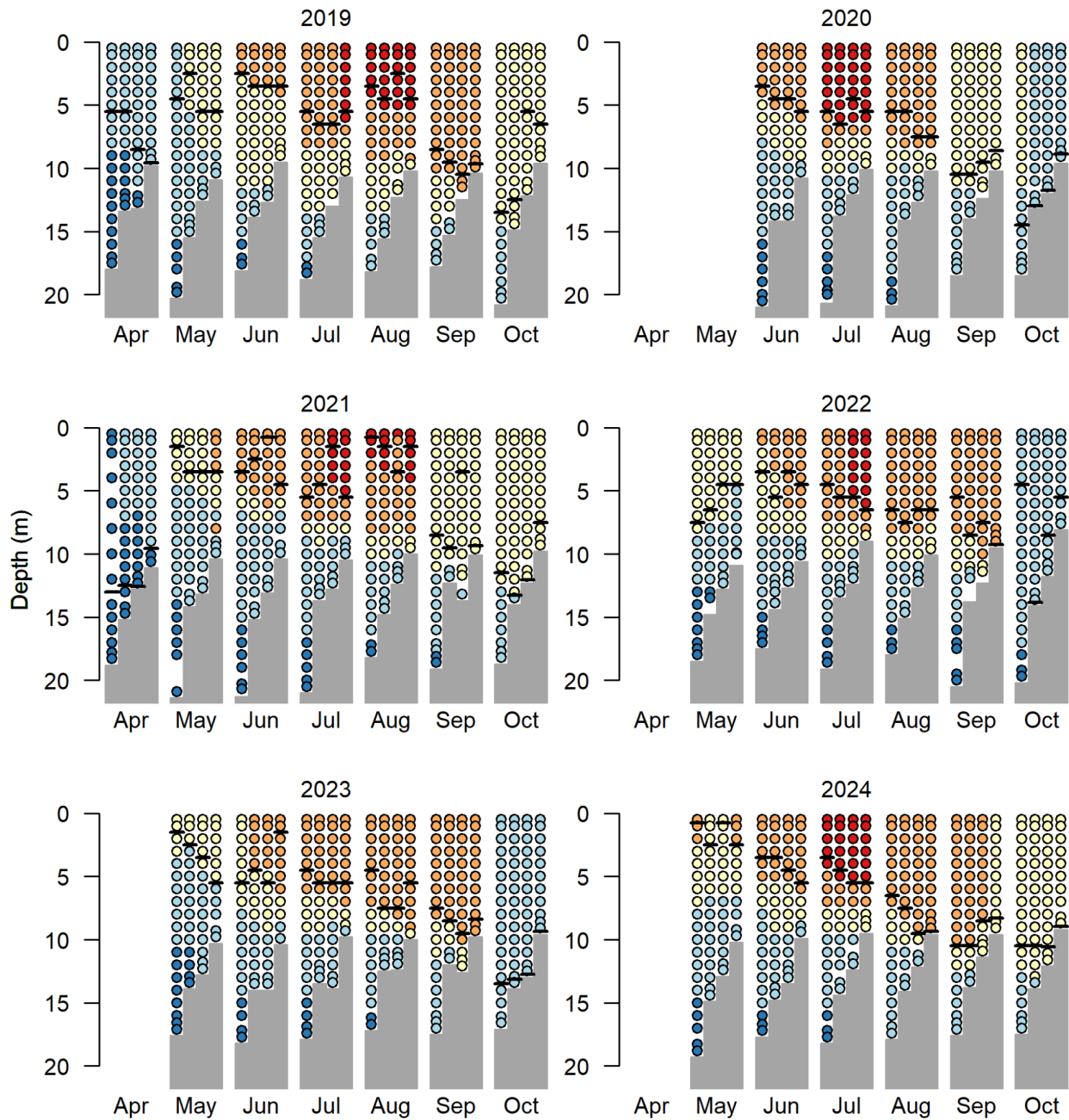


Figure 4, continued.

Changes in water temperature

Trends analysis for cove water temperatures was restricted to comparisons of the time periods 2009/2010 and 2014/2015, because the analysis could not adequately account for changes to the regularly monitored stations after 2015. Estimated seasonal (May–September) average

surface water temperature in the coves ranged from 20.7 to 21.3 °C in 2009/2010 and from 20.6 to 21.5 °C in 2014/2015. No significant changes among the time periods were detected in surface water temperatures at cove stations (Table 8). Estimated seasonal average bottom water temperature in the coves ranged from 18.7 to 20.8 °C in 2009/2010 and from 15.0 to 21.0 °C in 2014/2015. Bottom water temperatures significantly decreased in two coves (Cherry Creek Cove and Hoop Pole Cove) and significantly increased in Green Glade Run Cove (Table 9). Note that changes from 2009/2010 to 2014/2015 may not reflect ongoing trends. Additional years of monitoring will allow a more robust assessment of longer-term changes.

Table 8. Trends in cove surface water temperature.

n: number of training data points; r^2 : model fit (adjusted correlation coefficient); A1, A2: estimated seasonal (May–September) average temperature (°C) in 2009/2010 (period 1) and 2014/2015 (period 2); Significance: statistical significance of change from period 1 to period 2; very high: $p < 0.001$, high: $p < 0.01$, yes: $p < 0.05$, no (marginal): $p < 0.1$, no: $p \geq 0.1$.

#	Station	Description	n	r^2	A1	A2	Significance
1	MRC0011	Marsh Run Cove	51	0.93	20.7	20.6	no
2	CCC0008	Cherry Creek Cove	52	0.95	20.8	20.7	no
3	MMR0005	Meadow Mountain Run Cove	52	0.95	20.7	21.0	no
4	NGC0010	North Glade Run Cove	51	0.95	21.2	21.5	no
5	UDC0004	Hoop Pole Cove	51	0.97	21.0	21.0	no
6	PLV0004	Poland Run Cove	51	0.92	21.2	21.5	no
7	GGC0015	Green Glade Run Cove	51	0.91	21.3	21.4	no
8	PWC0004	Pawn Run Cove	51	0.93	20.8	21.2	no
9	DPR0119	Deep Creek Cove	51	0.93	21.0	21.3	no

Table 9. Trends in cove bottom water temperature.

A1, A2: estimated seasonal average temperature (°C) in 2009/2010 and 2014/2015. Other columns as in Table 8.

#	Station	Description	n	r^2	A1	A2	Significance
1	MRC0011	Marsh Run Cove	56	0.94	18.7	18.4	no
2	CCC0008	Cherry Creek Cove	53	0.90	19.8	15.0	very high
3	MMR0005	Meadow Mountain Run Cove	59	0.93	20.1	20.4	no
4	NGC0010	North Glade Run Cove	52	0.95	20.0	20.1	no
5	UDC0004	Hoop Pole Cove	52	0.93	18.7	16.4	very high
6	PLV0004	Poland Run Cove	57	0.92	20.8	20.9	no
7	GGC0015	Green Glade Run Cove	57	0.93	19.9	21.1	yes
8	PWC0004	Pawn Run Cove	59	0.94	20.0	20.1	no
9	DPR0119	Deep Creek Cove	56	0.94	20.5	20.2	no

Trends analysis for lake stations compared water temperatures in the two earliest years and the two most recent years of monitoring data (2009/2010 and 2023/2024). Estimated seasonal average surface water temperature ranged from 20.5 to 21.2 °C in 2009/2010 and from 21.5 to 22.0 °C in 2023/2024. The temperature increases were statistically significant at stations

DPR0056 (near the US 219 bridge) and DPR0082 (near Glendale Road Bridge; Table 10). The observed temperature increases were consistent with the well-established overall warming trend in Maryland (NOAA 2025, Runkle et al. 2022). Estimated seasonal average bottom water temperature ranged from 9.0 to 15.9 °C in 2009/2010 and from 9.0 to 16.4 °C in 2023/2024. The only significant change was a temperature decrease at station DPR0082 (near Glendale Road Bridge; Table 11).

Table 10. Trends in mainstem lake surface water temperature.

A1, A2: estimated seasonal average temperature (°C) in 2009/2010 and 2023/2024. Other columns as in Table 8.

#	Station	Description	n	r ²	A1	A2	Significance
10	DPR0056	US 219 Bridge	115	0.95	20.5	21.5	yes
11	DPR0021	Dam	105	0.91	20.5	21.5	no (marginal)
12	DPR0082	Glendale Road Bridge	134	0.96	20.6	21.6	yes
13	DPR0103	Turkey Neck	105	0.92	21.2	22.0	no (marginal)

Table 11. Trends in mainstem lake bottom water temperature.

A1, A2: estimated seasonal average temperature (°C) in 2009/2010 and 2023/2024. Other columns as in Table 8.

#	Station	Description	n	r ²	A1	A2	Significance
10	DPR0056	US 219 Bridge	131	0.92	12.3	11.9	no
11	DPR0021	Dam	123	0.80	9.0	9.0	no
12	DPR0082	Glendale Road Bridge	152	0.92	14.1	13.1	high
13	DPR0103	Turkey Neck	121	0.85	15.9	16.4	no

Oxygen

Deep Creek Lake surface water is generally oxygen-rich and thus favorable for aquatic life year-round (DNR 2017). Deep water, however, becomes oxygen-poor over the course of the summer due to increased activity by aquatic organisms and a lack of mixing with the oxygen-rich epilimnion (surface) layer (DNR 2017). While some organisms can avoid oxygen-poor conditions by moving to other parts of the lake, a combination of dangerously oxygen-poor deep water and dangerously warm surface water can leave even mobile species, such as trout, without favorable habitat. The intensity of oxygen-poor conditions is affected by many factors, including high temperatures (increasing metabolic rates) and high nutrient levels (increasing the amount of decomposing dead algae).

Surface water dissolved oxygen

Surface water dissolved oxygen concentration (Figure 5) had a strong and predictable seasonal pattern that explained the majority of differences among measurements (71% seasonality score). Irrespective of this pattern, surface water consistently had oxygen levels considered good for aquatic life (>5 mg/l, EPA 2024b), except for a single sample with 4.9 mg/l. Note that this pattern was almost entirely predictable by changes in water temperature (Figure 3). The solubility of oxygen in water decreases as temperature increases, and the observed oxygen levels were indicative of consistently high oxygen saturation.

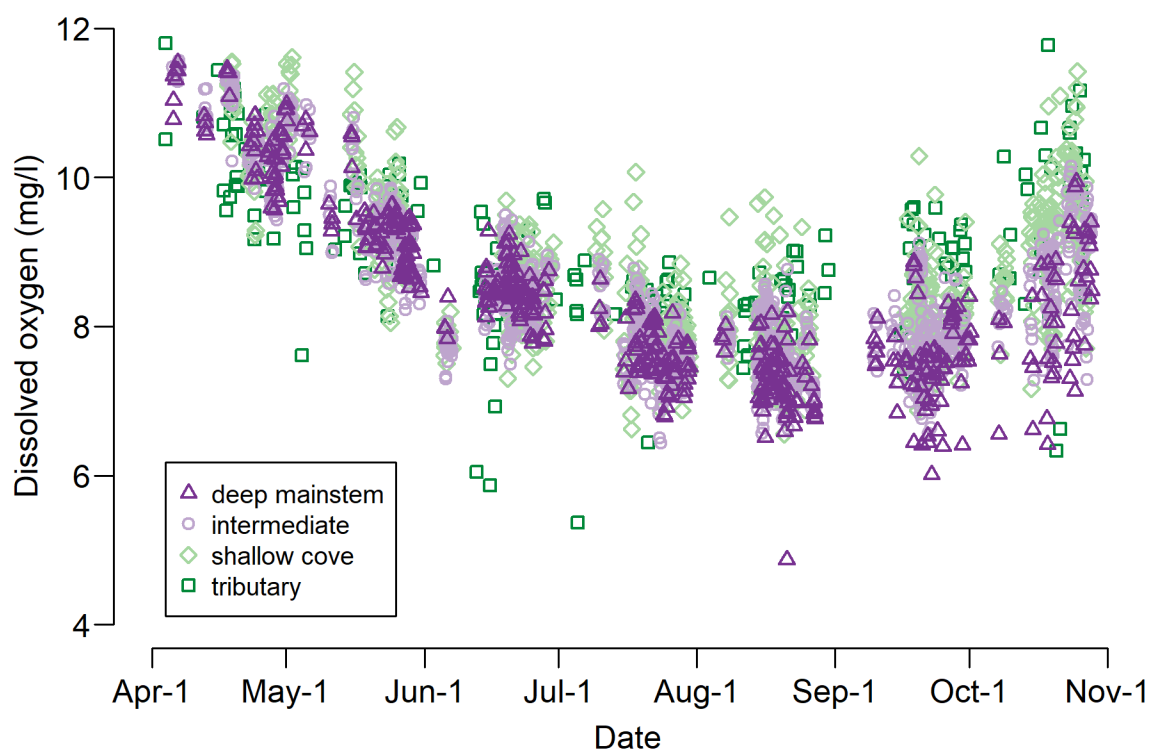


Figure 5. Seasonal cycle and variability in surface water oxygen levels.

Dissolved oxygen concentration decreased from around 10.5 mg/l in April to around 7.7 mg/l in July through September, before increasing to 9.0 mg/l in October. Most measurements were within 1.5 mg/l of median values for the time of year, but in October approximately 21% of tributary stations had concentrations >10.5 mg/l. Symbols as in Figure 3.

Sub-surface oxygen

Sub-surface oxygen levels ranged from good to fair to poor to anoxic (almost no oxygen), compared to the National Lakes Assessment benchmarks for dissolved oxygen concentration (>5 mg/l for good and >3 mg/l for fair; EPA 2024b) and an anoxia benchmark of <0.2 mg/l (EPA

2021a). While the timing and extent varied from year to year (Figure 6), a zone of water with poor oxygen levels was present in all years.

At shallow stations, the water column was generally well-mixed throughout the year, resulting in good oxygen levels at all depths. At intermediate-depth stations, bottom dissolved oxygen concentration ranged from similar to the surface to similar to the deepest part of the lake. See the previous DNR report for more details on individual cove stations (DNR 2017).

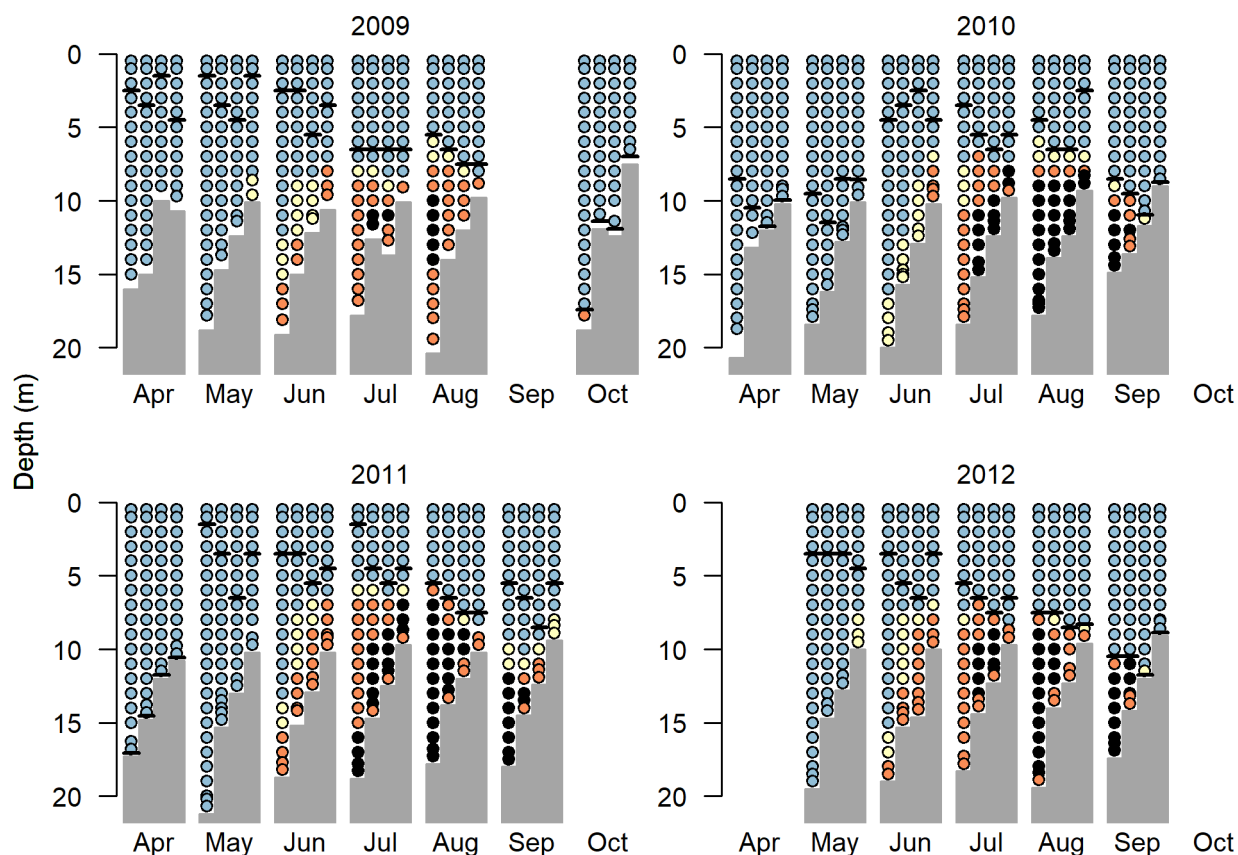


Figure 6. Vertical profiles of oxygen levels.

Dissolved oxygen concentration was color coded as good (blue), fair (yellow), poor (orange), or anoxic (black). Layout otherwise as in Figure 4. The epilimnion had good oxygen concentrations from April to October, with only one exception (August 2024, deepest station). Near the bottom, oxygen levels were typically good in April and May, fair to poor in June, and poor from July to September. In years with intensely poor oxygen levels, most of the lake deeper than 10 m (33 ft) was anoxic in July (2011, 2024), August (2010, 2011, 2012, 2021, 2022, 2023), or September (2010, 2011, 2012, 2022, 2023, 2024). Even in milder years, oxygen levels at these depths were mostly poor. By October, oxygen levels had returned to good at depths down to approximately 15 m (49 ft).

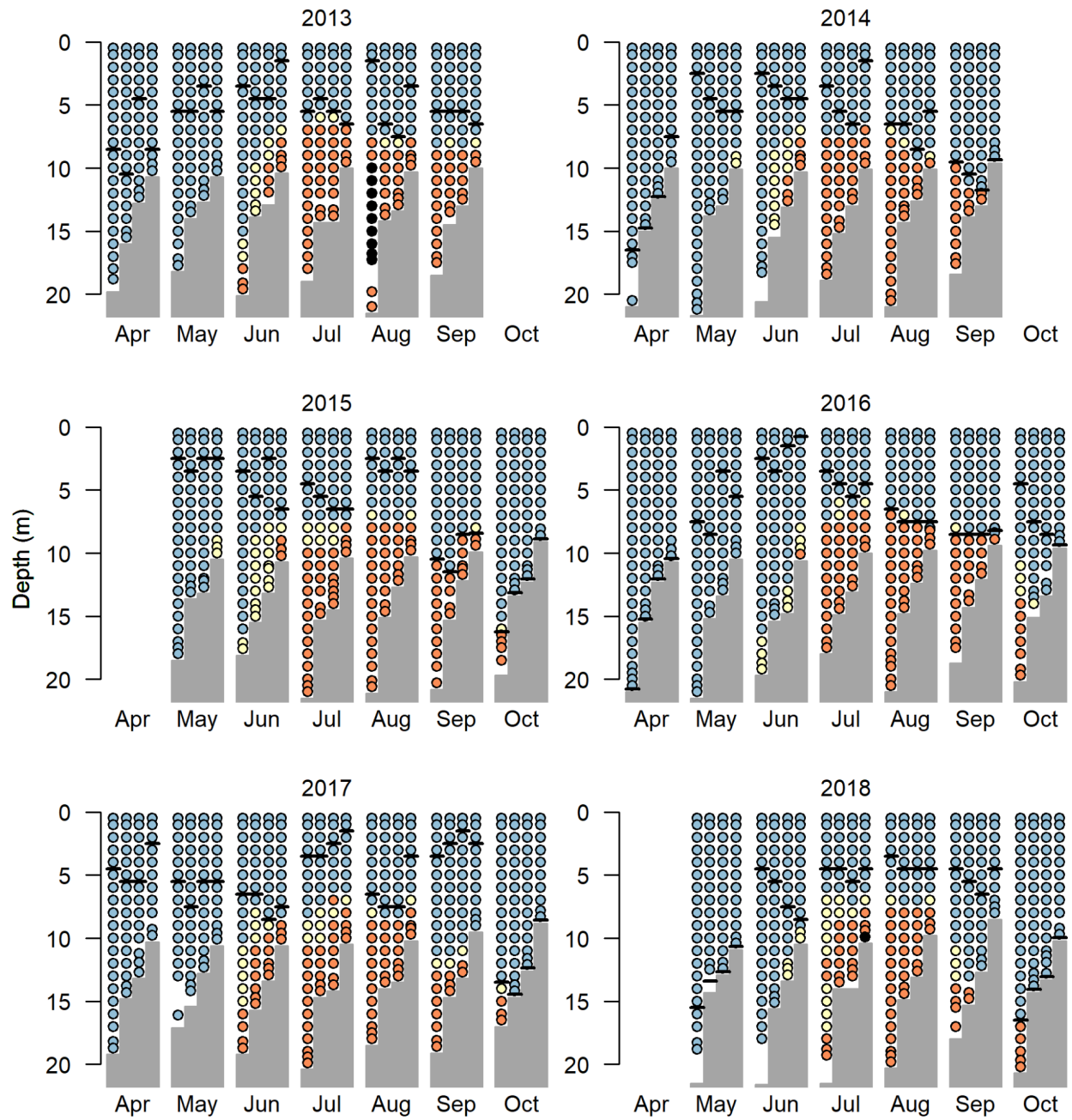


Figure 6, continued.

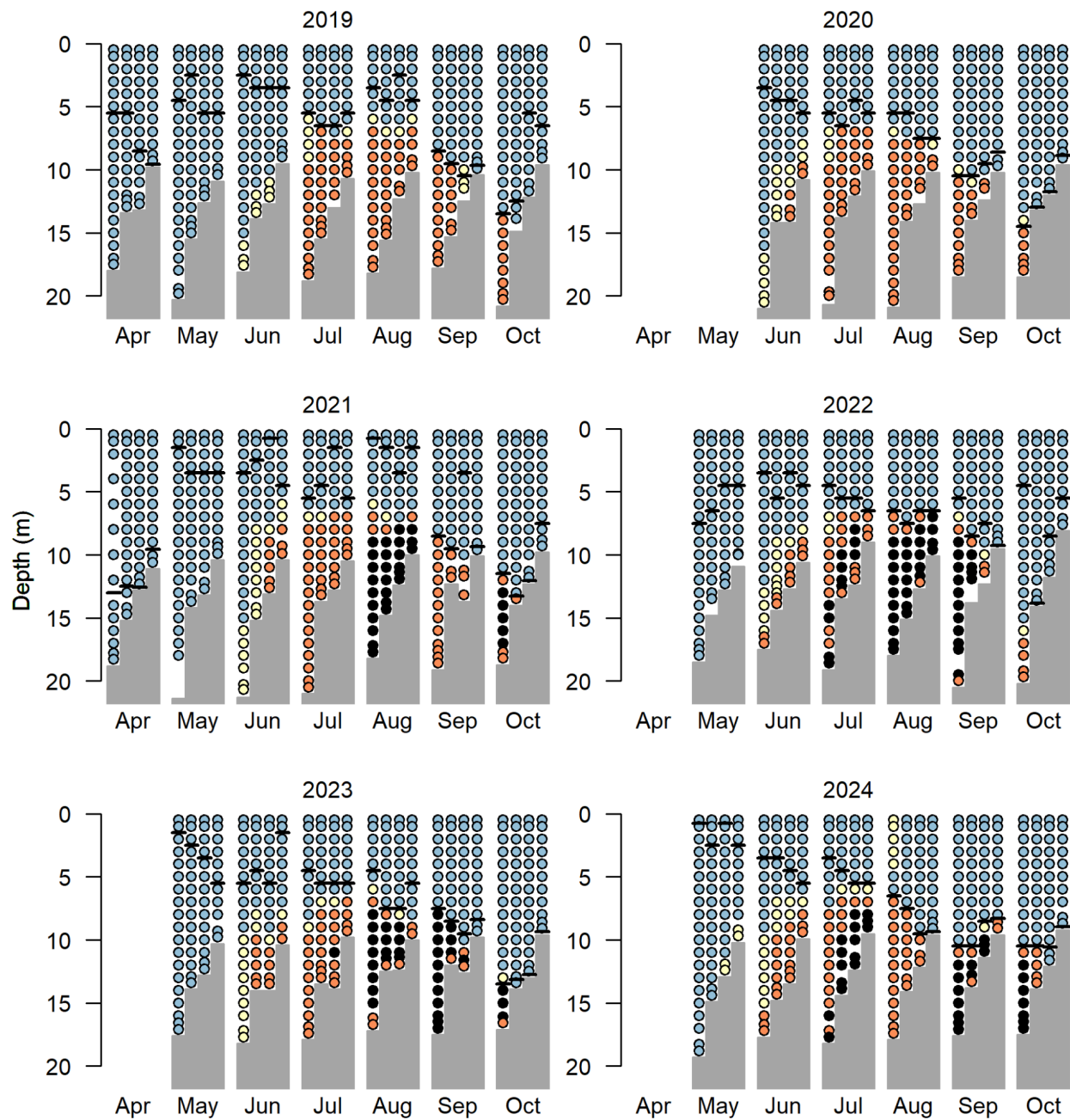


Figure 6, continued.

Changes in bottom dissolved oxygen

Trends analysis for coves was restricted to comparisons of 2009/2010 and 2014/2015, because the analysis could not adequately account for changes to the regularly monitored stations after 2015. Estimated seasonal (May–September) average bottom dissolved oxygen concentration

was good at all cove stations in 2009/2010 (6.1–8.0 mg/l). Oxygen significantly decreased in two coves (Cherry Creek Cove and Hoop Pole Cove), resulting in a change to fair habitat quality conditions in 2014/2015 (both 4.2 mg/l). All other coves maintained good conditions in 2014/2015 (6.5–8.0 mg/l; Figure 7; Table 12).

Table 12. Trends in cove bottom water oxygen levels.

n: number of training data points; r^2 : model fit (adjusted correlation coefficient); A1, A2: estimated seasonal (May–September) average dissolved oxygen concentration (mg/l) in 2009/2010 (period 1) and 2014/2015 (period 2); C1, C2: water quality category for periods 1 and 2; Significance: statistical significance of change from period 1 to period 2; very high: $p < 0.001$, high: $p < 0.01$, yes: $p < 0.05$, no (marginal): $p < 0.1$, no: $p \geq 0.1$.

#	Station	Description	n	r^2	A1	C1	A2	C2	Significance
1	MRC0011	Marsh Run Cove	55	0.79	6.1	good	6.5	good	no
2	CCC0008	Cherry Creek Cove	53	0.84	7.2	good	4.2	fair	very high
3	MMR0005	Meadow Mountain Run Cove	57	0.87	7.9	good	7.6	good	no (marginal)
4	NGC0010	North Glade Run Cove	51	0.74	7.0	good	6.9	good	no
5	UDC0004	Hoop Pole Cove	51	0.77	6.3	good	4.2	fair	very high
6	PLV0004	Poland Run Cove	56	0.89	8.0	good	8.0	good	no
7	GGC0015	Green Glade Run Cove	56	0.8	7.6	good	7.7	good	no
8	PWC0004	Pawn Run Cove	58	0.87	7.9	good	7.8	good	no
9	DPR0119	Deep Creek Cove	55	0.75	7.9	good	7.9	good	no

Trends analysis of lake stations compared bottom dissolved oxygen concentration in 2009/2010 and 2023/2024. Station DPR0082 (near Glendale Road Bridge) had a significant decrease from an estimated seasonal average of 3.3 mg/l (fair) in 2009/2010 to 2.2 mg/l (poor) in 2023/2024 (Figure 7, Table 13). The other three stations were in the poor category in 2009/2010 (2.2 to 2.8 mg/l), and both DPR0021 (near the dam) and DPR0056 (near the US 219 bridge) stayed in the poor category in 2023/2024. At station DPR0103 (near the Turkey Neck peninsula), bottom dissolved oxygen was in the fair category (3.3 mg/l) in 2023/2024, but the improvement was not significant.

Table 13. Trends in mainstem lake bottom water oxygen levels.

A1, A2: estimated seasonal average dissolved oxygen concentration (mg/l) in 2009/2010 and 2023/2024. Other columns as in Table 12.

#	Station	Description	n	r^2	A1	C1	A2	C2	Significance
10	DPR0056	US 219 Bridge	130	0.97	2.5	poor	2.2	poor	no
11	DPR0021	Dam	122	0.95	2.2	poor	2.4	poor	no
12	DPR0082	Glendale Road Bridge	150	0.92	3.3	fair	2.2	poor	high
13	DPR0103	Turkey Neck	120	0.85	2.8	poor	3.3	fair	no

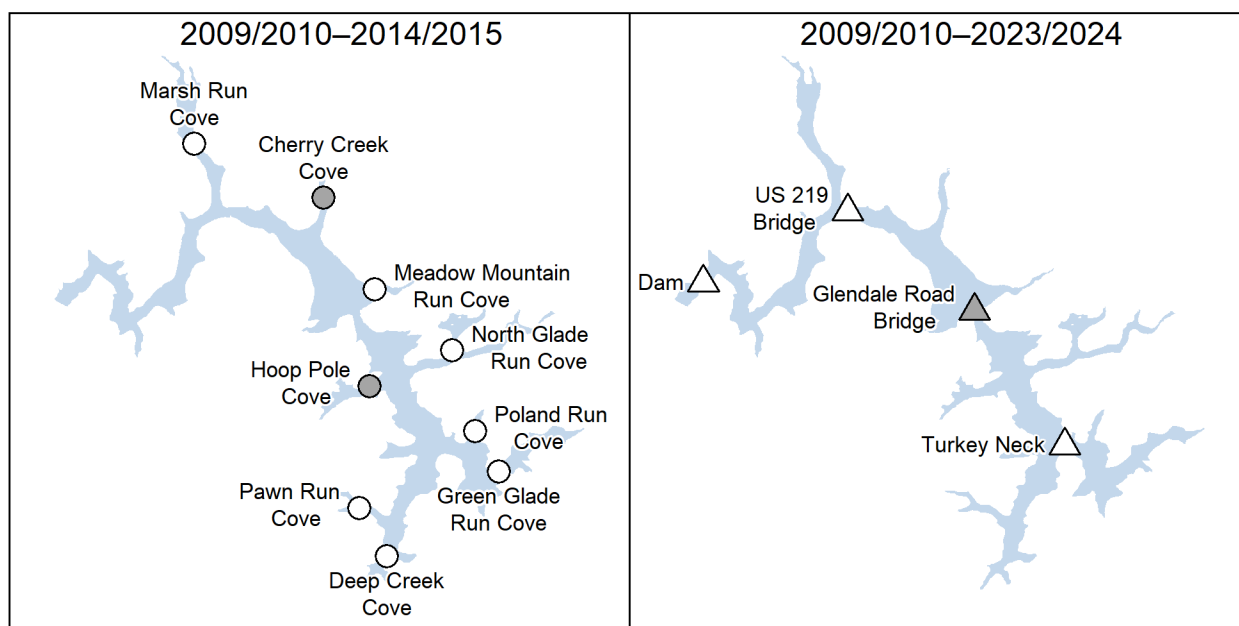


Figure 7. Trends in bottom water oxygen levels.

Tables 12–13 show the same data with additional details in tabular form. Statistical models detected significant decreases in dissolved oxygen concentration in three cases (gray). Changes at other locations were not significant (white). Left panel: trends at nine cove stations (circles) from 2009/2010 to 2014/2015. Right panel: trends at four lake stations (triangles) from 2009/2010 to 2023/2024.

Acidity (pH)

When water is either too acidic (low pH) or too basic (high pH), it can harm aquatic organisms by disrupting vital biochemical processes or by damaging sensitive tissues such as gills (EPA 2021b). A range of acidity from pH 6.5 (slightly acidic) to 8.5 (slightly basic) is considered optimal for most aquatic life (EPA 2024a). The same benchmarks are used to list Maryland waters as impaired, unless the cause of high or low acidity is natural. Cherry Creek, the largest Deep Creek Lake tributary, has been listed as impaired by low pH since 1996, due to ongoing acid mine drainage from abandoned coal mines (EPA 2012). After multiple successful mitigation projects in 1986–1989 and 1998–2001, Cherry Creek pH had dramatically improved by 2012 (EPA 2013). Note that due to irregularities with pH data in 2018–2021, this report focuses on surface water and trends analysis of surface and bottom water data prior to 2018.

Surface water acidity

For a great majority of 2009–2024 surface water measurements, including January–December for this analysis, pH was in the good range of 6.5–8.5. At lake stations, 100% of cases (546 of 546) fell inside the normal range, while at cove stations it was approximately 99% (one case <6.5, 1887 cases normal, 23 cases >8.5). At tributary stations, pH was <6.5 approximately 12% of the time (43 of 370 of cases), but most of these measurements came from just two stations. At the CCR0001 Cherry Creek station, which was monitored extensively from April 2009 to February 2020 (only five months missing data), pH was <6.5 approximately 15% of the time (20 of 131 cases). At the GGR0003 Green Glade Run tributary station, which was only sampled from November 2015 to December 2016 (one month without data) pH was <6.5 approximately 88% of the time (14 of 16 cases).

A weak seasonal cycle in surface acidity, essentially a decrease in pH by approximately 0.2 during the warmer months, explained a small part of the differences among measurements (10% seasonality score, not shown). Except for GGR0003 in 2016, seasonal medians of pH indicated good habitat quality (Figure 8).

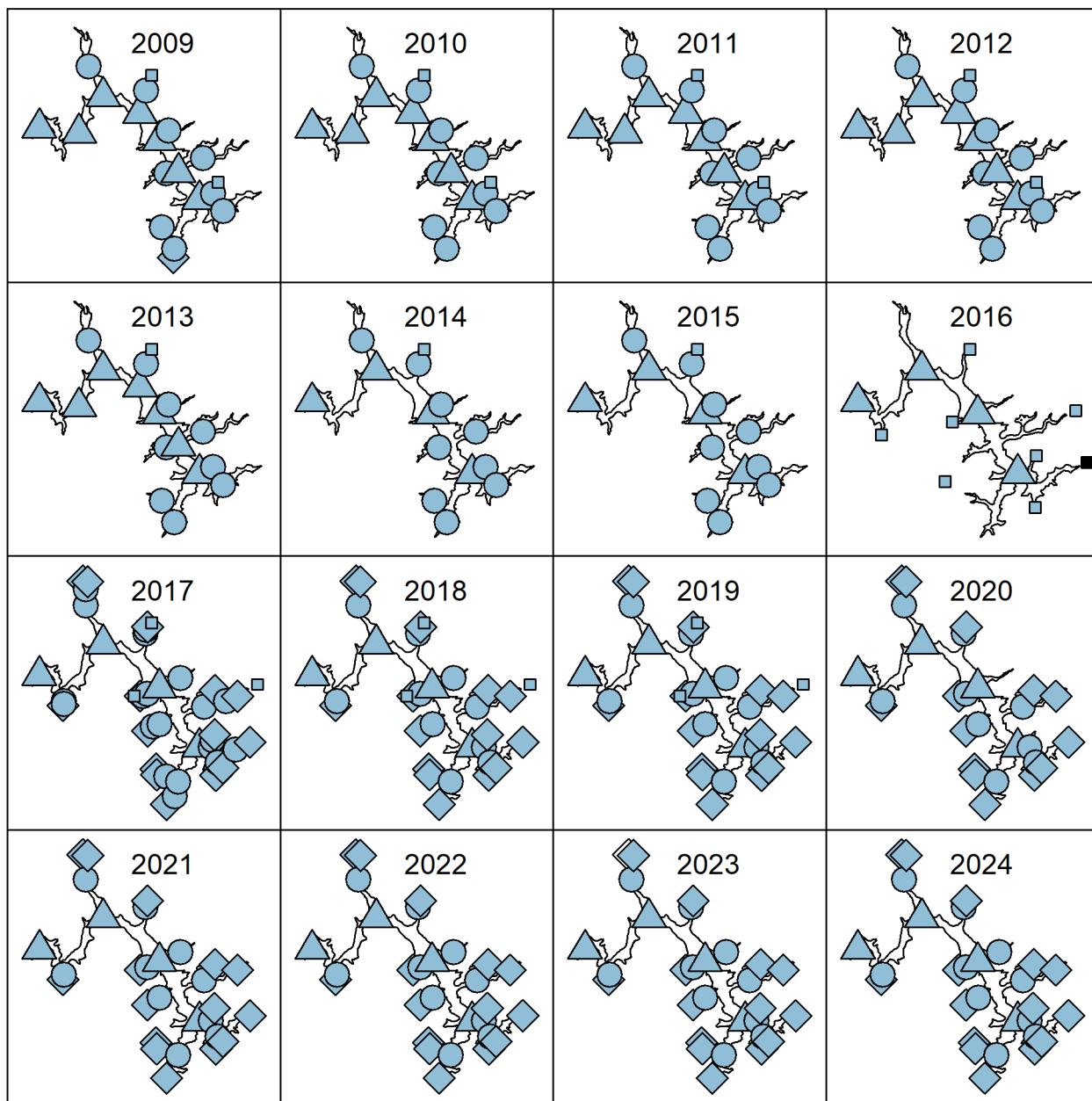


Figure 8. Surface water seasonal median acidity (pH).

Only stations sampled in 4–5 months of the growing season (May–September) are shown, including 4–7 deep stations, 0–21 intermediate stations, 0–15 shallow cove stations, and 0–8 tributary stations. Symbols as in Figure 2 (deep: triangles, intermediate: circles, shallow: diamonds, tributary: squares, <1.5 m: small). The total number of stations varied from 12 in 2016 to 43 in 2017. All but one median pH value were in the good range of 6.5–8.5 (blue). The southeast sub-watershed tributary station GGR0003, which was only sampled in the 2016 season, had a poor median pH of 6.325 (black).

Changes in acidity

Trends analysis for acidity was restricted to comparisons of 2009/2010 and 2014/2015 for both cove and lake stations. In four cases for surface water pH and one case for bottom water pH, the model fit was inadequate for trends assessment. At stations with a good model fit, estimated seasonal (May–September) averages for the surface and bottom were consistently in the good range. A significant decrease in surface water pH was detected in Meadow Mountain Run Cove (Table 14). Changes at other locations were not significant. Bottom water pH significantly decreased at three cove stations (Cherry Creek Cove, Meadow Mountain Run Cove and Hoop Pole Cove) and all four lake stations (Table 15). Note that changes from 2009/2010 to 2014/2015 may not reflect ongoing trends. Additional years of monitoring will allow a more robust assessment of longer-term changes.

Table 14. Trends in surface water acidity.

A1, A2: estimated seasonal average pH (unitless) in 2009/2010 and 2014/2015. Other columns as in Table 12.

#	Station	Description	n	r ²	A1	C1	A2	C2	Significance
1	MRC0011	Marsh Run Cove	50	0.57	7.14	good	7.09	good	no
2	CCC0008	Cherry Creek Cove	52	0.53	7.18	good	7.11	good	no
3	MMR0005	Meadow Mountain Run Cove	52	0.55	7.26	good	7.16	good	yes
4	NGC0010	North Glade Run Cove	51	0.60	7.12	good	7.14	good	no
5	UDC0004	Hoop Pole Cove	51	0.38	7.17	good	7.23	good	no
6	PLV0004	Poland Run Cove	51	0.30	7.33	good	7.36	good	no
7	GGC0015	Green Glade Run Cove	51	<0.30	NA	NA	NA	NA	NA
8	PWC0004	Pawn Run Cove	51	0.49	7.26	good	7.36	good	no (marginal)
9	DPR0119	Deep Creek Cove	51	<0.30	NA	NA	NA	NA	NA
10	DPR0056	US 219 Bridge	60	<0.30	NA	NA	NA	NA	NA
11	DPR0021	Dam	51	0.54	7.13	good	7.08	good	no
12	DPR0082	Glendale Road Bridge	79	<0.30	NA	NA	NA	NA	NA
13	DPR0103	Turkey Neck	51	0.40	7.23	good	7.27	good	no

Table 15. Trends in bottom water acidity.

A1, A2: estimated seasonal average pH (unitless) in 2009/2010 and 2014/2015. Other columns as in Table 12.

#	Station	Description	n	r ²	A1	C1	A2	C2	Significance
1	MRC0011	Marsh Run Cove	55	0.47	6.97	good	6.95	good	no
2	CCC0008	Cherry Creek Cove	53	0.71	7.08	good	6.79	good	very high
3	MMR0005	Meadow Mountain Run Cove	59	0.66	7.27	good	7.11	good	very high
4	NGC0010	North Glade Run Cove	52	0.48	7.01	good	6.95	good	no
5	UDC0004	Hoop Pole Cove	52	0.64	7.00	good	6.72	good	very high
6	PLV0004	Poland Run Cove	57	0.33	7.32	good	7.30	good	no
7	GGC0015	Green Glade Run Cove	57	0.34	7.13	good	7.21	good	no
8	PWC0004	Pawn Run Cove	59	0.45	7.15	good	7.15	good	no
9	DPR0119	Deep Creek Cove	56	0.24	NA	NA	NA	NA	NA
10	DPR0056	US 219 Bridge	71	0.74	6.85	good	6.66	good	high
11	DPR0021	Dam	60	0.81	6.66	good	6.59	good	yes
12	DPR0082	Glendale Road Bridge	91	0.73	6.90	good	6.65	good	very high
13	DPR0103	Turkey Neck	59	0.74	6.82	good	6.67	good	yes

Conductivity

Conductivity reflects the combined influence of any mineral salts dissolved in water, and is an important factor determining habitat quality for aquatic life. Too much or too little salt causes harmful physiological stress and is essentially toxic. Conductivity is most commonly measured as electrical conductivity, corrected for the influence of temperature, and reported as specific conductivity at a reference temperature of 25 °C (or simply “conductivity”). Since conductivity reflects the concentration of all dissolved salts (common or uncommon, naturally occurring or not), it indicates their combined physiological toxicity, as well as detecting pollution from various sources (e.g., road salt runoff or sewage spills; EPA 2011).

The Deep Creek Lake northwest sub-watershed and Cherry Creek sub-watershed are located in a geological region with naturally low conductivity in surface water (EPA Level III ecoregion region 69, Omernik and Griffith 2014), and the same can be expected for the adjacent region (ecoregion 67) of the southeast sub-watershed (EPA 2011). Calcium, magnesium, potassium, sodium, bicarbonate, carbonate, sulfate, and chloride are major components of naturally occurring salinity, and chronic exposure below 300 $\mu\text{S}/\text{cm}$ is considered sufficient to protect 95% of invertebrates (genera) in Central Appalachian streams (demonstrated for ecoregion 69 and proposed for ecoregion 67; EPA 2011).

Conductivity was measured at the same stations as acidity (Figure 8). For most of these measurements, including January–December for this analysis, conductivity was well below the threshold considered harmful (chronic exposure to 300 $\mu\text{S}/\text{cm}$, EPA 2011). At Deep Creek Lake cove and lake stations, conductivity of surface water ranged from 76 to 133 $\mu\text{S}/\text{cm}$ and conductivity among all depths pooled ranged from 59 to 199 $\mu\text{S}/\text{cm}$. At tributary stations, conductivity was typically below half of the EPA benchmark (289 of 369 cases <150 $\mu\text{S}/\text{cm}$) but

sometimes exceeded 300 $\mu\text{S}/\text{cm}$ (seven of 369 of cases, all in August–December). At the AWR0001 Arrowhead Run tributary station, which was monitored from October 2015 to December 2019 (seven months missing data), conductivity was $>300 \mu\text{S}/\text{cm}$ approximately 12% of the time (six of 51 cases).

The seasonal cycle in surface water conductivity was weak (7% seasonality score, not shown). Seasonal medians of conductivity were all below 300 $\mu\text{S}/\text{cm}$, indicating good habitat quality.

Changes in conductivity

Trends analysis for conductivity was restricted to comparisons of 2009/2010 and 2014/2015 for both cove and lake stations. Estimated seasonal (May–September) average conductivity was consistently far below the 300 $\mu\text{S}/\text{cm}$ EPA benchmark for streams, indicating consistently good water quality. Statistically significant increases in surface conductivity for May–September between 2009/10 and 2014/2015 were found in most coves (Marsh Run Cove was an exception) and at most lake stations (the station closest to the dam, DPR0021, was an exception; Table 16). In bottom waters, conductivity significantly increased at six out of nine cove stations (Marsh Run Cove, North Glade Run Cove, Green Glade Run Cove, Deep Creek Cove, Pawn Run Cove, and Hoop Pole Cove), but no significant changes were detected at lake stations (Table 17). Note that changes from 2009/2010 to 2014/2015 may not reflect ongoing trends. Additional years of monitoring will allow a more robust assessment of longer-term changes.

Table 16. Trends in surface water conductivity.

A1, A2: estimated seasonal average conductivity ($\mu\text{S}/\text{cm}$) in 2009/2010 and 2014/2015. Other columns as in Table 12.

#	Station	Description	n	r ²	A1	C1	A2	C2	Significance
1	MRC0011	Marsh Run Cove	51	0.71	101	good	104	good	no (marginal)
2	CCC0008	Cherry Creek Cove	52	0.60	97	good	101	good	high
3	MMR0005	Meadow Mountain Run Cove	52	0.75	97	good	100	good	high
4	NGC0010	North Glade Run Cove	51	0.74	95	good	99	good	very high
5	UDC0004	Hoop Pole Cove	51	0.75	94	good	98	good	very high
6	PLV0004	Poland Run Cove	51	0.72	94	good	97	good	yes
7	GGC0015	Green Glade Run Cove	51	0.71	94	good	97	good	high
8	PWC0004	Pawn Run Cove	51	0.72	93	good	97	good	high
9	DPR0119	Deep Creek Cove	51	0.74	93	good	97	good	high
10	DPR0056	US 219 Bridge	61	0.71	99	good	102	good	yes
11	DPR0021	Dam	51	0.67	98	good	99	good	no
12	DPR0082	Glendale Road Bridge	80	0.78	96	good	100	good	very high
13	DPR0103	Turkey Neck	51	0.74	94	good	98	good	high

Table 17. Trends in bottom water conductivity.

A1, A2: estimated seasonal average conductivity ($\mu\text{S}/\text{cm}$) in 2009/2010 and 2014/2015. Other columns as in Table 12.

#	Station	Description	n	r ²	A1	C1	A2	C2	Significance
1	MRC0011	Marsh Run Cove	56	0.70	103	good	107	good	high
2	CCC0008	Cherry Creek Cove	53	0.43	100	good	104	good	no (marginal)
3	MMR0005	Meadow Mountain Run Cove	59	0.36	96	good	99	good	no
4	NGC0010	North Glade Run Cove	52	0.48	95	good	100	good	high
5	UDC0004	Hoop Pole Cove	52	0.62	96	good	101	good	high
6	PLV0004	Poland Run Cove	57	0.63	94	good	97	good	no (marginal)
7	GGC0015	Green Glade Run Cove	57	0.70	94	good	97	good	high
8	PWC0004	Pawn Run Cove	59	0.73	93	good	97	good	high
9	DPR0119	Deep Creek Cove	56	0.69	93	good	97	good	high
10	DPR0056	US 219 Bridge	72	0.84	116	good	120	good	no (marginal)
11	DPR0021	Dam	60	0.78	119	good	118	good	no
12	DPR0082	Glendale Road Bridge	92	0.75	108	good	111	good	no
13	DPR0103	Turkey Neck	59	0.69	102	good	105	good	no

Algae and related water quality indicators

High levels of algae can result in murky water and are indicative of high levels of nutrients and poor water quality. From a human perspective, water with high cloudiness and low clarity is undesirable for boating, swimming, and other uses of Deep Creek Lake. They are also ecologically problematic, because of reduced light penetration into deeper water, where light is needed to support submerged aquatic vegetation (e.g., underwater grasses) and where photosynthesis by algae and submerged aquatic vegetation is needed to replenish dissolved oxygen (see oxygen, above). Moreover, any increase in dead algae sinking and decomposing in deeper water further exacerbates oxygen-poor conditions. Finally, blooms of certain harmful algae could pose health risks to humans and aquatic organisms. For more information on harmful algal bloom monitoring, see MDE (2024). For more information on Deep Creek Lake submerged aquatic vegetation, see Bortz et al. (2017).

The standard method for monitoring algae is to measure the concentration of chlorophyll-a, a green pigment used by algae and other plants to capture energy from sunlight. Concentrations of the nutrients nitrogen and phosphorus (which act as fertilizer) and water cloudiness (which is caused, in part, by algae) are all water quality indicators closely related to algal growth. For 2009–2024, all the above measurements were performed by analytical laboratories on samples taken from a subset of Deep Creek Lake stations. With few exceptions, only surface water samples and 2009–2021 bottom water samples from deep mainstem lake stations were collected (see surface water algae, below). Water clarity, another closely related indicator, was routinely measured in the field at all stations (see water clarity, below).

Surface water algae (chlorophyll-*a*)

Benchmarks of chlorophyll-*a* concentration were taken from the National Lakes Assessment ($>5.54 \mu\text{g/l}$ for fair and $>13.1 \mu\text{g/l}$ for poor; EPA 2024b). Deep Creek Lake surface water algal levels were generally good (less algae, 61% of samples), but sometimes fair (moderate algae, 33%), and occasionally poor (more algae, 6%). A weak seasonal cycle did little to explain variability during the growing season (6% seasonality score; Figure 9), but distinct spatial patterns were apparent (Figure 10).

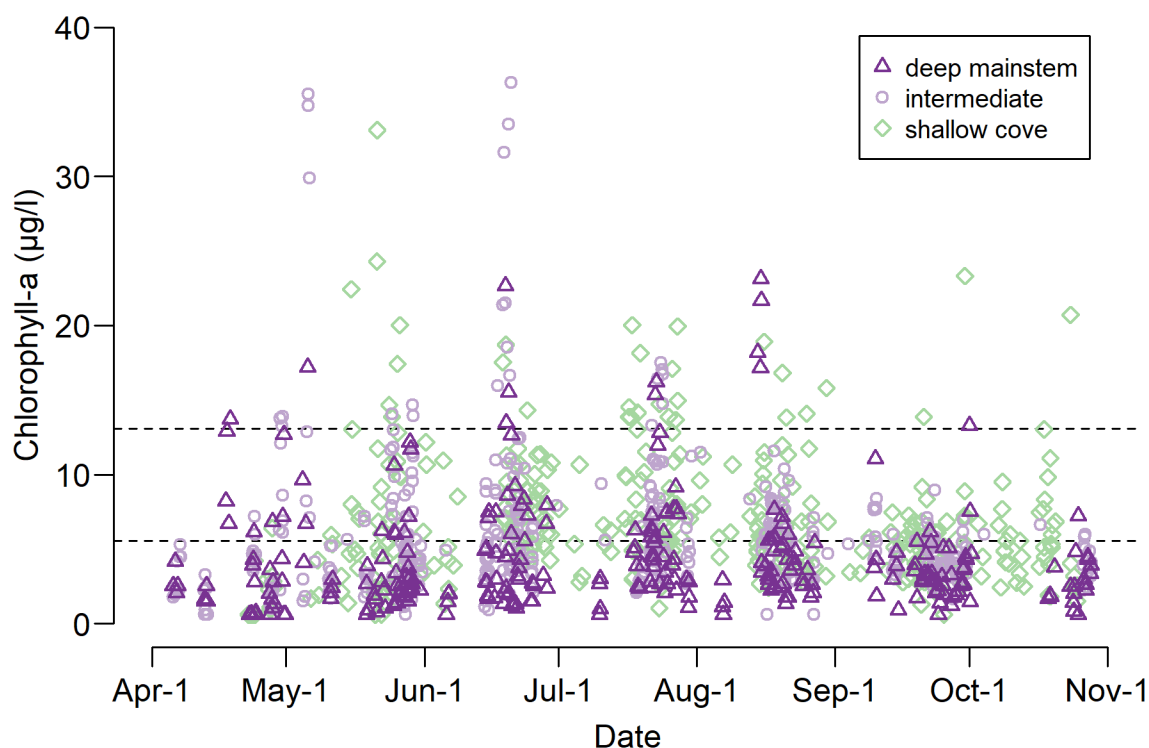


Figure 9. Seasonal cycle and variability in surface water algal levels.

Dashed lines indicate chlorophyll-*a* concentration benchmarks (Table 7). Samples with good, fair, and poor water quality occurred for all months and all types of stations (but not all combinations of month and type). Differences among months and among deep, intermediate, and shallow stations were subtle. Water quality indicated by monthly median values was good, except from June to August at shallow stations and from July to August at intermediate stations, when it was fair. Symbols as in Figure 3.

There were two important spatial patterns. First, stations in the northwest sub-watershed (downstream of Glendale Road Bridge) generally had less algae than stations in the southeast sub-watershed. Second, water quality was typically better at deeper mainstem lake stations and worse at shallow cove stations. Both patterns were consistent with enhanced algal growth in areas with higher nutrient levels (see surface water nitrogen and surface water phosphorus,

below). However, there was no simple one-to-one correspondence, meaning that stations with lower nutrient levels did not consistently have lower chlorophyll-*a* concentrations. Note, that the National Lakes Assessment classifies lakes and reservoirs based entirely on surface samples at the deepest part of the water body (EPA 2024b). If Deep Creek Lake had been included in the National Lakes Assessment during 2009–2024, water quality would most likely have been scored as good, in terms of algae.

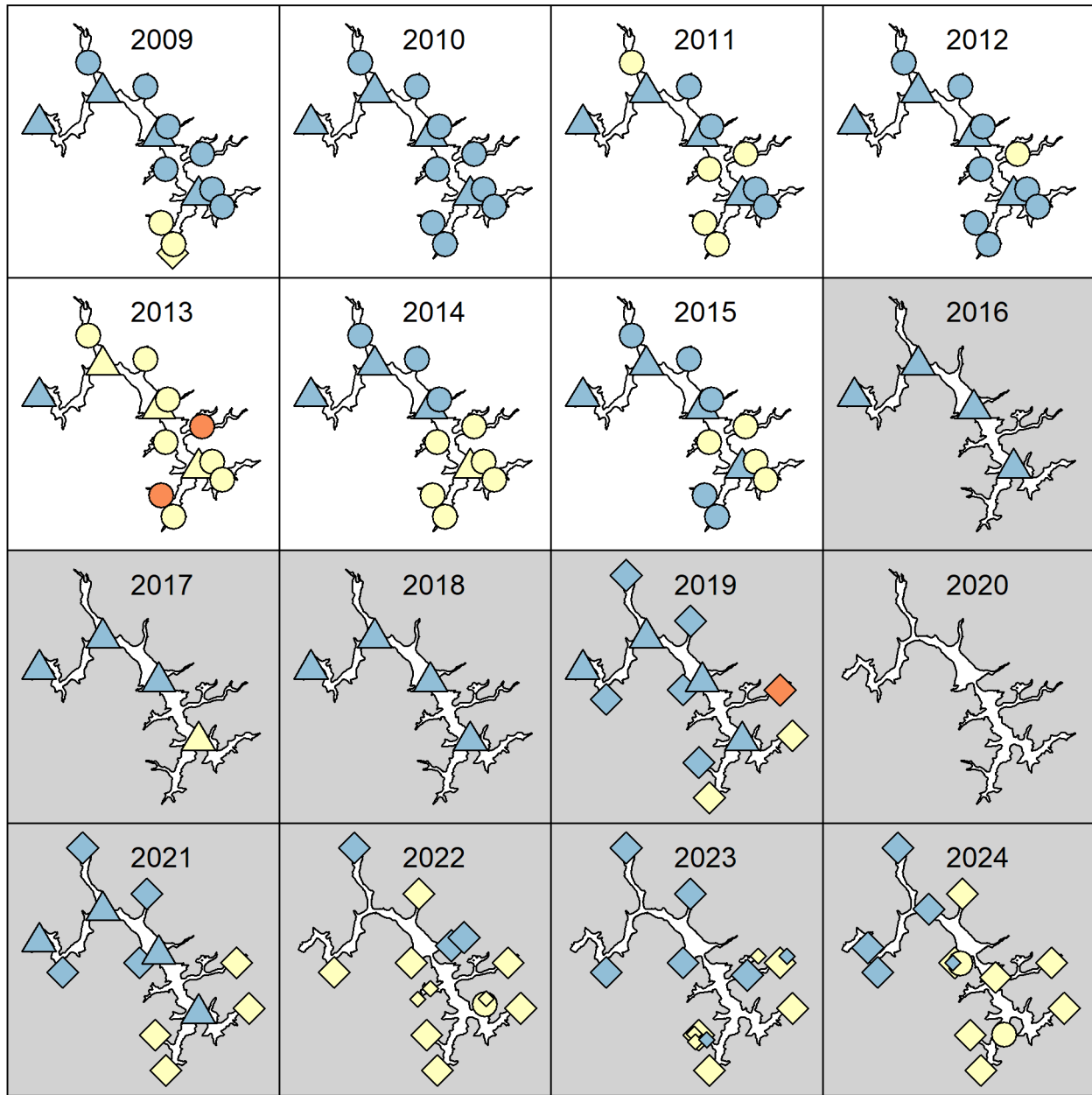


Figure 10. Surface water seasonal median algal levels.

Monitored locations included four deep mainstem lake stations (2009–2019 and 2021), nine intermediate-depth cove stations (2009–2015), one and two intermediate cove stations (2022 and 2024), one shallow cove station (2009), and 8–14 shallow cove stations (2019 and 2021–2024). Starting in mid-2016 (gray background), measurements were from different laboratories. Despite differences among stations and years, 2013 appeared to have the lowest water quality (one good, 10 fair, two poor stations), whereas 2010 was clearly a year with good water quality (all 13 stations). Colors: water quality (blue: good, yellow: fair, orange: poor; Table 7). Symbols as in Figure 2 (triangles: deep, circles: intermediate, diamonds: shallow, small: <1.5 m).

Changes in algal levels

Trends analysis for surface water chlorophyll-a was restricted to comparisons of 2009/2010 and 2014/2015, due to changes in laboratories and monitored stations that could not be adequately accounted for in the analysis. At three of 13 stations, the analysis did not yield sufficiently well-fitting models for trends assessment. Note that changes from 2009/2010 to 2014/2015 may not reflect ongoing trends. Additional years of monitoring will allow a more robust assessment of longer-term changes.

At all stations with a good model fit, estimated seasonal (May-September) average surface chlorophyll-a concentration was in the good range in 2009/2010 (2.9–4.6 µg/l). There were significant increases in four coves (North Glade Run Cove, Poland Run Cove, Green Glade Run Cove and Hoop Pole Cove) resulting in fair water quality conditions in 2014/2015 (5.6–9.1 µg/l; Table 18; Figure 11). There was also a significant increase at one lake station (DPR0103, near the Turkey Neck peninsula), but water quality remained in the good range (5.5 µg/l), as did the four other stations.

Table 18. Trends in surface water algal levels.

A1, A2: estimated seasonal average chlorophyll-a concentration (µg/l) in 2009/2010 and 2014/2015. Other columns as in Table 12.

#	Station	Description	n	r ²	A1	C1	A2	C2	Significance
1	MRC0011	Marsh Run Cove	49	0.45	3.1	good	4.7	good	no (marginal)
2	CCC0008	Cherry Creek Cove	50	0.50	4.4	good	4.0	good	no
3	MMR0005	Meadow Mountain Run Cove	51	NA	NA	NA	NA	NA	NA
4	NGC0010	North Glade Run Cove	50	0.59	4.4	good	9.1	fair	very high
5	UDC0004	Hoop Pole Cove	50	0.42	3.8	good	5.6	fair	yes
6	PLV0004	Poland Run Cove	50	0.39	4.6	good	7.5	fair	yes
7	GGC0015	Green Glade Run Cove	50	0.43	3.6	good	7.0	fair	high
8	PWC0004	Pawn Run Cove	50	0.40	3.6	good	5.5	good	no (marginal)
9	DPR0119	Deep Creek Cove	50	0.30	4.2	good	5.1	good	no
10	DPR0056	US 219 Bridge	54	<0.30	NA	NA	NA	NA	NA
11	DPR0021	Dam	50	<0.30	NA	NA	NA	NA	NA
12	DPR0082	Glendale Road Bridge	54	0.48	2.9	good	3.9	good	no
13	DPR0103	Turkey Neck	50	0.37	3.1	good	5.5	good	high

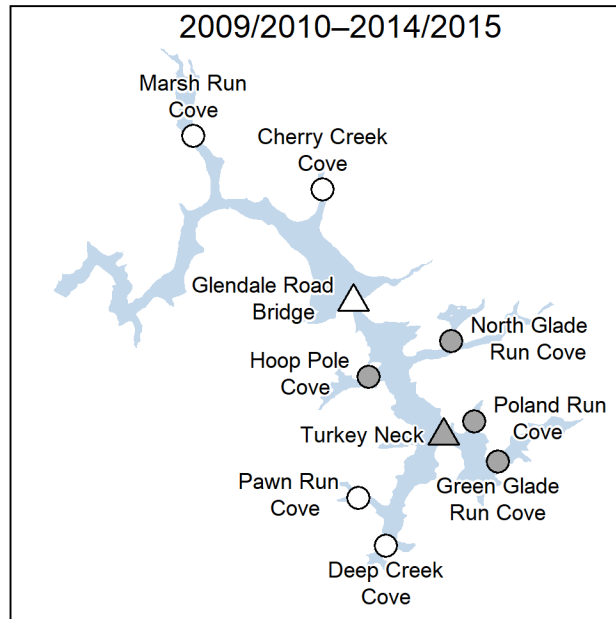


Figure 11. Trends in surface water algal levels from 2009/2010 to 2014/2015.

Table 18 shows the same data with additional details in tabular form. Statistical models detected significant increases (gray) at four of eight cove stations (circles) and one of two lake stations (triangles).

Surface water nitrogen

Levels of the nutrient nitrogen showed strong seasonal and spatial patterns, with surface water quality ranging from good (less nitrogen, 30% of samples) to fair (moderate nitrogen, 46%) to poor (more nitrogen, 24%). Benchmarks of total nitrogen concentration were taken from the National Lakes Survey (>0.266 mg/l for fair and >0.409 mg/l for poor, EPA 2024b). A strong and predictable seasonal cycle was apparent at non-tributary stations (53% seasonality score; Figure 12). Note that seasonality score was calculated from a standardized subset of data that did not include tributary stations (Appendix C).

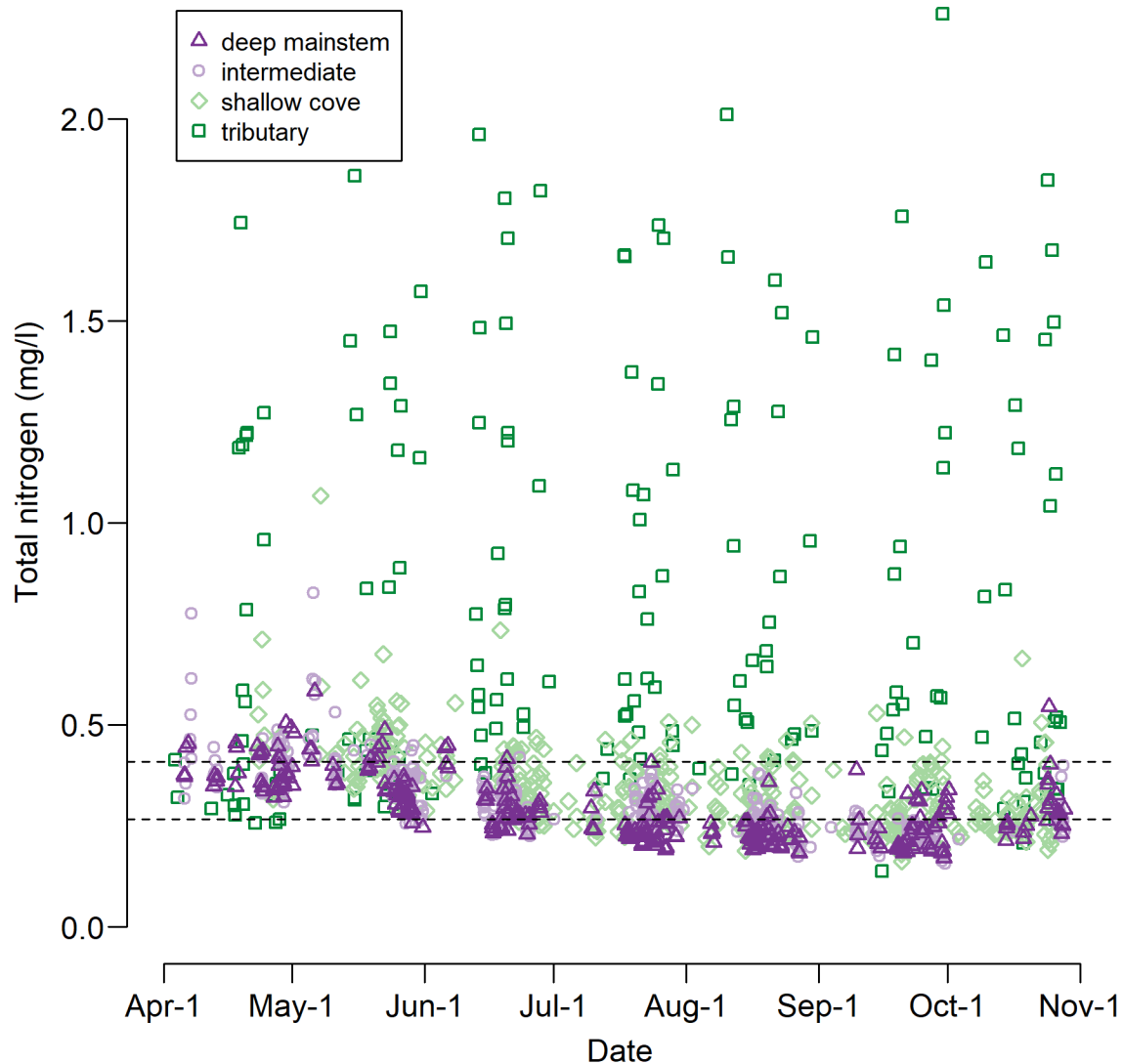


Figure 12. Seasonal cycle and variability in surface water nitrogen levels.

Non-tributary stations were somewhat similar, with pooled median total nitrogen concentrations decreasing by almost 40% from around 0.38 mg/l in April and May to around 0.24 mg/l in September, before increasing to around 0.27 mg/l in October. Most non-tributary samples were within 0.10 mg/l of median values for the time of year. At tributary stations, monthly median nitrogen levels ranged from 0.39 mg/l to 0.71 mg/l, but the large variability among samples masked any underlying seasonal pattern (most samples within 1.0 mg/l of median values). Symbols as in Figure 3. Lines as in Figure 9. One extreme value not shown.

Spatial patterns for nitrogen were similar to spatial patterns for algae. First, nitrogen levels were generally lower in the northwest sub-watershed than in the southeast sub-watershed (Figure 13). Second, water quality was strongly associated with the locations of monitoring stations: most commonly good at deep mainstem lake locations, fair at intermediate-depth stations, and poor at tributary stations (Figures 12–13).

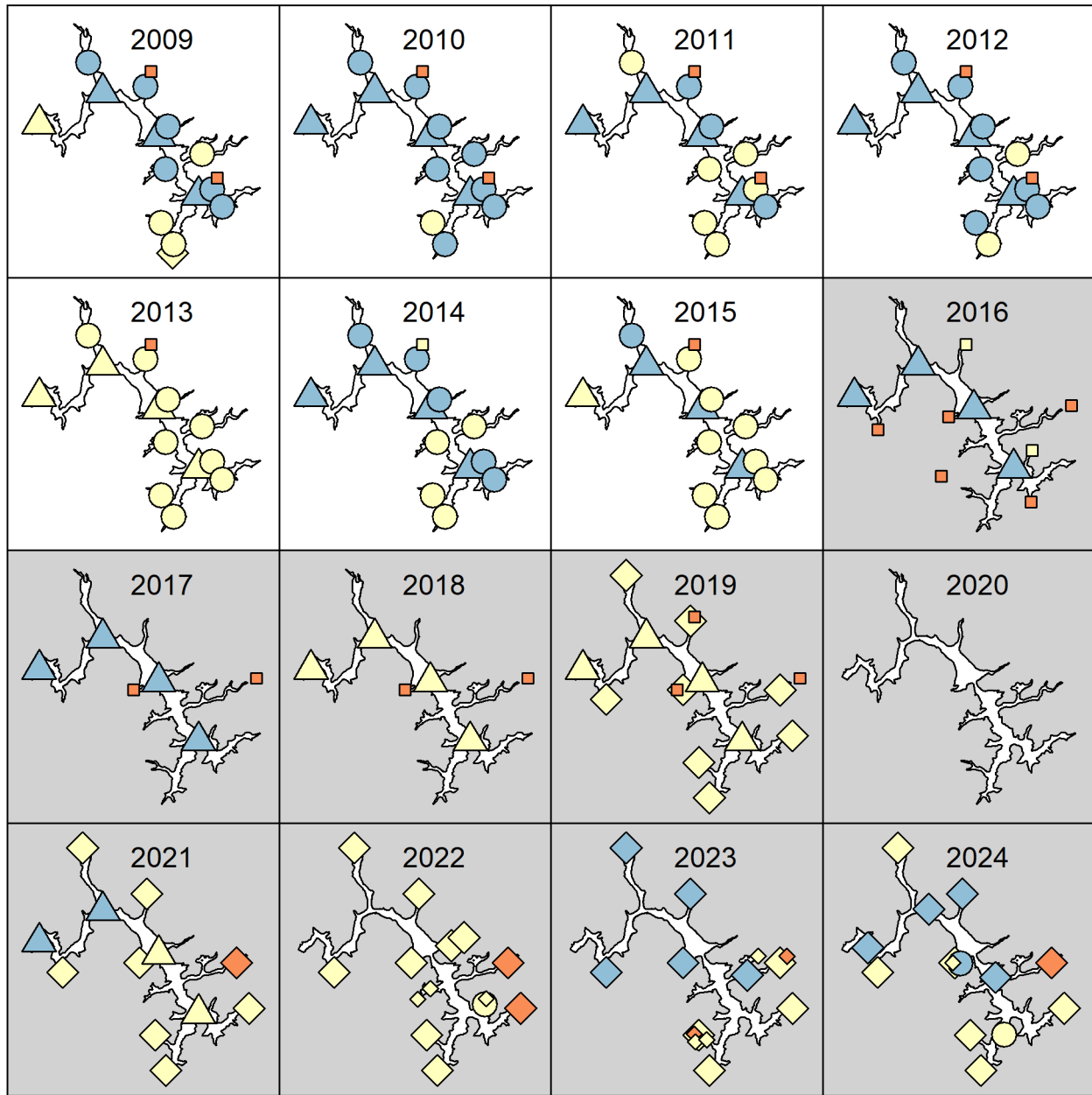


Figure 13. Surface water seasonal median nitrogen levels.

In terms of total nitrogen concentration, water quality was generally best at deep mainstem lake stations and worst at tributary stations (also shown in Figure 12). There was a tendency for stations in the northwest sub-watershed to have better water quality than stations in the southeast sub-watershed (2009–2012, 2014–2015, and 2021–2024). Stations as in Figure 10 plus 1–3 tributary stations (2009–2015 and 2017–2019) or seven tributary stations (2016). Colors: water quality (blue: good, yellow: fair, orange: poor; Table 7; gray: different laboratories). Symbols as in Figure 2 (triangles: deep, circles: intermediate, diamonds: shallow, squares: tributaries, small: <1.5 m).

Nitrogen levels substantially higher than the benchmark for poor water quality were common at tributary stations (Figure 12). Whereas 40% of tributary samples exceeded twice the benchmark for poor nitrogen levels, the same was almost never the case for cove or lake samples (two cases total, <0.1% of samples). In terms of monthly median values, the highest nitrogen level among cove and lake stations with >3 m (>10 ft) nominal bottom depth was still in the fair water quality range. Among shallower cove stations, the highest median was slightly worse than fair (1.2 times the benchmark for poor). At tributary stations, the highest value was much worse than fair (4.8 times the benchmark for poor).

Changes in nitrogen

Trends analysis for surface water total nitrogen levels was restricted to comparisons of 2009/2010 and 2014/2015, due to changes in laboratories and monitored stations that could not be adequately accounted for in the analysis. Note that changes from 2009/2010 to 2014/2015 may not reflect ongoing trends. Additional years of monitoring will allow a more robust assessment of longer-term changes.

Estimated seasonal average total nitrogen levels were in the good range at all four lake stations and four out of nine cove stations, and in the fair range at the other five cove stations in 2009/2010. There were significant increases at five of 13 stations (Table 19, Figure 14). For three coves (Cherry Creek Cove, Meadow Mountain Run Cove, and Poland Run Cove), the increase resulted in a change in water quality conditions from good in 2009/2010 to fair in 2014/2015. For two coves (North Glade Run Cove and Green Glade Run Cove), water quality was in the fair range in both time periods. Station DPR0056 (near the US 219 bridge) was the only one with good water quality in 2014/2015. At the remaining stations, seasonal average total nitrogen levels changed from the good to the fair range, but the magnitude of the change was not statistically significant.

Table 19. Trends in surface water nitrogen levels.

A1, A2: estimated seasonal average total nitrogen concentration (mg/l) in 2009/2010 and 2014/2015. Other columns as in Table 12.

#	Station	Description	n	r ²	A1	C1	A2	C2	Significance
1	MRC0011	Marsh Run Cove	50	0.77	0.272	fair	0.279	fair	no
2	CCC0008	Cherry Creek Cove	50	0.75	0.254	good	0.291	fair	high
3	MMR0005	Meadow Mountain Run Cove	51	0.83	0.255	good	0.281	fair	high
4	NGC0010	North Glade Run Cove	51	0.74	0.287	fair	0.326	fair	high
5	UDC0004	Hoop Pole Cove	51	0.83	0.258	good	0.288	fair	high
6	PLV0004	Poland Run Cove	51	0.70	0.262	good	0.278	fair	no
7	GGC0015	Green Glade Run Cove	51	0.67	0.270	fair	0.299	fair	yes
8	PWC0004	Pawn Run Cove	51	0.58	0.303	fair	0.297	fair	no
9	DPR0119	Deep Creek Cove	51	0.54	0.289	fair	0.307	fair	no
10	DPR0056	US 219 Bridge	53	0.77	0.247	good	0.254	good	no
11	DPR0021	Dam	49	0.69	0.259	good	0.268	fair	no
12	DPR0082	Glendale Road Bridge	53	0.83	0.249	good	0.268	fair	no (marginal)
13	DPR0103	Turkey Neck	50	0.73	0.254	good	0.275	fair	no (marginal)

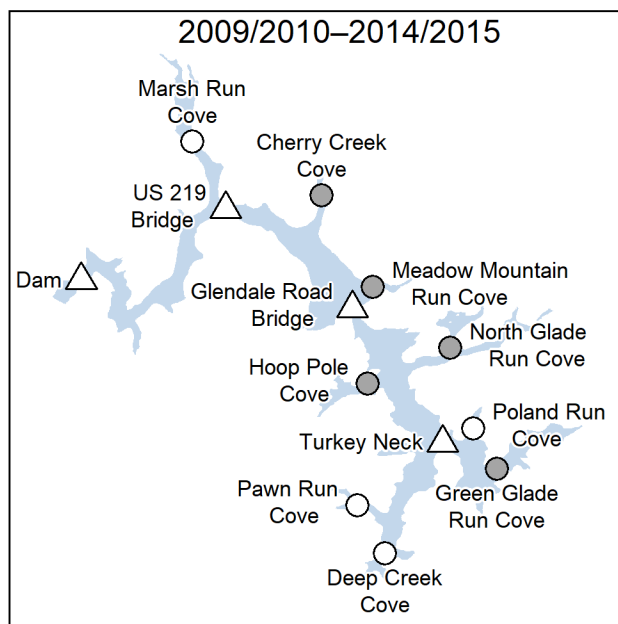


Figure 14. Trends in surface water nitrogen levels from 2009/2010 to 2014/2015.

Table 19 shows the same data with additional details in tabular form. Statistical models detected significant increases in total nitrogen concentration (gray) at five of nine cove stations (circles) and zero of four lake stations (triangles).

Surface water phosphorus

Levels of the nutrient phosphorus were mostly good (less phosphorus, 80% of samples), but sometimes fair (moderate phosphorus, 17%), and occasionally poor (more phosphorus, 3%). Benchmarks of total phosphorus concentration were taken from the National Lakes Assessment (>0.018 mg/l for fair and >0.033 mg/l for poor; EPA 2024b). Total phosphorus levels showed no meaningful seasonal pattern (2% seasonality score, not shown). Spatial patterns were similar to those for chlorophyll-*a* and nitrogen, in that stations in the northwest sub-watershed and deeper stations generally had better water quality (Figure 15).

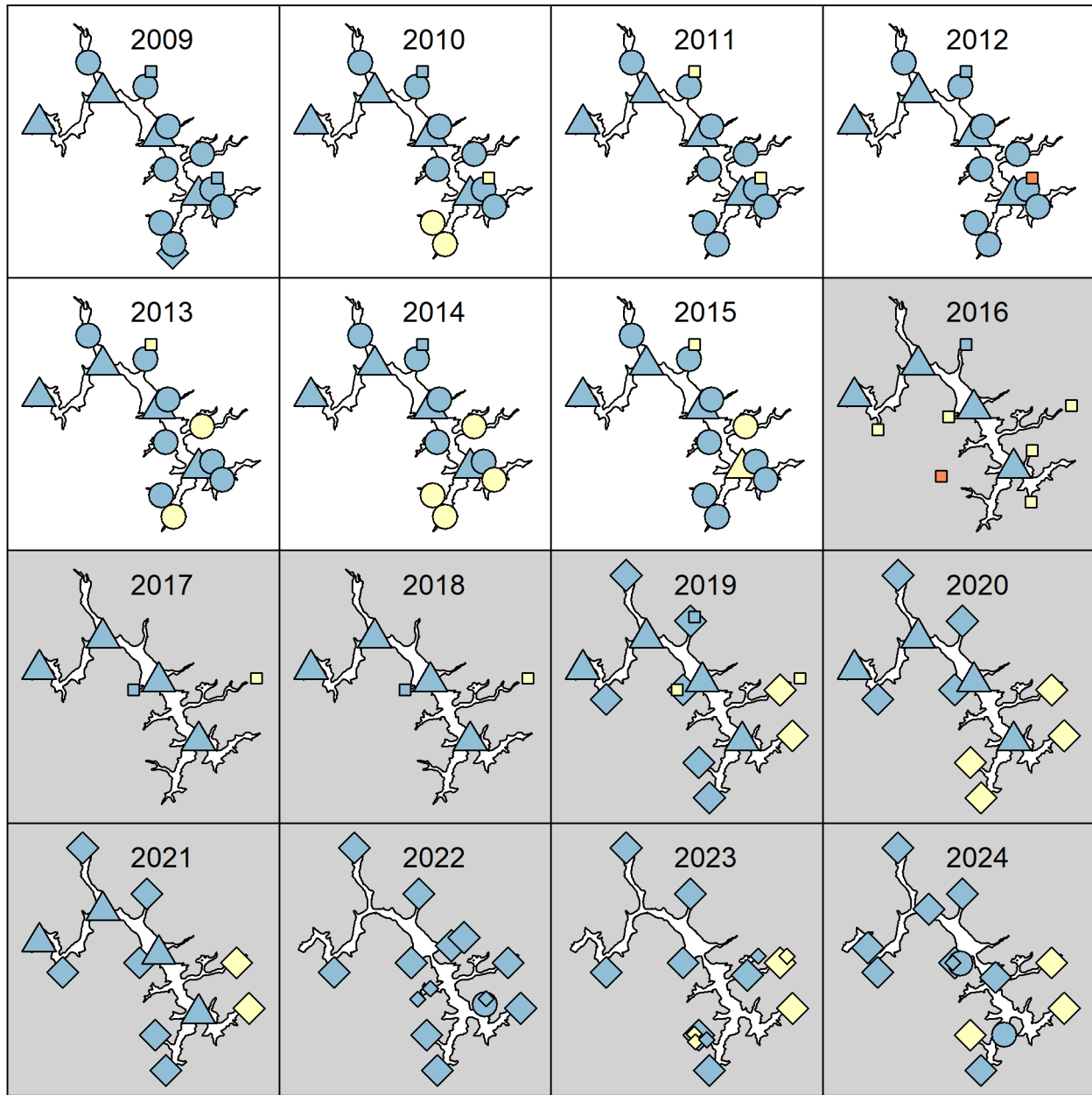


Figure 15. Surface water seasonal median phosphorus levels.

Median total phosphorus concentrations consistently indicated good water quality at deep mainstem lake stations (sampled in 2009–2021) and at lake and cove stations in the northwest sub-watershed. At southeast sub-watershed cove stations and northwest sub-watershed tributary stations, median water quality ranged from good to fair. At southeast sub-watershed tributary stations, median water quality ranged from good to poor. Stations as in Figure 13 plus data from four deep stations and eight shallow stations in 2020. Colors: water quality (blue: good, yellow: fair, orange: poor; Table 7; gray: different laboratories). Symbols as in Figure 2 (triangles: deep, circles: intermediate, diamonds: shallow, squares: tributaries, small: <1.5 m).

Changes in phosphorus

Trends analysis for surface water total phosphorus levels was restricted to the period of 2009/2010 to 2014/2015 due to changes in laboratories and monitored stations that could not be adequately accounted for in the analysis. Trends assessment was not possible due to poor model fit for three cove stations (Green Glade Run Cove, Deep Creek Cove and Pawn Run Cove) and one lake station (DPR0103). Note that changes from 2009/2010 to 2014/2015 may not reflect ongoing trends. Additional years of monitoring will allow a more robust assessment of longer-term changes.

At all stations with a good model fit, estimated seasonal average total phosphorus levels were in the good range in 2009/2010. Statistically significant increases were detected in two coves (North Glade Run Cove and Hoop Pole Cove) and at one lake station (DPR0082; Table 20; Figure 16). At one cove station (North Glade Run Cove) the increase resulted in a change in water quality conditions to fair. At all other stations, water quality remained in the good range.

Table 20. Trends in surface water phosphorus levels.

A1, A2: estimated seasonal average total phosphorus concentration (mg/l) in 2009/2010 and 2014/2015. Other columns as in Table 12.

#	Station	Description	n	r ²	A1	C1	A2	C2	Significance
1	MRC0011	Marsh Run Cove	51	0.37	0.011	good	0.013	good	no
2	CCC0008	Cherry Creek Cove	51	0.61	0.012	good	0.013	good	no
3	MMR0005	Meadow Mountain Run Cove	51	0.35	0.012	good	0.013	good	no
4	NGC0010	North Glade Run Cove	51	0.57	0.013	good	0.019	fair	very high
5	UDC0004	Hoop Pole Cove	51	0.50	0.012	good	0.015	good	yes
6	PLV0004	Poland Run Cove	51	0.58	0.014	good	0.016	good	no
7	GGC0015	Green Glade Run Cove	51	<0.30	NA	NA	NA	NA	NA
8	PWC0004	Pawn Run Cove	51	<0.30	NA	NA	NA	NA	NA
9	DPR0119	Deep Creek Cove	51	<0.30	NA	NA	NA	NA	NA
10	DPR0056	US 219 Bridge	53	0.31	0.010	good	0.011	good	no
11	DPR0021	Dam	51	0.47	0.010	good	0.011	good	no
12	DPR0082	Glendale Road Bridge	55	0.50	0.010	good	0.013	good	high
13	DPR0103	Turkey Neck	51	<0.30	NA	NA	NA	NA	NA

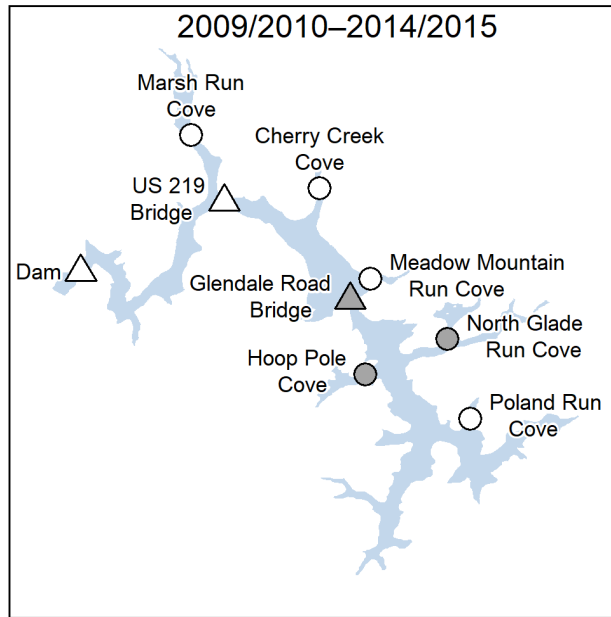


Figure 16. Trends in surface water phosphorus levels from 2009/2010 to 2014/2015.

Table 20 shows the same data with additional details in tabular form. Statistical models detected significant increases in total phosphorus concentration (gray) at three of six cove stations (circles) and one of three lake stations (triangles).

Nutrient limitation

Algal growth in lakes can be limited due to different water quality and environmental conditions. Algae can be limited by 1) phosphorus, 2) nitrogen, 3) a combination of phosphorus and nitrogen, 4) light, or 5) temperature. Algal levels can also be limited due to grazing by zooplankton. Lakes are often phosphorus limited, meaning that increased levels of phosphorus would result in additional algal growth, whereas decreased levels of phosphorus would result in reduced algal growth.

The most conclusive way to test for nutrient limitation is by measuring algal growth in water samples with and without the addition of nitrogen and/or phosphorus in controlled conditions called bioassays. EPA (1975) found that the addition of phosphorus to Deep Creek Lake water samples increased algal growth, whereas the addition of nitrogen did not, which indicated phosphorus limitation of algal growth.

A second way to assess algal growth limitation is to infer the presence of nutrient limitation from expected relationships of chlorophyll-*a* and nutrient concentrations (Carlson 1977, Carlson and Havens 2005). For example, a low total phosphorus concentration should be insufficient to sustain a high concentration of chlorophyll-*a*.

A third approach is to compare the ratio of total nitrogen to total phosphorus. When nutrient limitation is purely due to nitrogen, this ratio is expected to be less than 9:1 and when nutrient limitation is purely due to phosphorus, it is expected to be greater than 22.6:1 (by weight; Guildford and Hecky 2000, Kolzau et al. 2014). At intermediate ratios, algae are generally limited to some extent by both nitrogen and phosphorus.

For this report, a combination of the second and third approaches was used to score algae as limited by phosphorus and/or nitrogen or by other factors. When both phosphorus and nitrogen levels were sufficient to sustain the observed chlorophyll-*a* level, the data were scored as limited by other factors (e.g., light). All other cases were scored using the total nitrogen to total phosphorus ratio benchmarks of 22.6:1 and 9:1. Tributary stations could not be included because chlorophyll-*a* was not monitored there.

The factors limiting algal growth in Deep Creek Lake surface water varied by location and month (Table 21, Figure 17). Pure phosphorus-limitation was most common overall, including the majority of samples and measurements from April to July and in October. In August and September, nutrient co-limitation (by both phosphorus and nitrogen) was most common. Other limiting factors were occasionally found in April and May, and rarely in June to September. There was only one sample indicating pure nitrogen-limitation.

Table 21. Factors limiting algal growth.

Numbers indicate Deep Creek Lake surface water samples by month classified as N (purely nitrogen limited), NP (nutrient co-limited), P (purely phosphorus limited), and other (e.g., light-limited).

Limited by	Apr	May	Jun	Jul	Aug	Sep	Oct
N	0	0	0	0	0	1	0
NP	4	21	55	77	107	95	35
P	60	146	118	97	65	68	52
Other	28	25	7	2	5	5	0

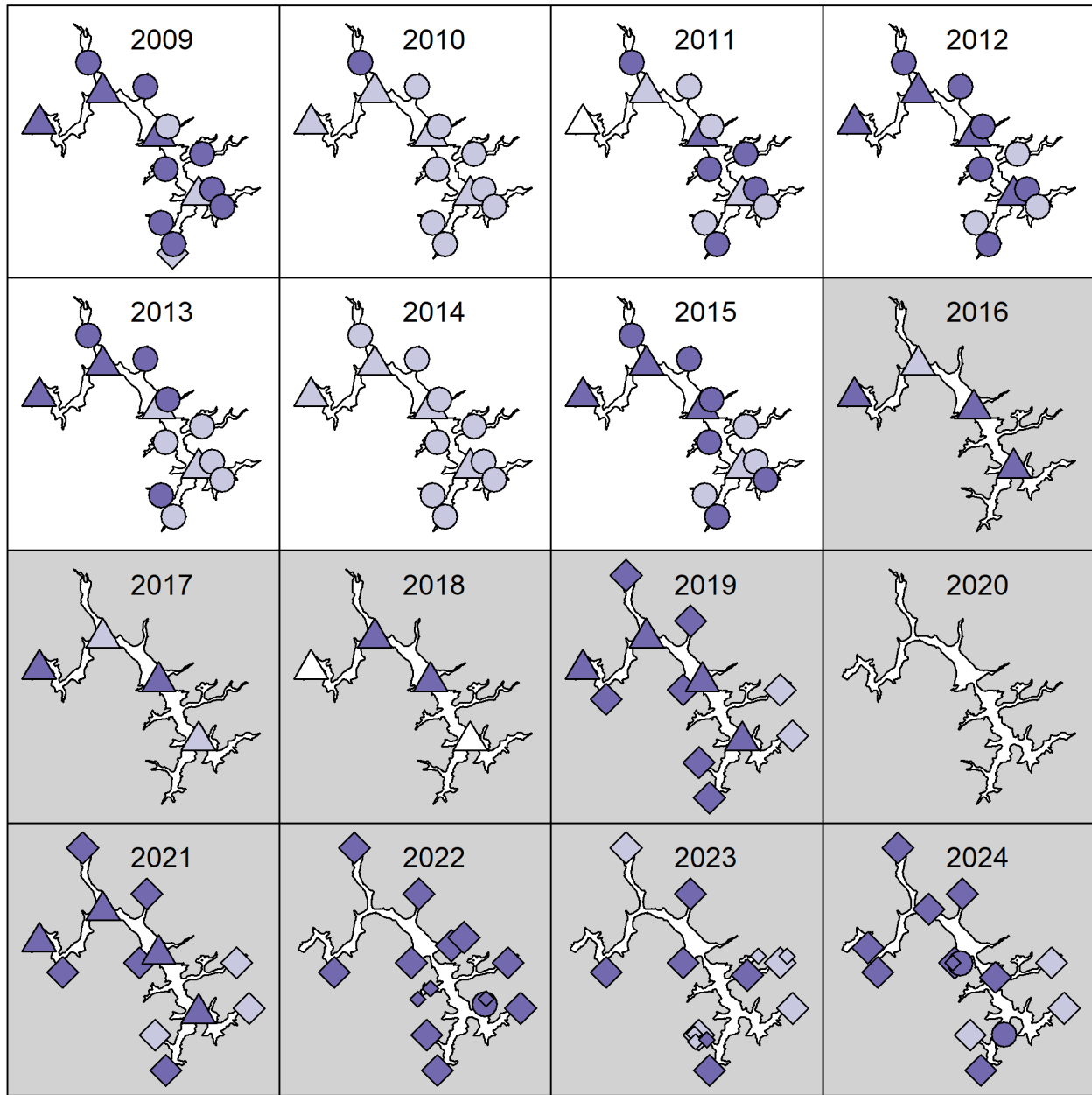


Figure 17. Factors limiting algal growth.

Classification was based on seasonal (May-September) medians of chlorophyll-*a* and nutrient concentrations. In most years, more of the lake appeared to be purely phosphorus limited (dark purple) than nutrient co-limited (light purple). One deep station in 2011 and two deep stations in 2018 were limited by factors other than nutrients (white). In 2022 all 14 stations were purely phosphorus limited and in 2014 all 13 stations were nutrient co-limited. Stations as in Figure 10. Symbols as in Figure 2 (triangles: deep, circles: intermediate, diamonds: shallow, squares: tributaries, small: <1.5 m). Starting in mid-2016 (gray background), measurements were from different laboratories.

Surface water growing season medians (Figure 17) indicated that nutrient co-limitation was more common in the southeast sub-watershed (55% of cases) than in the northwest sub-watershed (23%). Some links among indicators were detected. Among the stations and years shown in Figure 17, only 22 cases had elevated (fair) median phosphorus levels. This relative excess of phosphorus was consistently associated with a shift towards nutrient co-limitation (100% of cases). An additional 37 cases had good water quality in terms of chlorophyll-a and phosphorus levels despite elevated (fair) nitrogen levels. This relative excess of nitrogen was associated with a shift in the opposite direction, towards pure phosphorus limitation (>90% of cases).

Cloudiness (turbidity)

The cloudiness of surface water was mostly good (least cloudy, 77% of samples), but sometimes fair (moderately cloudy, 11%) or poor (most cloudy, 12%). Benchmarks for turbidity were taken from the National Lakes Survey (>2.83 NTU for fair and >4.21 NTU for poor water quality; EPA 2024b). Spatial patterns were similar to those for algae and nutrients (Figure 18). The seasonal cycle in turbidity was weak (5% seasonality score, not shown).

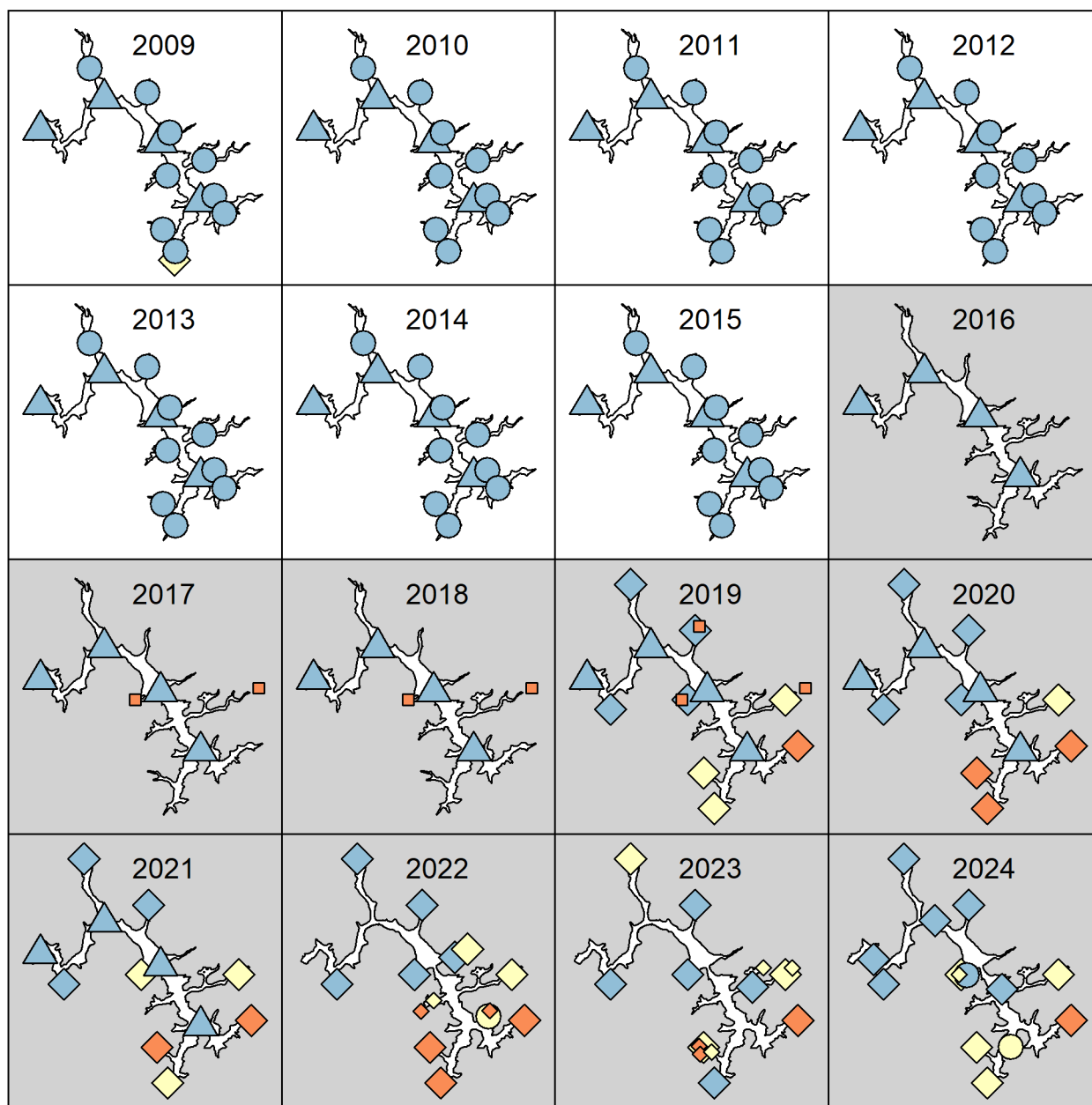


Figure 18. Seasonal median surface water turbidity.

Median cloudiness was consistently good at four deep stations (2009–2021), and consistently poor at two to three tributary stations (2017–2019). Among 8–14 shallow cove stations (2019–2024) median turbidity was better (mostly good) in the northwest sub-watershed than in the southeast sub-watershed (mostly fair or poor). Stations otherwise as in Figure 10. Colors: water quality (blue: good, yellow: fair, orange: poor; Table 7; gray: different laboratories). Symbols as in Figure 2 (triangles: deep, circles: intermediate, diamonds: shallow, squares: tributaries, small: <1.5 m).

Changes in turbidity

Trends analysis for surface turbidity levels was restricted to comparisons of 2009/2010 and 2014/2015 due to changes in laboratories and monitored stations that could not be adequately accounted for in the analysis. At one lake station (DPR0103), the analysis did not yield a sufficiently well-fitting model for trends assessment. Note that changes from 2009/2010 to 2014/2015 may not reflect ongoing trends. Additional years of monitoring will allow a more robust assessment of longer-term changes.

At all stations with a good model fit, estimated seasonal average turbidity was in the good range for 2009/2010. There were significant increases in turbidity in seven of nine coves and at two of three lake stations (Table 22). Despite these changes, water quality remained in the good range at all stations for 2014/2015.

Table 22. Trends in surface water turbidity.

A1, A2: estimated seasonal average turbidity (NTU) in 2009/2010 and 2014/2015. Other columns as in Table 12.

#	Station	Description	n	r ²	A1	C1	A2	C2	Significance
1	MRC0011	Marsh Run Cove	51	0.33	1.18	good	1.60	good	high
2	CCC0008	Cherry Creek Cove	51	0.46	1.08	good	1.29	good	no
3	MMR0005	Meadow Mountain Run Cove	51	0.74	0.91	good	1.20	good	very high
4	NGC0010	North Glade Run Cove	51	0.69	1.46	good	2.17	good	very high
5	UDC0004	Hoop Pole Cove	51	0.69	1.07	good	1.49	good	very high
6	PLV0004	Poland Run Cove	51	0.55	1.44	good	1.96	good	very high
7	GGC0015	Green Glade Run Cove	51	0.62	1.53	good	2.36	good	very high
8	PWC0004	Pawn Run Cove	51	0.41	1.67	good	1.72	good	no
9	DPR0119	Deep Creek Cove	51	0.43	1.55	good	2.02	good	high
10	DPR0056	US 219 Bridge	53	0.45	1.01	good	1.23	good	no (marginal)
11	DPR0021	Dam	51	0.64	0.76	good	1.01	good	high
12	DPR0082	Glendale Road Bridge	54	0.80	0.85	good	1.25	good	very high
13	DPR0103	Turkey Neck	51	<0.30	NA	NA	NA	NA	NA

Water clarity (Secchi depth)

Clarity was measured as the maximum depth at which contrasting black and white parts of a “Secchi disk” instrument could be distinguished from the surface and scored using Secchi depth benchmarks of <4 m for fair and <2 m for poor water clarity (1m = 3.3 ft). These benchmarks are commonly used to classify lakes as having different trophic states: oligotrophic (less algae/more transparent), mesotrophic (intermediate), and eutrophic (more algae/less transparent), following Carlson (1977, 1979). Under exceedingly eutrophic conditions, Deep Creek Lake would become impaired in terms of high algae concentrations and high turbidity (COMAR 26.08.02.03).

Consequently, a eutrophic state (potentially impaired) was labeled as poor and an oligotrophic state (furthest removed from impairment) was considered good. For a more comprehensive discussion of Deep Creek Lake trophic state, see the previous report (DNR 2017). At very shallow stations, Secchi depth measurements can be limited by bottom depth instead of clarity. To avoid this issue, Secchi depth was only analyzed for stations with nominal bottom depth >3 m (relative to 750 m elevation, MGS 2016).

Water clarity ranged from good (more transparent, 13% of stations) to fair (intermediate, 71%) to poor (less transparent, 16%), relative to Secchi depth benchmarks of 4 and 2 m. The seasonal cycle in water clarity was weak (8% seasonality score, not shown). Consistent with other water quality indicators, clarity was often better in the northwest sub-watershed than in the southeast sub-watershed (Figure 19).

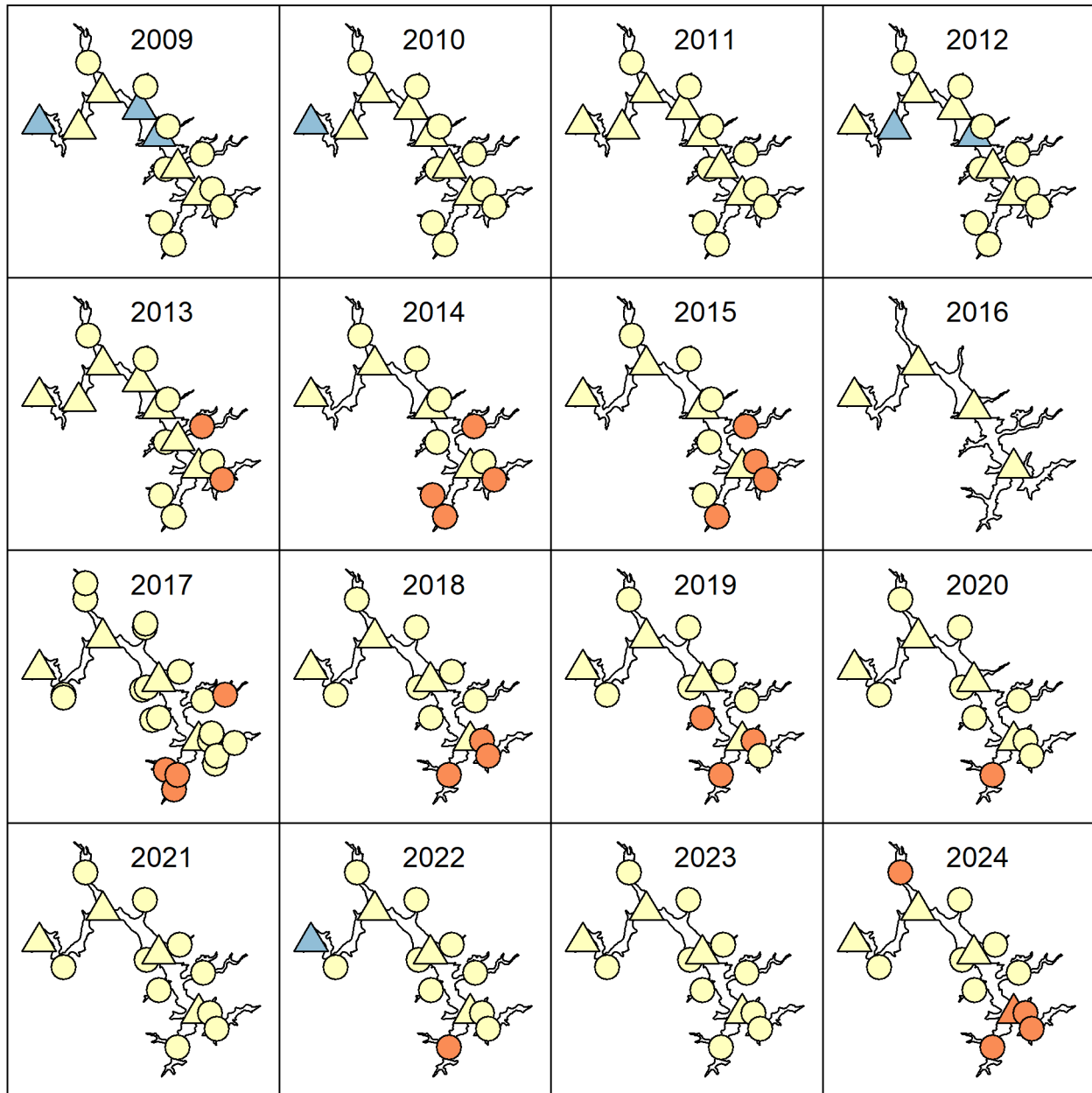


Figure 19. Seasonal median water clarity.

Four deep mainstem lake stations were sampled in all years (2009–2024). The number of intermediate stations varied from zero (2016) to 21 (2017) but was generally 9–12 (all other years). Median Secchi depth was good to fair at stations in the northwest sub-watershed and fair to poor at stations in the southeast sub-watershed. Colors: water quality (blue: good, yellow: fair, orange: poor; Table 7). Symbols as in Figure 2 (triangles: deep, circles: intermediate).

Changes in water clarity

Trends analysis for coves was restricted to comparisons of 2009/2010 and 2014/2015, because the analysis could not adequately account for changes to the regularly monitored stations after 2015. Estimated seasonal average Secchi depth was fair at all cove stations in 2009/2010 (2.5–3.5 m). Water clarity significantly decreased (worsened) in six coves (Marsh Run Cove, Cherry Creek Cove, Meadow Mountain Run Cove, North Glade Run Cove, Green Glade Run Cove and Hoop Pole Cove; Table 23, Figure 20). At Green Glade Run Cove this resulted in a change to poor water quality in 2014/2015 (1.8 m). All other coves maintained fair conditions in 2014/2015 (2.1–2.6 m).

Table 23. Trends in cove water clarity.

A1, A2: estimated seasonal average Secchi depth (m) in 2009/2010 and 2014/2015. Other columns as in Table 12.

#	Station	Description	n	r ²	A1	C1	A2	C2	Significance
1	MRC0011	Marsh Run Cove	51	0.67	2.7	fair	2.3	fair	yes
2	CCC0008	Cherry Creek Cove	52	0.70	3.2	fair	2.6	fair	yes
3	MMR0005	Meadow Mountain Run Cove	52	0.46	3.4	fair	2.6	fair	high
4	NGC0010	North Glade Run Cove	51	0.59	2.7	fair	2.1	fair	high
5	UDC0004	Hoop Pole Cove	51	0.43	3.5	fair	2.6	fair	high
6	PLV0004	Poland Run Cove	51	0.30	2.5	fair	2.2	fair	no (marginal)
7	GGC0015	Green Glade Run Cove	51	0.87	2.8	fair	1.8	poor	very high
8	PWC0004	Pawn Run Cove	51	0.41	2.6	fair	2.2	fair	no
9	DPR0119	Deep Creek Cove	51	0.35	2.5	fair	2.2	fair	no (marginal)

Trends analysis of lake stations was focused on comparisons of Secchi depth in the two earliest years and the two most recent years of monitoring data (2009/2010 and 2023/2024). In 2009/2010, estimated seasonal average Secchi depth was in the fair range at three lake stations and in the good range at one station (DPR0082, near the Glendale Road bridge). Water clarity significantly decreased at all four stations (Table 24, Figure 20). At station DPR0082 water quality worsened to fair in 2023/2024. At the other lake stations water quality remained in the fair category in 2023/2024.

Table 24. Trends in mainstem lake water clarity.

A1, A2: estimated seasonal average Secchi depth (m) in 2009/2010 and 2023/2024. Other columns as in Table 12.

#	Station	Description	n	r ²	A1	C1	A2	C2	Significance
10	DPR0056	US 219 Bridge	105	0.42	3.3	fair	2.8	fair	yes
11	DPR0021	Dam	104	0.36	3.9	fair	3.1	fair	yes
12	DPR0082	Glendale Road Bridge	124	0.45	4.2	good	2.8	fair	very high
13	DPR0103	Turkey Neck	104	0.35	2.9	fair	2.3	fair	yes

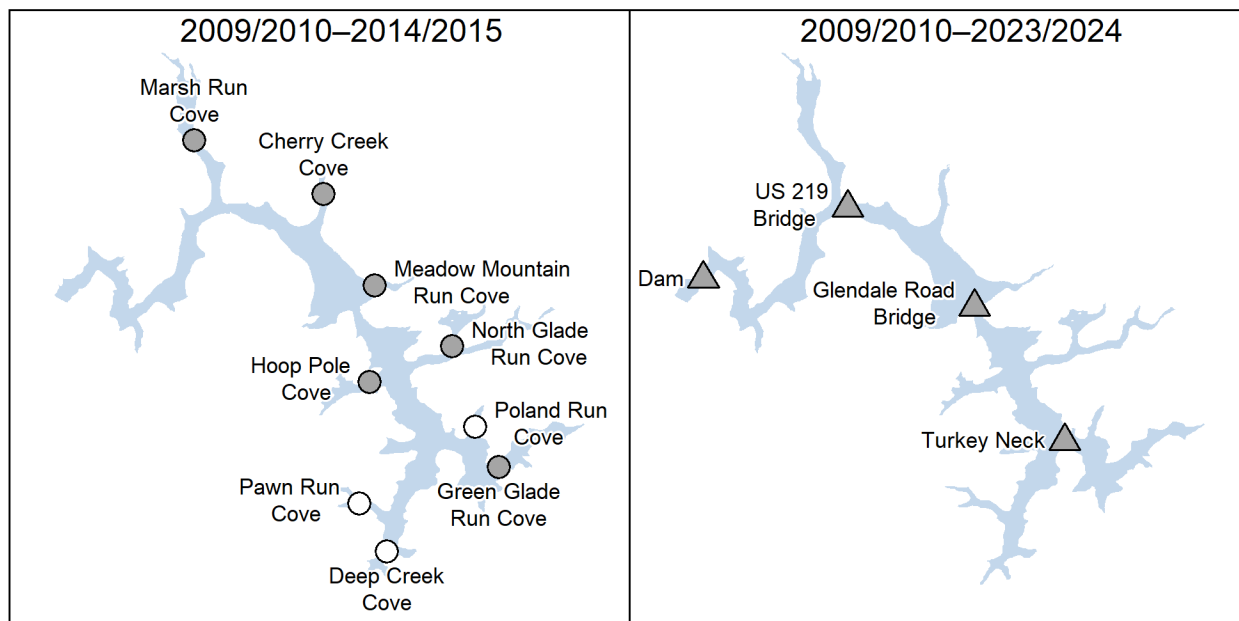


Figure 20. Trends in water clarity.

Tables 23–24 show the same data with additional details in tabular form. Statistical models detected significant decreases in Secchi depth in ten cases (gray). Changes at other locations were not significant (white). Left panel: trends at nine cove stations (circles) from 2009/2010 to 2014/2015. Right panel: trends at four lake stations (triangles) from 2009/2010 to 2023/2024.

Synthesis of spatial patterns

There was a clear environmental gradient in surface water quality from nearshore tributary stations to the deep mainstem lake. At one end of the gradient, tributary stations exhibited the highest levels of algae, nutrients, and turbidity. At the other end of the gradient, the lake mainstem was furthest removed (in terms of distance and dilution of nutrients) from tributary and other runoff inputs along the shoreline, and characterized by the lowest levels of algae, nutrients, and turbidity, and best water clarity. Cove stations were in-between mainstem lake stations and nearshore tributary stations not only in terms of location and depth, but also with respect to water quality.

The observed gradient strongly indicates that conditions were not uniform at individual coves. This is important for the interpretation of water quality data, because it means that comparisons among coves must consider the depth and distance to nutrient input sources (shoreline and tributaries) of monitored stations. The same is true for comparisons among different years. For example, the nutrient levels at intermediate-depth cove stations in 2009–2016 are difficult to compare with the nutrient levels at shallow cove stations in 2019–2024, because the higher levels in 2019–2024 may reflect changes in location (i.e., depth and distance from nutrient input sources), or trends over time, or a combination of both.

Superimposed on the tributary-to-mainstem gradient was a second spatial pattern: the southeast part of the lake had distinctly lower water quality than the northwest part with respect to algal levels and related indicators. This difference was consistent with and potentially linked to land use. Since the southeast sub-watershed had the highest proportion of cropland, buffered by the lowest proportion of forest, nutrient runoff and algal growth was expected to be more intense there than in the northwest sub-watershed (to which the Cherry Creek sub-watershed contributes).

Summary of results

Monitoring data were used to assess water quality conditions in Deep Creek Lake during the warmer months (May–September) of 2009–2024. For a subset of water quality indicators, monitoring stations, and years, changes (trends) in seasonal conditions were also assessed. Published data from the Chesapeake Bay Land Use/Land Cover Database (Claggett et al. 2025) were used to analyze Deep Creek watershed land cover during part of the 2009–2024 period (2013–2022).

Overall, surface water habitat and water quality of Deep Creek Lake was found to be good to fair for most indicators, years, and locations. However, the lake routinely exhibited intense summer stratification (layering). This stratification was characterized by a warm and oxygen-rich epilimnion layer and deeper water cut off from the epilimnion and thus cooler, but oxygen-depleted to the point of poor water quality during peak summer.

Land uses in the Deep Creek watershed varied by sub-watersheds. The southeast sub-watershed was least forested and most agricultural, while the northwest sub-watershed was most forested and most developed. Forested land has decreased in all three sub-watersheds. Between 2013/2014 and 2021/2022, there was a total net loss of 560 acres of forest. However, forest cover remained the primary land use type within each sub-watershed, and approximately 63.1% of the land area excluding water was forest. Developed land in the watershed has increased. Overall, pervious developed land expanded by 140 acres and impervious developed surfaces expanded by 108 acres. Despite this growth, the overall proportion of impervious surfaces across the watershed was still relatively low, accounting for only 4.4% of the total land area excluding water.

The monitoring program maintained consistent coverage of a suite of water quality variables across 13 key cove and lake stations during 2009–2015. This baseline period was followed by a period with multiple changes to the regularly monitored stations and to the analytical laboratories contracted for sample processing. Coverage of key field-measured variables was maintained at four mainstem lake stations from 2009–2024. For other variables and stations, a statistically robust analysis of the full time period was not yet feasible but should become so if

the current (2026) monitoring methods are maintained for some additional years of data collection.

Water temperature was related to multiple factors. Influences of seasonal cycles, sample depth, and location (tributary or non-tributary station) resulted in predictable patterns, whereas other factors (e.g., changes in epilimnion depth, lake inflow and outflow, and air temperature) likely contributed to measurement variability. The most robust trend was that summer surface temperatures for the mainstem lake increased from 2009/2010 to 2023/2024, and significantly so at two of four mainstem stations.

Dissolved oxygen levels at the surface and throughout the epilimnion layer were consistently good (with rare exceptions). Starting around June, poor oxygen levels were common at depths deeper than the epilimnion. In periods with intensely poor oxygen levels, most of the lake deeper than 10 m (33 ft) was anoxic. The severity of low oxygen levels in bottom water increased significantly at some locations (Cherry Creek Cove and Hoop Pole Cove from 2009/2010 to 2014/2015, and DPR0082 from 2009/2010 to 2023/2024).

Acidity (pH) conditions throughout the lake were generally good, with most surface measurements falling in the healthy range. Nevertheless, bottom water became slightly but significantly more acidic from 2009/2010 to 2014/2015 at some locations. A localized problem with acidic water was apparent at the Green Glade Run Cove tributary station, where pH was too acidic approximately 88% of the time between November 2015 and December 2016.

Conductivity was consistently good across all lake stations, all cove stations, and most tributary stations. There was a slight but widespread increase in conductivity, with statistically significant changes in both surface and bottom water across most coves and lake stations between 2009/2010 and 2014/2015. Occasional spikes in conductivity above the good range were measured at the Arrowhead Run tributary station (approximately 12% of the time between October 2015 and December 2019).

Algal levels were generally good in mainstem surface water and often good in the northwest sub-watershed coves, but often fair in the southeast sub-watershed coves. Conditions at some locations in the southeast sub-watershed declined significantly from 2009/2010 to 2014/2015, including four coves where water quality deteriorated from good to fair (North Glade Run Cove, Hoop Pole Cove, Poland Run Cove, Green Glade Run Cove).

Surface water nitrogen levels were most commonly good at deep mainstem lake locations, fair at intermediate-depth stations, and poor at tributary stations. Coves in the northwest sub-watershed tended to have better water quality than stations in the southeast sub-watershed. There were slight increases in nitrogen level at most stations from 2009/2010 to 2014/2015; in five coves these increases were identified as statistically significant.

Surface water phosphorus levels were routinely good in the mainstem lake and in northwest sub-watershed coves, but sometimes fair at southeast sub-watershed coves and often fair at

tributary stations. There were slight increases in phosphorus level at most stations from 2009/2010 to 2014/2015; at three stations these increases were identified as statistically significant.

The main factor limiting algal growth was phosphorus. From April to July and in October, pure phosphorus limitation was more typical than nutrient co-limitation by both phosphorus and nitrogen. In August and September, co-limitation by both nutrients was more typical. Other limiting factors were much less common, and instances of pure nitrogen limitation were exceptionally rare.

Surface water cloudiness (turbidity) was generally good at mainstem lake stations and intermediate-depth cove stations, despite exhibiting statistically significant increases at a majority of the monitored stations between 2009/2010 and 2014/2015. For shallow cove stations, turbidity was often good in the northwest sub-watershed, but often fair or poor in the southeast sub-watershed.

Water clarity (Secchi depth) was generally fair and occasionally good in the northwest sub-watershed, while ranging from fair to poor in the southeast sub-watershed. Water clarity slightly decreased at all stations relative to 2009/2010 conditions. These declines were statistically significant at six cove stations and four mainstem lake stations.

Two clear spatial patterns in algae and related water quality indicators were apparent. First, there was a gradient from lower water quality at shallow nearshore tributary stations to intermediate water quality in intermediate-depth coves to higher water quality in the mainstem lake. Second, the water quality was generally better in the northwest sub-watershed than in the southeast sub-watershed, potentially driven by differences in agricultural nutrient inputs.

Acknowledgements

The DNR Resource Assessment Service monitoring, data management, and web teams collected, processed, and made available online the data, and helped review this report. Data collection and analysis was funded by the DNR Maryland Park Service. The Deep Creek Watershed Foundation provided water quality sondes and organized the “The Deep Creek Watershed: Past Present and Future” symposium.

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Appendix A. Simplified land use categories

The Chesapeake Bay Land Use/Land Cover (LULC) Database used a system with 56 detailed categories, 18 general categories, and four macro categories described in depth by McDonald et al. (2025). Here, a system of seven simplified land use categories was constructed, as follows:

1. Locations in LULC macro category “water” were classified as “water.”
2. Locations in LULC general category “forest” were classified as “forest.”
3. Other (non-forest) locations in LULC macro category “natural” were classified as “other natural.”
4. Locations in LULC general category “cropland” were classified as “cropland.”
5. Locations in the LULC general category “pasture and hay” were classified as “pasture and hay.”
6. Locations in LULC macro category “developed” and not in LULC detailed categories including the word “impervious” were classified as “pervious developed.”
7. Locations in LULC macro category “developed” and in LULC detailed categories including the word “impervious” were classified as “impervious developed.”

Appendix B. Monitoring stations

In addition to the key stations shown in Figure A.1 and Table A.1, many other stations have been monitored as part of the DNR Deep Creek Lake water quality monitoring program. Figure A.1 and Table A.1 provide information on stations with multiple years of field measurements (temperature, oxygen, pH, conductivity, and Secchi depth) but without laboratory analysis of water samples (chlorophyll-a, nutrients, turbidity). Figure A.2 and Table A.2 show stations that were monitored in less than two growing seasons. These include many stations where autonomous instruments were deployed for continuous monitoring in conjunction with regular laboratory analysis of water samples (stations 64–81 in Figure A.2 and Table A.2).

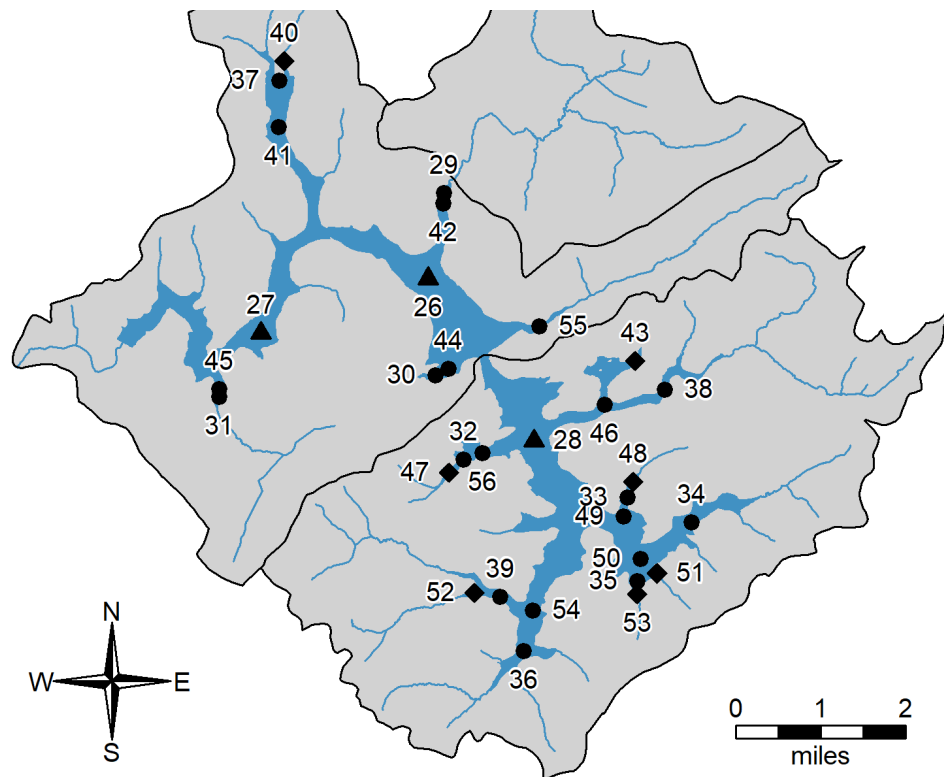


Figure A.1. Selected water quality monitoring stations.

Deep Creek Lake stations with May–September monitoring (not including nutrient or algal growth measurements) during multiple years in the 2009–2024 period. Table A.1 shows the same data with additional details in tabular form. Symbols and layout as in Figure 2. Numbers: field “#” in Table A.1.

Table A.1. Selected water quality monitoring stations.

Deep Creek Lake stations with May–September monitoring (not including nutrient or algal growth measurements) during multiple years in the 2009–2024 period. #: numbers continued from Table 6.

#	Station	Waterbody	Type	Depth (m)	Longitude (°W)	Latitude (°N)	Years
26	DPR0069	Deep Creek Lake	Lake	>10.7	79.32325	39.51958	2009–2014
27	DPR0041	Deep Creek Lake	Lake	>10.7	79.36037	39.51080	2009–2014
28	DPR0094	Deep Creek Lake	Lake	>10.7	79.30052	39.49147	2009–2014
29	CCC6	Cherry Creek Cove	Cove	3.0–10.7	79.31938	39.53419	2016–2018
30	AWC6	Arrowhead Cove	Cove	3.0–10.7	79.32208	39.50300	2016–2018
31	RRC6	Red Run Cove	Cove	3.0–10.7	79.36982	39.49998	2016–2018
32	HPC6	Hoop Pole Cove	Cove	3.0–10.7	79.31610	39.48846	2016–2018
33	PLV6	Poland Run Cove	Cove	3.0–10.7	79.28012	39.48151	2016–2018
34	GGC6	Green Glade Run Cove	Cove	3.0–10.7	79.26614	39.47701	2016–2018
35	HZC6	Hazelhurst Cove	Cove	3.0–10.7	79.27833	39.46716	2016–2018
36	DCC6	Deep Creek Cove	Cove	3.0–10.7	79.30367	39.45558	2016–2018
37	MRC6	Marsh Run Cove	Cove	3.0–10.7	79.35527	39.55384	2016–2019
38	NGC6	North Glade Run Cove	Cove	3.0–10.7	79.27149	39.49977	2016–2019
39	PWC6	Pawn Run Cove	Cove	3.0–10.7	79.30867	39.46495	2016–2019
40	MRCRight	Marsh Run Cove	Cove	1.5–3.0	79.35408	39.55720	2016–2024
41	MRC9	Marsh Run Cove	Cove	3.0–10.7	79.35561	39.54598	2016–2024
42	CCC9	Cherry Creek Cove	Cove	3.0–10.7	79.31961	39.53232	2016–2024
43	Beckmans	Beckman's Cove	Cove	1.5–3.0	79.27781	39.50482	2016–2024
44	AWC9	Arrowhead Cove	Cove	3.0–10.7	79.31910	39.50407	2016–2024
45	RRC9	Red Run Cove	Cove	3.0–10.7	79.36979	39.50129	2016–2024
46	NGC9	North Glade Run Cove	Cove	3.0–10.7	79.28477	39.49739	2016–2024
47	HPC3	Hoop Pole Cove	Cove	1.5–3.0	79.31938	39.48632	2016–2024
48	PLV3	Poland Run Cove	Cove	1.5–3.0	79.27870	39.48411	2016–2024
49	PLV9	Poland Run Cove	Cove	3.0–10.7	79.28106	39.47823	2016–2024
50	HZGG9	Hazelhurst Cove, Green Glade Run Cove	Cove	3.0–10.7	79.27746	39.47089	2016–2024
51	HZCRight	Hazelhurst Cove	Cove	1.5–3.0	79.27389	39.46836	2016–2024
52	PNC	Penn Cove	Cove	1.5–3.0	79.31426	39.46568	2016–2024
53	HZC3	Hazelhurst Cove	Cove	1.5–3.0	79.27835	39.46493	2016–2024
54	DCPW9	Deep Creek Pawn	Cove	3.0–10.7	79.30148	39.46245	2016–2024
55	MMC6	Meadow Mountain Run Cove	Cove	3.0–10.7	79.29885	39.51106	2017–2024
56	HPC9	Hoop Pole Cove	Cove	3.0–10.7	79.31193	39.48958	2017–2024

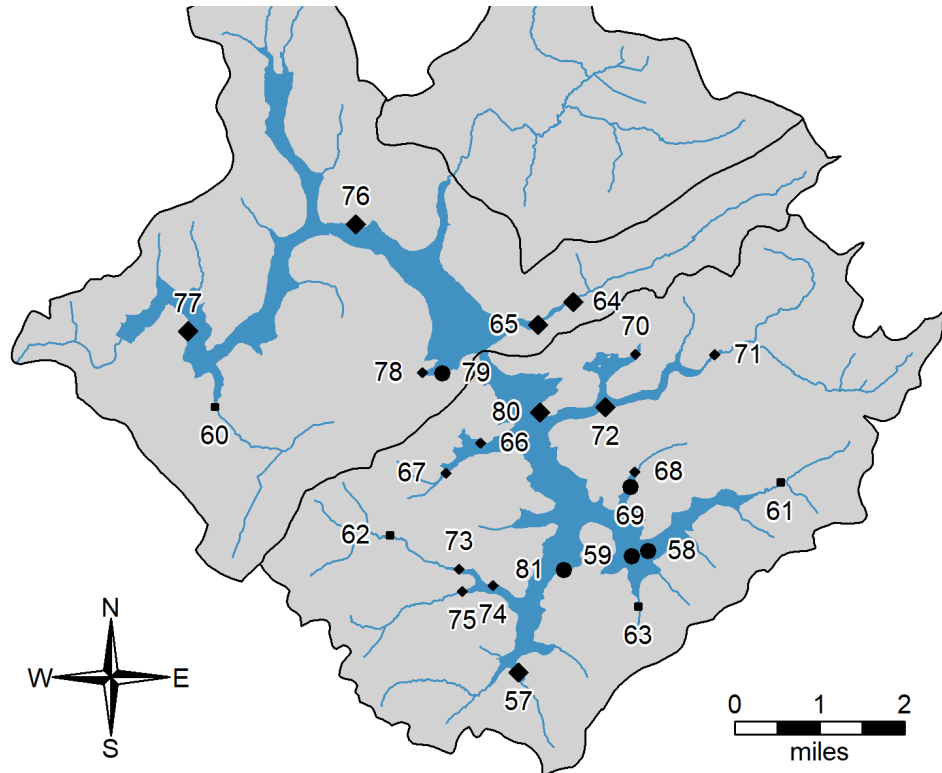


Figure A.2. Selected water quality monitoring stations.

Deep Creek Lake stations with May–September monitoring in only one year. Table A.2 shows the same data with additional details in tabular form. Symbols and layout as in Figure 2. Numbers: field “#” in Table A.2.

Table A.2. Selected water quality monitoring stations.

Deep Creek Lake stations with May–September monitoring in only one year. #: numbers continued from Table A.1.

#	Station	Waterbody	Type	Depth (m)	Longitude (°W)	Latitude (°N)	Years
57	UGX0001	Deep Creek Cove	Cove	1.5–3.0	79.30461	39.45123	2009
58	GGC9	Green Glade Run Cove	Cove	3.0–10.7	79.27563	39.47157	2016
59	HZC9	Hazelhurst Cove	Cove	3.0–10.7	79.27928	39.47077	2016
60	RED0000	Red Run	Tributary	0–1.5	79.37062	39.49759	2016
61	GGR0003	Green Glade Run	Tributary	0–1.5	79.24609	39.48284	2016
62	PWR0008	Pawn Run	Tributary	0–1.5	79.33250	39.47512	2016
63	HZL0001	Hazelhurst Run	Tributary	0–1.5	79.27795	39.46209	2016
64	MMT	Meadow Mountain Run Cove	Cove	1.5–3.0	79.29098	39.51439	2022
65	MMC	Meadow Mountain Run Cove	Cove	1.5–3.0	79.29886	39.51055	2022
66	HPC	Hoop Pole Cove	Cove	0–1.5	79.31207	39.49053	2022
67	HPT	Hoop Pole Cove	Cove	0–1.5	79.31985	39.48554	2022
68	PLDT	Poland Run Cove	Cove	0–1.5	79.27810	39.48510	2022
69	PLDC	Poland Run Cove	Cove	3.0–10.7	79.27926	39.48257	2022
70	BCK	Beckman's Cove	Cove	0–1.5	79.27757	39.50527	2023
71	NGT	North Glade Run Cove	Cove	0–1.5	79.26012	39.50493	2023
72	NGC	North Glade Run Cove	Cove	1.5–3.0	79.28442	39.49629	2023
73	PWT	Pawn Run Cove	Cove	0–1.5	79.31739	39.46909	2023
74	PWC	Pawn Run Cove	Cove	0–1.5	79.30994	39.46618	2023
75	PEN	Penn Cove	Cove	0–1.5	79.31667	39.46526	2023
76	LEF	Lake Shore	Cove	1.5–3.0	79.33871	39.52836	2024
77	LFT	Lake Shore	Cove	1.5–3.0	79.37627	39.51063	2024
78	AWT	Arrowhead Cove	Cove	0–1.5	79.32465	39.50277	2024
79	STL	Arrowhead Cove	Cove	3.0–10.7	79.32028	39.50258	2024
80	BKP	Lake Shore	Cove	1.5–3.0	79.29876	39.49561	2024
81	TYC	Lake Shore	Cove	3.0–10.7	79.29432	39.46857	2024

Appendix C. Generalized additive modeling of seasonal cycles

To examine predictable seasonal patterns over the course of the growing season, generalized additive models (Wood 2017) were fitted to a standardized, well-balanced subset of data. The subset included 13 lake and cove stations that were sampled every month from May to September in the years from 2009 to 2015. In 2015, all stations were sampled once in early May and once in late May. In all other combinations of month and year each station was sampled once. All stations had nominal bottom depths of at least 4.6 m (15 ft) relative to a reference elevation of 750 m (MGS 2016).

Each model was specified with a water quality indicator as the response variable, an intercept term, and a smooth function of date as the only explanatory variable. The smooth function was a cyclic cubic regression spline with a cycle of 365.25 days and only two degrees of freedom (limited wiggleness). Model parameters were determined by maximum likelihood optimization. For indicators that were concentrations (chlorophyll-*a*, total nitrogen, total phosphorus) or concentration-like (conductivity as a proxy for salt concentration, turbidity and Secchi depth as proxies for suspended solid concentration), a gamma distribution family and log link function were specified. For temperature and pH, a Gaussian family and identity link function were used. In all cases, standard model diagnostic plots were examined and models were found to be acceptable (Wood 2017). The metric “percent deviance explained,” which quantified the degree to which fitted models reproduced variability in the original data, was used to characterize seasonal cycle strength.

Appendix D. Baytrends model specifications

Trends analysis was performed using the R package baytrends (Murphy et al. 2024), which in turn used the R package mgcv (Wood 2017) to fit generalized additive models as described in Murphy et al. (2019). Depending on the water quality indicator and station, data from 2009 to mid-2016 or from 2009 to 2024 were used to train initial models for testing and final models for trends assessment. In the trends assessment, baytrends was used to estimate the statistical significance of differences among modeled seasonal averages among the first two years and the last two years of the trend period.

For each water quality indicator (response variable), three standard model formulations, termed GAM0, GAM1, and GAM2 by Murphy et al. (2019), were tested. The GAM0 formulation models the response variable as a function of a linear trend (date as a continuous variable) plus seasonality (a cyclic cubic regression spline of day-of-year with a one-year cycle). GAM1 uses the same predictors as GAM0 plus a nonlinear smooth function of date (a thin plate regression spline). GAM2 uses the same predictors as GAM1 plus an interaction between the seasonality term and the nonlinear date term (a tensor product smooth). Default baytrends settings were used for GAM0, GAM1, and GAM2 models, including link function, optimization method, smoothing spline details, and indicator-specific data transformations (most response variables were log-transformed). Default settings also specify that smooth model terms can be completely removed during model fitting when they provide no benefit. For each indicator, model performance of all three models was compared in terms of Akaike information criterion (AIC) scores. Since GAM2 was the best-performing model in almost all cases, GAM2 models were used as final models for trends assessment. Trends were considered significant at $p < 0.05$. For more information on baytrends, see Murphy et al. (2024).