Water Quality Monitoring

Pentwater Lake
Water Quality Monitoring Report

Prepared for:
Pentwater Lake Improvement Board
PO Box 314
Hart, MI 49420

Prepared by:
Progressive AE
1811 4 Mile Road, NE
Grand Rapids, MI 49525-2442
616/361-2664

December 2018

Project No: 54440103

progressive|ae

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Introduction

As part of a multi-year lake improvement program being coordinated by the Pentwater Lake Improvement Board, water quality monitoring of Pentwater Lake has been conducted on a periodic basis since 1988. This report includes an analysis and discussion of data collected to date.

Lake water quality is determined by a unique combination of processes that occur both within and outside of the lake. In order to make sound management decisions, it is necessary to have an understanding of the current physical, chemical, and biological condition of the lake, and the potential impact of drainage from the surrounding watershed.

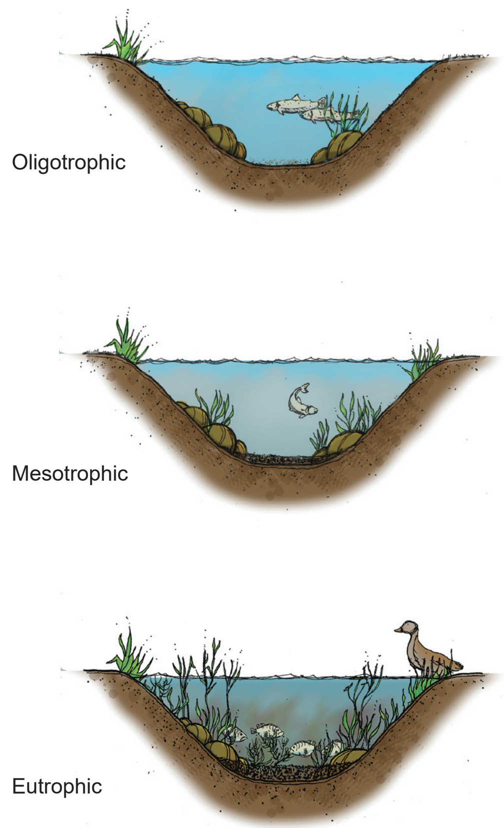

Figure 1. Lake classification.

Scientists classify lakes as oligotrophic, mesotrophic, or eutrophic (Figure 1). Oligotrophic lakes are generally deep and clear with little aquatic plant growth. These lakes maintain sufficient dissolved oxygen in the cool, deep bottom waters during late summer to support cold water fish such as trout and whitefish. By contrast, eutrophic lakes are generally shallow, turbid, and support abundant aquatic plant growth. In deep eutrophic lakes, the cool bottom waters usually contain little or no dissolved oxygen. Therefore, these lakes can only support warm water fish such as bass and pike. Lakes that fall between these two extremes are called mesotrophic lakes.

Under natural conditions, most lakes will ultimately evolve to a eutrophic state as they gradually fill with sediment and organic matter transported to the lake from the surrounding watershed. As the lake becomes shallower, the process accelerates. When aquatic plants become abundant, the lake slowly begins to fill in as sediment and decaying plant matter accumulate on the lake bottom. Eventually, terrestrial plants become established and the lake is transformed to a marshland. The aging process in lakes is called "eutrophication" and may take anywhere from a few hundred to several thousand years, generally depending on the size of the lake and its watershed. The natural lake aging process can be greatly accelerated if excessive amounts of sediment and nutrients (which stimulate aquatic plant growth) enter the lake from the surrounding watershed. Because these added inputs are usually associated with human activity, this accelerated lake aging process is often referred to as "cultural eutrophication." The problem of cultural eutrophication can be managed by identifying sources of sediment and nutrient loading (i.e., inputs) to the lake and developing strategies to halt or slow the inputs. Thus, in developing a management plan, it is necessary to determine the limnological (i.e., the physical, chemical, and biological) condition of the lake and the physical characteristics of the watershed as well. Key parameters used to evaluate the limnological condition of a lake include temperature, dissolved oxygen, total phosphorus, chlorophyll-*a*, and Secchi transparency.

TEMPERATURE

Temperature is important in determining the type of organisms that may live in a lake. For example, trout prefer temperatures below 68°F. Temperature also determines how water mixes in a lake. As the ice cover breaks up on a lake in the spring, the water temperature becomes uniform from the surface to the bottom. This period is referred to as "spring turnover" because water mixes throughout the entire water column. As the surface waters warm, they are underlain by a colder, more dense strata of water. This process is called thermal stratification. Once thermal stratification occurs, there is little mixing of the warm surface waters with the cooler bottom waters. The transition layer that separates these layers is referred to as the "thermocline." The thermocline is characterized as the zone where temperature drops rapidly with depth. As fall approaches, the warm surface waters begin to cool and become more dense. Eventually, the surface temperature drops to a point that allows the lake to undergo complete mixing. This period is referred to as "fall turnover." As the season progresses and ice begins to form on the lake, the lake may stratify again. However, during winter stratification, the surface waters (at or near 32°F) are underlain by slightly warmer water (about 39°F). This is sometimes referred to as "inverse stratification" and occurs because water is most dense at a temperature of about 39°F. As the lake ice melts in the spring, these stratification cycles are repeated (Figure 2). Shallow lakes do not stratify. Lakes that are 15 to 30 feet deep may stratify and destratify with storm events several times during the year.

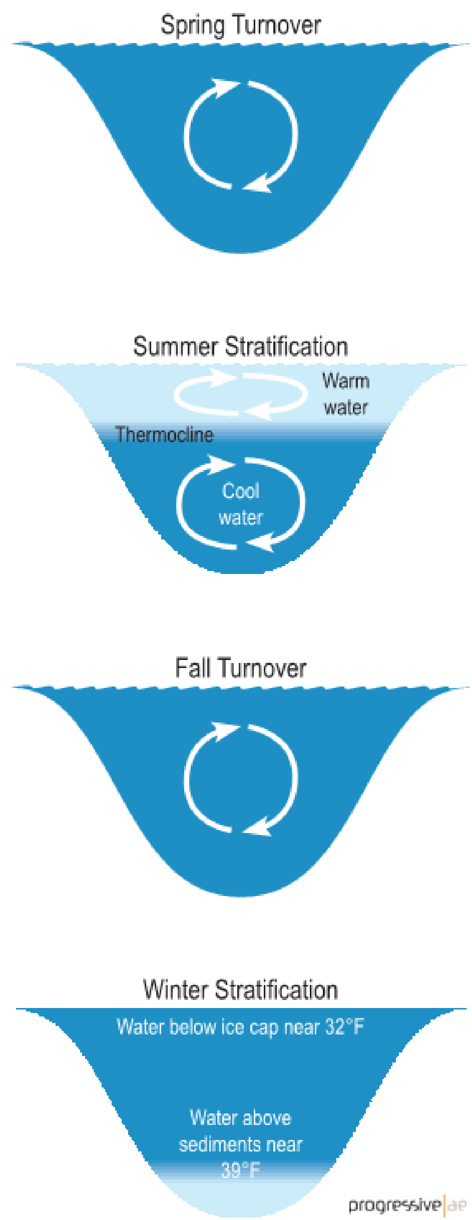

Figure 2. Seasonal thermal stratification cycles.

DISSOLVED OXYGEN

An important factor influencing lake water quality is the quantity of dissolved oxygen in the water column. The major inputs of dissolved oxygen to lakes are the atmosphere and photosynthetic activity by aquatic plants. An oxygen level of about 5 mg/L (milligrams per liter, or parts per million) is required to support warm water fish. In lakes deep enough to exhibit thermal stratification, oxygen levels are often reduced or depleted below the thermocline once the lake has stratified. This is because deep water is cut off from plant photosynthesis and the atmosphere, and oxygen is consumed by bacteria that use oxygen as they decompose organic matter (plant and animal remains) at the bottom of the lake. Bottom-water oxygen depletion is a common occurrence in eutrophic and some mesotrophic lakes. Thus, eutrophic and most mesotrophic lakes cannot support cold water fish because the cool, deep water (that the fish require to live) does not contain sufficient oxygen.

PHOSPHORUS

The quantity of phosphorus present in the water column is especially important since phosphorus is the nutrient that most often controls aquatic plant growth and the rate at which a lake ages and becomes more eutrophic. In the presence of oxygen, lake sediments act as a phosphorus trap, retaining phosphorus and, thus, making it unavailable for aquatic plant growth. However, if bottom-water oxygen is depleted, phosphorus will be released from the sediments and may be available to promote aquatic plant growth. In some lakes, the internal release of phosphorus from the bottom sediments is the primary source of phosphorus loading (or input).

By reducing the amount of phosphorus in a lake, it may be possible to control the amount of aquatic plant growth. In general, lakes with a phosphorus concentration greater than 20 µg/L (micrograms per liter, or parts per billion) are able to support abundant plant growth and are classified as nutrient-enriched or eutrophic.

CHLOROPHYLL-*a*

Chlorophyll-*a* is a pigment that imparts the green color to plants and algae. A rough estimate of the quantity of algae present in lake water can be made by measuring the amount of chlorophyll-*a* in the water column. A chlorophyll-*a* concentration greater than 6 µg/L is considered characteristic of a eutrophic condition.

SECCHI TRANSPARENCY

A Secchi disk is often used to estimate water clarity. The measurement is made by fastening a round, black and white, 8-inch disk to a calibrated line (Figure 3). The disk is lowered over the deepest point of the lake until it is no longer visible, and the depth is noted. The disk is then raised until it reappears. The average between these two depths is the Secchi transparency. Generally, it has been found that aquatic plants can grow at a depth of approximately twice the Secchi transparency measurement. In eutrophic lakes, water clarity is often reduced by algae growth in the water column, and Secchi disk readings of 7.5 feet or less are common.

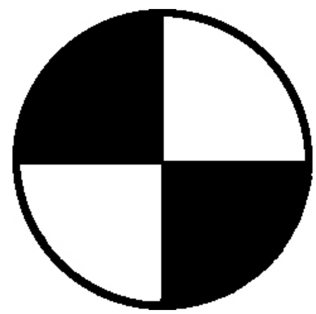

Figure 3. Secchi disk.

Ordinarily, as phosphorus inputs (both internal and external) to a lake increase, the amount of algae the lake can support will also increase. Thus, the lake will exhibit increased chlorophyll-*a* levels and decreased transparency. A summary of lake classification criteria developed by the Michigan Department of Environmental Quality is shown in Table 1.

TABLE 1
LAKE CLASSIFICATION CRITERIA

Lake Classification	Total Phosphorus (µg/L)[1]	Chlorophyll-*a* (µg/L)[1]	Secchi Transparency (feet)
Oligotrophic	Less than 10	Less than 2.2	Greater than 15.0
Mesotrophic	10 to 20	2.2 to 6.0	7.5 to 15.0
Eutrophic	Greater than 20	Greater than 6.0	Less than 7.5

1 µg/L = micrograms per liter = parts per billion.

In addition to the measurements used to evaluate lake trophic state, pH and alkalinity are important measures of lake water quality.

pH and TOTAL ALKALINITY

pH is a measure of the amount of acid or base in the water. The pH scale ranges from 0 (acidic) to 14 (alkaline or basic) with neutrality at 7. The pH of most lakes in the Upper Midwest ranges from 6.5 to 9.0 (MDEQ 2012; Table 3). In addition, according to MDEQ (2013):

> While there are natural variations in pH, many pH variations are due to human influences. Fossil fuel combustion products, especially automobile and coal-fired power plant emissions, contain nitrogen oxides and sulfur dioxide, which are converted to nitric acid and sulfuric acid in the atmosphere. When these acids combine with moisture in the atmosphere, they fall to earth as acid rain or acid snow. In some parts of the United States, especially the Northeast, acid rain has resulted in lakes and streams becoming acidic, resulting in conditions which are harmful to aquatic life. The problems associated with acid rain are lessened if limestone is present, since it is alkaline and neutralizes the acidity of the water.
>
> Most aquatic plants and animals are adapted to a specific pH range, and natural populations may be harmed by water that is too acidic or alkaline. Immature stages of aquatic insects and young fish are extremely sensitive to pH values below 5. Even microorganisms which live in the bottom sediment and decompose organic debris cannot live in conditions which are too acidic. In very acidic waters, metals which are normally bound to organic matter and sediment are released into the water. Many of these metals can be toxic to fish and humans. Below a pH of about 4.5, all fish die.

The Michigan Water Quality Standard (Part 4 of Act 451) states that pH shall be maintained within the range of 6.5 to 9.0 in all waters of the state.

Alkalinity, also known as acid-neutralizing capacity or ANC, is the measure of the pH-buffering capacity of water in that it is the quantitative capacity of water to neutralize an acid. pH and alkalinity are closely linked and are greatly impacted by the geology and soil types that underlie a lake and its watershed. According to MDEQ (2012):

> Michigan's dominant limestone geology in the Lower Peninsula and the eastern Upper Peninsula contributes to the vast majority of Michigan lakes being carbonate-bicarbonate dominant [which increases alkalinity and moderates pH] and lakes in the western Upper Peninsula having lower alkalinity and thus lesser buffering capacity.

The alkalinity of most lakes in the Upper Midwest is within the range of 23 to 148 milligrams per liter, or parts per million, as calcium carbonate (MDEQ 2012; Table 3).

TABLE 3
pH AND ALKALINITY OF UPPER MIDWEST LAKES

Measurement	Low	Moderate	High
pH (in standard units)	Less than 6.5	6.5 to 9.0	Greater than 9.0
Total Alkalinity or ANC (in mg/L as $CaCO_3$[1])	Less than 23	23 to 148	Greater than 148

1 mg/L $CaCO_3$ = milligrams per liter as calcium carbonate.

SAMPLING METHODS

Water quality sampling was conducted in the spring and summer of 2018 at the deep basin within Pentwater Lake (Figure 4). Temperature was measured using an AquaCal Clinefinder temperature probe. Samples were collected with a Van Dorn bottle at 10-foot intervals from the surface to the bottom at the deep-basin sampling site. Samples were analyzed for dissolved oxygen, pH, total alkalinity, and total phosphorus. Dissolved oxygen samples were fixed in the field and then transported to Progressive AE for analysis using the modified Winkler method (Standard Methods procedure 4500-O C). pH was measured in the field using an Oakton EcoTestr 2 pH meter. Total alkalinity and total phosphorus samples were placed on ice and transported to the laboratory for analysis. Total alkalinity was titrated at Progressive AE using Standard Methods procedure 2320 B. Total phosphorus was analyzed using Standard Methods procedure 4500-P E at Prein and Newhof[1]. In addition to the depth-interval samples at each deep basin, Secchi transparency was measured and composite chlorophyll-*a* samples were collected from the surface to a depth equal to twice the Secchi transparency. Chlorophyll-*a* samples were analyzed using Standard Methods procedure 10200 H by Prein and Newhof.

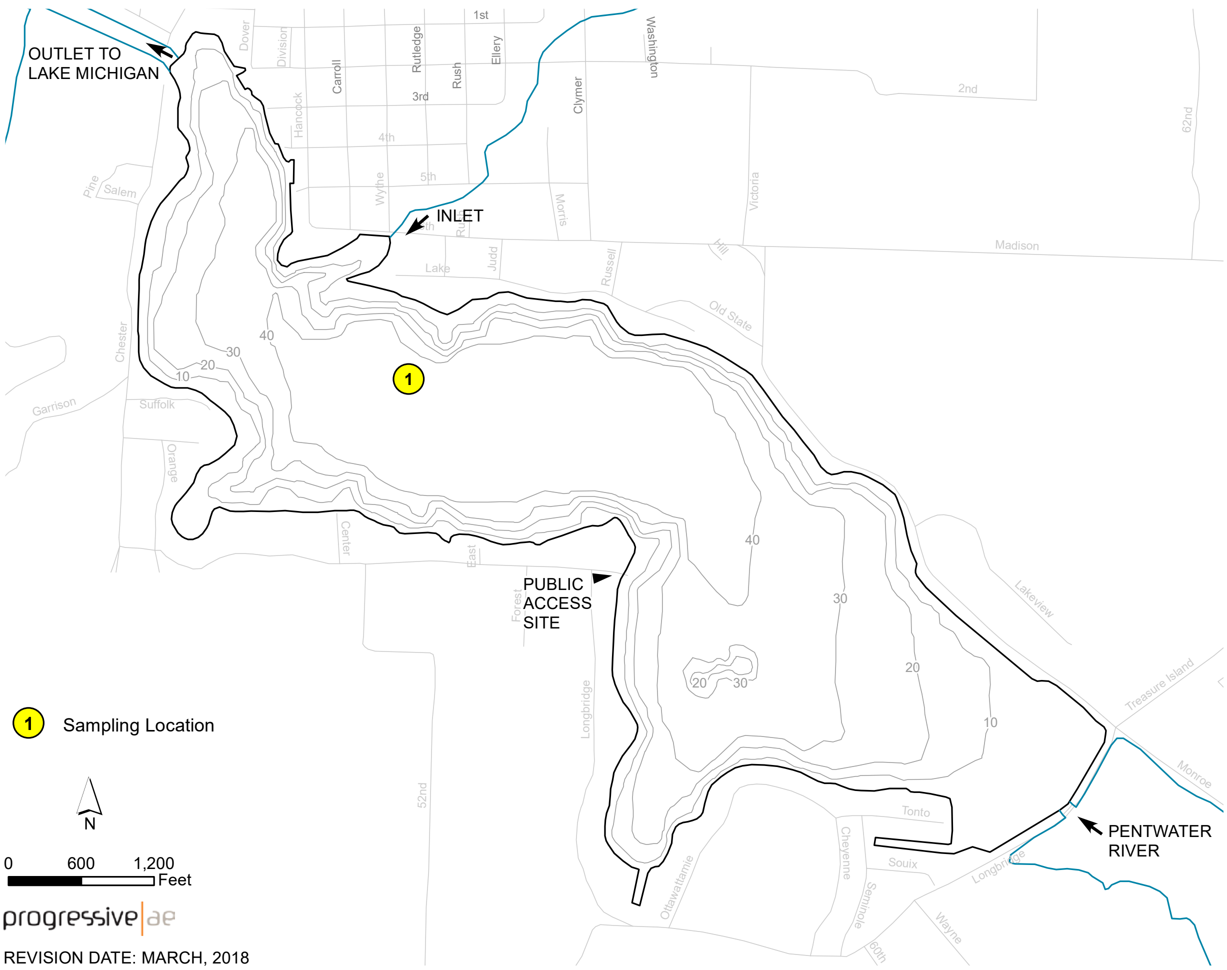

Figure 4. Pentwater Lake sampling location map.

1 Prein and Newhof Prein and Newhof, 3260 Evergreen Drive, NE, Grand Rapids, MI 49525.

Sampling Results and Discussion

Water quality collected from Pentwater Lake in 2018 is provided in Tables 2 and 3. Summary statistics for key data collected since 1988 are provided in Table 4. Historical total phosphorus, chlorophyll-a, and Secchi transparency measurements are summarized in Figures 5 through 7.

TABLE 2
PENTWATER LAKE 2018 DEEP BASIN WATER QUALITY DATA

Date	Station	Sample Depth (feet)	Temperature (°F)	Dissolved Oxygen (mg/L)[1]	Total Phosphorus (μg/L)[2]	pH (S.U.)[3]	Total Alkalinity (mg/L as $CaCO_3$)[4]
11-Apr-18	1	1	41	11.3	5	8.8	150
11-Apr-18	1	10	41	11.5	5	8.8	155
11-Apr-18	1	20	41	9.7	5	8.8	155
11-Apr-18	1	30	40	10.0	5	8.8	153
11-Apr-18	1	40	40	9.4	5	8.8	153
11-Apr-18	1	48	40	10.0	5	8.7	153
06-Sep-18	1	1	73	7.8	5	8.0	137
06-Sep-18	1	10	72	4.6	21	7.4	136
06-Sep-18	1	20	68	2.2	27	7.5	142
06-Sep-18	1	30	60	0.2	11	7.4	147
06-Sep-18	1	40	55	0.2	22	7.3	149
06-Sep-18	1	50	53	0.0	228	7.2	160

TABLE 3
PENTWATER LAKE 2018 SURFACE WATER QUALITY DATA

Date	Sample Location	Secchi Transparency (feet)	Chlorophyll-*a* (μg/L)[2]
11-Apr-18	1	7.0	0
6-Sep-18	1	5.5	5

1 mg/L = milligrams per liter = parts per million.
2 μg/L = micrograms per liter = parts per billion.
3 S.U. = standard units.
4 mg/L $CaCO_3$ = micrograms per liter as calcium carbonate.

TABLE 4
PENTWATER LAKE SUMMARY STATISTICS, 1988-2016

	Total Phosphorus (µg/L)[1]	Chlorophyll-*a* (µg/L)[1]	Secchi Transparency (feet)
Mean	45	3	6.4
Standard Deviation	70	4	1.6
Median	21	2	6.0
Minimum	2	0	3.0
Maximum	443	21	10.5
Number	232	40	40

Sampling in 2018 was conducted during spring turnover and summer thermal stratification (Table 2). During the spring sampling, temperature and dissolved oxygen were nearly uniform from the surface to the bottom. During the summer sampling, warm water near the surface was underlain by colder water near the bottom. The thermocline, where temperature drops rapidly with depth, occurred between 20 and 30 feet. The reduced dissolved oxygen levels below the thermocline indicate that Pentwater Lake is biologically productive. The lack of dissolved oxygen below the thermocline in Pentwater Lake prevents fish and many other aquatic organisms from colonizing the deep waters of the lake during the summer months.

Total phosphorus levels in Pentwater Lake were relatively low during the spring sampling and increased during the summer sampling period (Table 2). The elevated phosphorus level measured at the lake bottom during summer is an indication of phosphorus release from the sediments caused by bottom-water oxygen depletion. While internal loading of phosphorus occurs in Pentwater Lake, the volume of water with high phosphorus levels is small. Internal loading does not appear to be a large source of phosphorus input to the lake.

Secchi transparency was moderate in the spring and slightly reduced during the summer sampling period (Table 3). During spring, algae growth in the open water of Pentwater Lake was low as indicated by the lack of chlorophyll-a measured in the water column at that time. In summer, chlorophyll-a levels increased, indicating increased algae abundance. The moderate Secchi transparency in Pentwater Lake appears to be influenced less by algae than other factors such as suspended solids.

Alkalinity in Pentwater Lake is moderate to high and the lake is well-buffered against pollution inputs that could impact pH (Table 2). The pH in Pentwater Lake is within a range that can readily support aquatic life.

Pentwater Lake is meso-eutrophic in that it has characteristics of a mesotrophic lake (i.e., low chlorophyll-a levels) and some characteristics of a eutrophic lake (i.e., elevated phosphorus levels, low Secchi transparency, deep-water oxygen depletion, and phosphorus release from deep-water sediments).

1 µg/L = micrograms per liter = parts per billion.

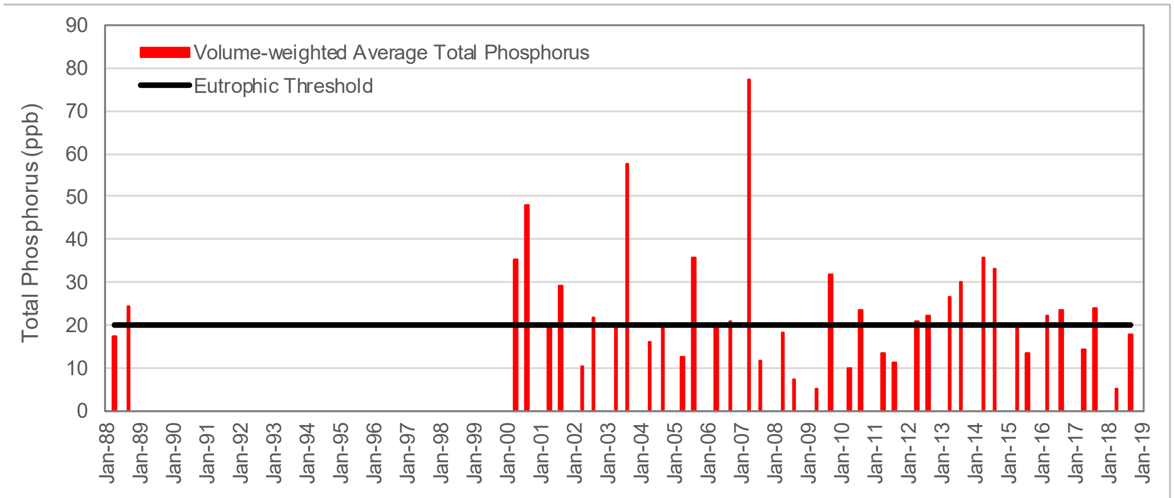

Figure 5. Average springtime total phosphorus concentrations, 1988 - 2018.

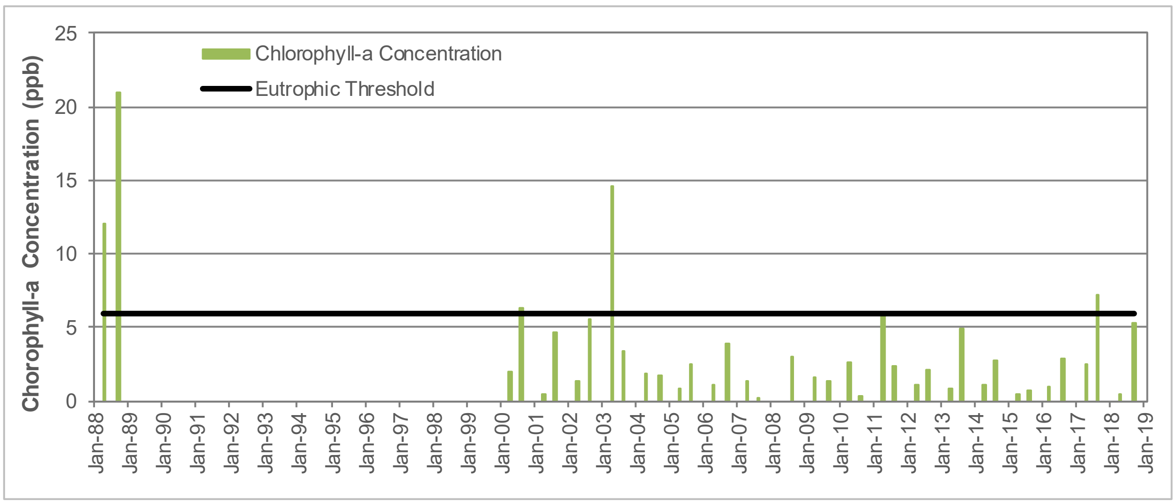

Figure 6. Chlorophyll-a concentrations, 1988 - 2018.

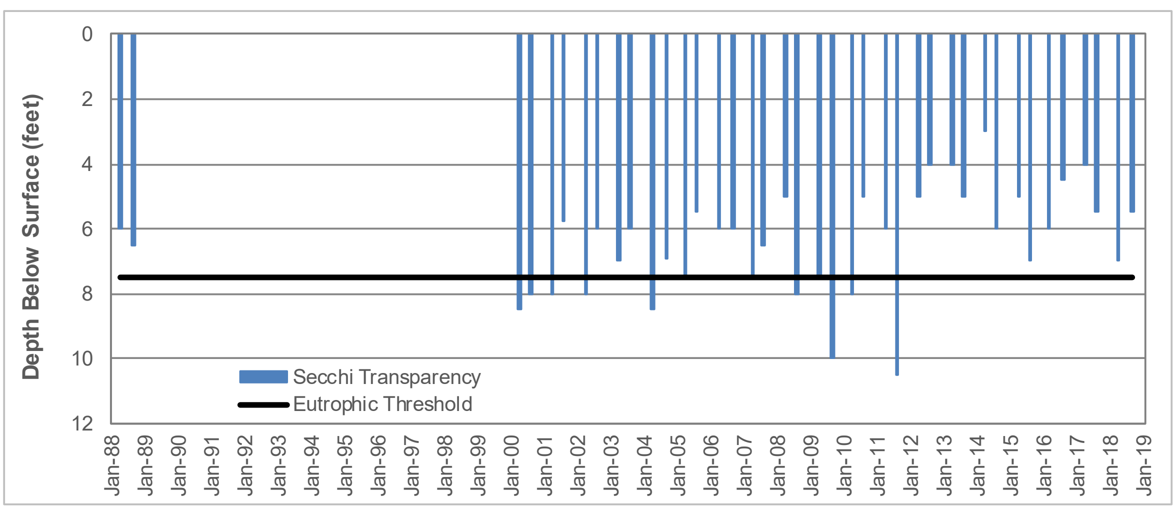

Figure 7. Secchi transparency measurements, 1988 - 2018.

Appendix A
Pentwater Lake
Historical Water Quality Data

TABLE A1
PENTWATER LAKE 1988-2017 DEEP BASIN WATER QUALITY DATA

Date	Station	Sample Depth (feet)	Temperature (°F)	Dissolved Oxygen (mg/L)[1]	Total Phosphorus (µg/L)[2]	pH (S.U.)[3]	Total Alkalinity (mg/L as $CaCO_3$)[4]
19-Apr-88	1	1	46	11.5	17	8.4	
19-Apr-88	1	25	46		18	8.4	134
19-Apr-88	1	46	46	11.6	18	8.4	
13-Sep-88	1	1	67	10.8	22	8.7	
13-Sep-88	1	35	62	4.0	23	7.8	
13-Sep-88	1	45	56	0.1	250	7.3	
26-Apr-00	1	1	51	11.5	57	8.3	166
26-Apr-00	1	10	50	11.6	29	8.3	167
26-Apr-00	1	20	49	11.6	22	8.3	163
26-Apr-00	1	30	48	11.5	18	8.3	159
26-Apr-00	1	40	48	11.1	28	8.3	149
26-Apr-00	1	47	47	10.6	30	8.2	162
3-Aug-00	1	1	64	9.2	48	8.6	170
3-Aug-00	1	10	82	8.7	66		
3-Aug-00	1	20	86	1.8	26		
3-Aug-00	1	30	118	0.1	26	7.9	169
3-Aug-00	1	40	151	0.1	72		
3-Aug-00	1	48	79	0.2	276	7.9	173
24-Apr-01	1	1	52	10.5	22	8.1	139
24-Apr-01	1	10	52	10.9	22	8.0	137
24-Apr-01	1	20	52	11.0	6	8.0	140
24-Apr-01	1	30	52	11.3	30	8.0	144
24-Apr-01	1	40	51	11.5	28	7.9	141
24-Apr-01	1	47	51	11.4	27	8.0	136
22-Aug-01	1	1	71	8.5	48	8.2	136
22-Aug-01	1	10	71	7.9	14	8.1	138
22-Aug-01	1	20	67	3.7	6	8.1	142
22-Aug-01	1	30	61	0.7	6	8.0	149
22-Aug-01	1	40	58	0.8	187	7.9	161
22-Aug-01	1	45	57	0.7	303	7.9	175

1 mg/L = milligrams per liter = parts per million.
2 µg/L = micrograms per liter = parts per billion.
3 S.U. = standard units.
4 mg/L $CaCO_3$ = micrograms per liter as calcium carbonate.

TABLE A1 (continued)
PENTWATER LAKE 1988-2017 DEEP BASIN WATER QUALITY DATA

Date	Station	Sample Depth (feet)	Temperature (°F)	Dissolved Oxygen (mg/L)[1]	Total Phosphorus (µg/L)[2]	pH (S.U.)[3]	Total Alkalinity (mg/L as $CaCO_3$)[4]
8-Apr-02	1	1	39	10.5	10	7.9	139
8-Apr-02	1	10	39	10.5	10	7.8	138
8-Apr-02	1	20	39	10.5	11	7.5	138
8-Apr-02	1	30	39	10.4	10	7.4	137
8-Apr-02	1	40	39	10.4	10	7.4	139
8-Apr-02	1	48	39	10.4	10	7.4	126
29-Aug-02	1	1	73	8.3	21	8.1	149
29-Aug-02	1	10	73	7.9	20	8.2	150
29-Aug-02	1	20	68	2.4	16	8.0	153
29-Aug-02	1	30	62	0.5	17	8.0	152
29-Aug-02	1	40	57	0.4	81	7.9	167
29-Aug-02	1	45	56	0.4	140	7.9	171
14-Apr-03	1	1	45	8.3	17	7.4	149
14-Apr-03	1	10	44	8.2	20	7.8	148
14-Apr-03	1	20	44	8.2	23	7.8	
14-Apr-03	1	30	43	8.0	23	7.4	154
14-Apr-03	1	40	42	7.8	28	7.6	147
14-Apr-03	1	45	43	7.9	42	7.6	149
26-Aug-03	1	1	75	9.8	39	8.8	146
26-Aug-03	1	10	75	9.8	45	8.6	143
26-Aug-03	1	20	67	0.2	43	7.8	143
26-Aug-03	1	30	60	0.1	112	7.7	149
26-Aug-03	1	40	58	0.1	141	7.7	158
26-Aug-03	1	46	57	0.0	443	7.8	178
6-Apr-04	1	1	45	10.1	13	8.0	140
6-Apr-04	1	10	45	9.7	13	7.9	141
6-Apr-04	1	20	45	9.8	27	7.9	137
6-Apr-04	1	30	45	9.7	10	7.8	144
6-Apr-04	1	40	45	9.9	10	7.9	142
6-Apr-04	1	50	45	9.7	72	8.1	142

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TABLE A1 (continued)
PENTWATER LAKE 1988-2017 DEEP BASIN WATER QUALITY DATA

Date	Station	Sample Depth (feet)	Temperature (°F)	Dissolved Oxygen (mg/L)[1]	Total Phosphorus (μg/L)[2]	pH (S.U.)[3]	Total Alkalinity (mg/L as $CaCO_3$)[4]
7-Sep-04	1	1	70	10.0	11	9.2	163
7-Sep-04	1	10	70	9.0	21	9.1	160
7-Sep-04	1	20	67	2.8	12	8.5	168
7-Sep-04	1	30	64	0.6	23	8.3	167
7-Sep-04	1	40	61	0.6	73	8.3	163
7-Sep-04	1	47	60	0.6	263	8.2	165
28-Apr-05	1	1	51	11.1	16	8.7	150
28-Apr-05	1	10	50	10.8	9	8.7	149
28-Apr-05	1	20	50	10.9	9	8.7	151
28-Apr-05	1	30	50	10.5	5	8.7	150
28-Apr-05	1	40	49	10.4	18	8.7	148
28-Apr-05	1	48	49	9.5	11	8.6	151
31-Aug-05	1	1	73	11.3	52	9.1	148
31-Aug-05	1	10	72	11.0	33	9.0	148
31-Aug-05	1	20	66	3.5	12	8.4	145
31-Aug-05	1	30	60	1.4	16	8.2	151
31-Aug-05	1	40	59	1.4	35	8.1	162
31-Aug-05	1	45	59	1.4	324	8.1	187
18-Apr-06	1	1	50	10.4	20	8.5	137
18-Apr-06	1	10	50	10.5	19	8.3	133
18-Apr-06	1	20	50	10.7	15	8.3	133
18-Apr-06	1	30	49	10.6	25	8.3	132
18-Apr-06	1	40	48	8.9	24	8.2	135
18-Apr-06	1	47	48	9.6	29	8.2	136
6-Sep-06	1	1	73	11.4	12	9.0	155
6-Sep-06	1	10	70	12.5	22	8.9	156
6-Sep-06	1	20	65	4.2	12	8.5	152
6-Sep-06	1	30	63	1.3	22	8.4	147
6-Sep-06	1	40	59	0.0	141	8.4	158
6-Sep-06	1	46	57	0.1	197	8.3	162

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TABLE A1 (continued)
PENTWATER LAKE 1988-2017 DEEP BASIN WATER QUALITY DATA

Date	Station	Sample Depth (feet)	Temperature (°F)	Dissolved Oxygen (mg/L)[1]	Total Phosphorus (µg/L)[2]	pH (S.U.)[3]	Total Alkalinity (mg/L as $CaCO_3$)[4]
24-Apr-07	1	1	53	11.7	81	7.9	146
24-Apr-07	1	10	52	11.8	86	7.9	145
24-Apr-07	1	20	46	11.3	72	7.9	144
24-Apr-07	1	30	45	11.4	58	7.8	145
24-Apr-07	1	40	44	10.6	75	7.7	140
24-Apr-07	1	45	43	10.2	74	7.8	139
23-Aug-07	1	1	71	9.5	5	8.9	147
23-Aug-07	1	10	69	8.4	5	8.7	142
23-Aug-07	1	20	67	6.3	5	8.5	150
23-Aug-07	1	30	63	6.1	5	8.1	149
23-Aug-07	1	40	55	0.1	205	7.9	166
23-Aug-07	1	47	54	0.1	263	7.9	170
22-Apr-08	1	1	56	12.5	16	8.5	140
22-Apr-08	1	10	55	11.7	24	8.6	138
22-Apr-08	1	20	50	10.7	10	8.2	144
22-Apr-08	1	30	47	10.8	21	8.1	137
22-Apr-08	1	40	46	9.6	31	8.1	129
22-Apr-08	1	45	46	9.5	30	7.9	134
4-Aug-08	1	1	78	6.8	<5	8.4	161
4-Aug-08	1	10	75	7.5	<5	8.2	152
4-Aug-08	1	20	68	0.8	<5	7.4	156
4-Aug-08	1	30	64	0.6	<5	7.2	153
4-Aug-08	1	40	60	0.3	59	7.2	162
4-Aug-08	1	47	58	0.2	107	7.1	165
20-Apr-09	1	1	48	12.0	5	8.2	143
20-Apr-09	1	10	48	12.3	5	8.2	145
20-Apr-09	1	20	48	12.2	5	8.1	146
20-Apr-09	1	30	47	12.4	5	8.0	142
20-Apr-09	1	40	47	11.9	8	7.9	144
20-Apr-09	1	47	45	11.3	7	8.1	145

1 mg/L = milligrams per liter = parts per million.
2 µg/L = micrograms per liter = parts per billion.
3 S.U. = standard units.
4 mg/L $CaCO_3$ = micrograms per liter as calcium carbonate.

TABLE A1 (continued)
PENTWATER LAKE 1988-2017 DEEP BASIN WATER QUALITY DATA

Date	Station	Sample Depth (feet)	Temperature (°F)	Dissolved Oxygen (mg/L)[1]	Total Phosphorus (µg/L)[2]	pH (S.U.)[3]	Total Alkalinity (mg/L as $CaCO_3$)[4]
1-Sep-09	1	1	68	7.8	14	8.5	164
1-Sep-09	1	10	67	7.6	10	8.4	165
1-Sep-09	1	20	66	7.0	11	8.2	163
1-Sep-09	1	30	61	1.8	110	7.8	158
1-Sep-09	1	40	58	0.5	247	7.7	159
1-Sep-09	1	50	56	4.2	168	7.9	147
5-Apr-10	1	1	49	11.1	11	8.2	165
5-Apr-10	1	10	49	11.5	8	8.2	166
5-Apr-10	1	20	49	11.5	11	8.1	165
5-Apr-10	1	30	49	11.0	10	8.1	164
5-Apr-10	1	40	48	10.9	9	8.1	168
5-Apr-10	1	45	48	10.9	9	8.0	170
24-Aug-10	1	1	76	4.3	12	9.3	146
24-Aug-10	1	10	76	9.2	27	9.9	142
24-Aug-10	1	20	74	10.1	20	8.9	145
24-Aug-10	1	30	67	2.0	13	8.6	144
24-Aug-10	1	40	59	0.8	98	8.5	170
24-Aug-10	1	46	57	0.4	376	8.3	182
21-Apr-11	1	1	47	11.4	13	8.4	138
21-Apr-11	1	10	46	10.7	14	8.5	138
21-Apr-11	1	20	46	11.9	15	8.5	143
21-Apr-11	1	30	45	11.6	11	8.5	142
21-Apr-11	1	40	45	11.1	12	8.4	140
21-Apr-11	1	45	45	10.9	12	8.4	142
8-Aug-11	1	1	79	7.7	11	8.7	153
8-Aug-11	1	10	78	8.4	12	8.5	151
8-Aug-11	1	20	71	7.8	7	8.4	150
8-Aug-11	1	30	63	5.3	13	8.2	152
8-Aug-11	1	40	59	4.4	15	8.1	150
8-Aug-11	1	45	58	3.6	55	7.9	154

1 mg/L = milligrams per liter = parts per million.
2 µg/L = micrograms per liter = parts per billion.
3 S.U. = standard units.
4 mg/L $CaCO_3$ = micrograms per liter as calcium carbonate.

TABLE A1 (continued)
PENTWATER LAKE 1988-2017 DEEP BASIN WATER QUALITY DATA

Date	Station	Sample Depth (feet)	Temperature (°F)	Dissolved Oxygen (mg/L)[1]	Total Phosphorus (µg/L)[2]	pH (S.U.)[3]	Total Alkalinity (mg/L as $CaCO_3$)[4]
19-Apr-12	1	1	52	9.7	22	8.5	158
19-Apr-12	1	10	52	9.6	28	8.6	158
19-Apr-12	1	20	52	10.0	13	8.6	
19-Apr-12	1	30	52	10.6	17	8.6	154
19-Apr-12	1	40	52	10.5	12	8.6	
19-Apr-12	1	44	52	10.4	<5	8.6	175
13-Aug-12	1	1	73	9.5	26		145
13-Aug-12	1	10	72	10.7	24		145
13-Aug-12	1	20	70	5.7	<5		148
13-Aug-12	1	30	63	1.4	24		162
13-Aug-12	1	40	58	0.0	99		172
13-Aug-12	1	46	57				
24-Apr-13	1	1	44	9.6	28	8.1	119
24-Apr-13	1	10	44	9.2	28	8.1	116
24-Apr-13	1	20	44	9.7	20	8.1	114
24-Apr-13	1	30	44	10.0	29	8.1	115
24-Apr-13	1	40	44	11.2	33	8.1	113
24-Apr-13	1	45	43	7.0	30	8.1	112
5-Aug-13	1	1	70	9.3	30	8.9	158
5-Aug-13	1	10	70	9.9	33	8.8	161
5-Aug-13	1	20	64	6.9	18	8.3	161
5-Aug-13	1	30	60	9.5	21	8.5	158
5-Aug-13	1	40	56	0.0	50	8.0	152
5-Aug-13	1	47	55	0.3	280	7.8	159
24-Apr-14	1	1	49	10.2	34	8.4	107
24-Apr-14	1	10	48	10.3	39	8.2	104
24-Apr-14	1	20	48	10.2	34	8.1	106
24-Apr-14	1	30	48	10.3	34	8.0	103
24-Apr-14	1	40	48	10.2	38	8.0	105
24-Apr-14	1	46	47	9.5	4	7.9	103

1 mg/L = milligrams per liter = parts per million.
2 µg/L = micrograms per liter = parts per billion.
3 S.U. = standard units.
4 mg/L $CaCO_3$ = micrograms per liter as calcium carbonate.

TABLE A1 (continued)
PENTWATER LAKE 1988-2017 DEEP BASIN WATER QUALITY DATA

Date	Station	Sample Depth (feet)	Temperature (°F)	Dissolved Oxygen (mg/L)[1]	Total Phosphorus (µg/L)[2]	pH (S.U.)[3]	Total Alkalinity (mg/L as $CaCO_3$)[4]
5-Aug-14	1	1	75	13.0	22	8.9	155
5-Aug-14	1	10	73	12.0	46	8.8	164
5-Aug-14	1	20	65	7.1	19	8.2	145
5-Aug-14	1	30	61	3.6	22	7.8	138
5-Aug-14	1	40	56	0.5	115	7.7	145
5-Aug-14	1	47	55	0.5	319	7.5	147
23-Apr-15	1	1	48	10.6	19	8.1	142
23-Apr-15	1	10	49	11.1	21	8.1	139
23-Apr-15	1	20	49	10.7	18	8.1	
23-Apr-15	1	30	49	10.6	24	8.1	140
23-Apr-15	1	40	49	10.7	20	7.8	140
23-Apr-15	1	46	49	10.7	20	8.1	142
13-Aug-15	1	1	75	11.5	9		
13-Aug-15	1	10	74	10.0	11		
13-Aug-15	1	20	70	2.0	9		
13-Aug-15	1	30	61	1.8	30		
13-Aug-15	1	40	56	1.2	55		
13-Aug-15	1	45	56	2.3			
29-Mar-16	1	1	43	11.7	23	7.7	145
29-Mar-16	1	10	43	11.5	18	7.6	146
29-Mar-16	1	20	43	11.4	26	7.7	141
29-Mar-16	1	30	43	11.8	23	7.7	146
29-Mar-16	1	40	43	11.2	16	7.7	149
29-Mar-16	1	46	43	11.6	22	7.7	146
16-Aug-16	1	1	79	10.9	15	8.9	156
16-Aug-16	1	10	78.2	7.8	24	8.5	155
16-Aug-16	1	20	71.8	2.5	14	7.7	156
16-Aug-16	1	30	61.2	1.1	33	7.7	161
16-Aug-16	1	40	55.8	0.7	121	7.6	170
16-Aug-16	1	45	54.4	0.6	168	7.6	171

1 mg/L = milligrams per liter = parts per million.
2 µg/L = micrograms per liter = parts per billion.
3 S.U. = standard units.
4 mg/L $CaCO_3$ = micrograms per liter as calcium carbonate.

TABLE A1 (continued)
PENTWATER LAKE 1988-2017 DEEP BASIN WATER QUALITY DATA

Date	Station	Sample Depth (feet)	Temperature (°F)	Dissolved Oxygen (mg/L)[1]	Total Phosphorus (µg/L)[2]	pH (S.U.)[3]	Total Alkalinity (mg/L as $CaCO_3$)[4]
17-Apr-17	1	1	55.7	10.8	19	8.5	146
17-Apr-17	1	10	51.8	10.8	18	8.5	151
17-Apr-17	1	20	51.4	10.8	2	8.5	148
17-Apr-17	1	30	49.6	10.8	13	8.5	181
17-Apr-17	1	40	48.3	10.2	22	8.5	148
17-Apr-17	1	49	46.8	10.2	10	8.6	149
08-Aug-17	1	1	74.4	10.9	16	8.3	158
08-Aug-17	1	10	72.4	8.9	19	8.3	156
08-Aug-17	1	20	67.5	2.8	23	7.7	156
08-Aug-17	1	30	62.0	2.5	39	7.3	155
08-Aug-17	1	40	58.1	1.0	113	7.3	160
08-Aug-17	1	46	56.2	0.9	48	7.3	160

1 mg/L = milligrams per liter = parts per million.
2 µg/L = micrograms per liter = parts per billion.
3 S.U. = standard units.
4 mg/L $CaCO_3$ = micrograms per liter as calcium carbonate.

TABLE A2
PENTWATER LAKE 1988-2017 SURFACE WATER QUALITY DATA

Date	Sample Location	Secchi Transparency (feet)	Chlorophyll-*a* (μg/L)[1]
19-Apr-88	1	6.0	12
13-Sep-88	1	6.5	21
26-Apr-00	1	8.5	2
3-Aug-00	1	8.0	6
24-Apr-01	1	8.0	0
22-Aug-01	1	5.8	5
08-Apr-02	1	8.0	1
29-Aug-02	1	6.0	6
14-Apr-03	1	7.0	15
26-Aug-03	1	6.0	3
06-Apr-04	1	8.5	2
07-Sep-04	1	6.9	2
28-Apr-05	1	7.5	1
31-Aug-05	1	5.5	3
18-Apr-06	1	6.0	1
6-Sep-06	1	6.0	4
24-Apr-07	1	7.5	1
23-Aug-07	1	6.5	0
22-Apr-08	1	5.0	0
4-Aug-08	1	8.0	3
20-Apr-09	1	7.5	2
1-Sep-09	1	10.0	1
5-Apr-10	1	8.0	3
24-Aug-10	1	5.0	0
21-Apr-11	1	6.0	6
8-Aug-11	1	10.5	2
19-Apr-12	1	5.0	1
13-Aug-12	1	4.0	2
24-Apr-13	1	4.0	1
5-Aug-13	1	5.0	5
24-Apr-14	1	3.0	1
5-Aug-14	1	6.0	3
23-Apr-15	1	5.0	1
13-Aug-15	1	7.0	1
29-Mar-16	1	6.0	1
16-Aug-16	1	4.5	3
17-Apr-17	1	4.0	3
8-Aug-17	1	5.5	7

1 μg/L = micrograms per liter = parts per billion.

References

Wetzel, R.G. 1983. Limnology. 2nd edition. Saunders College Publishing, Philadelphia, Pennsylvania.