Evaluation of Lake Level Drawdown at Highland Lake 2008-2016

Prepared for:
Highland Lake Water Level Committee
Town of Winchester

Prepared by:
Northeast Aquatic Research, LLC
George W. Knoecklein, Ph.D.

February 28, 2017

Table of Contents

List of Figures

List of Tables

Summary

This report examines Highland Lake winter water level drawdown records, lake limnological monitoring data and aquatic plant distribution information collected between 2008 and 2016. Water level records were analyzed in similar fashion as done in the prior report for the years 2000 to 2008[1]. Drawdown at Highland Lake may be justified, exclusively, due to over 90% of the shoreline composed of permanent structures that exists below the summer water level and are susceptible to ice damage during winter.

Recommendation = Collect inventory data on all permanent structures around the lake to determine the water level drawdown required to protect each from ice damage.

The current practice of lowering the lake to between 36-40 inches below spillway appears to be protecting masonry structures. However, an inventory of the water level at the toe of each structure is needed. The data could be obtained by visiting the lake in October or November and assessing the shoreline features in relation to water level.

Recommendation = Obtain more frequent information on aquatic plant distribution changes. Annual aquatic plant surveys should be conducted to closely track the distribution of both invasive and protected species.

The deeper drawdown to 96 inches may not be providing justifiable control of invasive aquatic plants, but may be harming protected species.

- Variable-leaf milfoil was present during 2015 and 2016 plant surveys at similar low frequencies over the same depth range of 0-7ft water depth, suggesting plants withstand the drawdown in sheltered refuge areas that remain wet during drawdown. No variable-leaf milfoil was found deeper than 7 feet of water depth.
- Eurasian milfoil had highest abundance between 6 and 12 feet of water depth, suggesting that deep drawdown has not significantly impacted its growth.
  - Less milfoil found between 0-4 feet of water depth indicates that drawdown to 40 inches is probably limiting Eurasian milfoil spread in shallower water.
- The diversity and presence of native plants was similar in all three surveys, 2016, 2015 and 2009 suggesting that drawdown is not negatively impacting submersed plant species presence in the lake.
  - However two protected species were not recorded in 2015 or 2016 surveys.

[1] Evaluation Of Lake Level Drawdown At Highland Lake, Winchester, CT 2008, Northeast Aquatic Research

- However, floating-leaved plant species were scarce in Highland Lake during all survey years, probably due to continued exposure of shallow water zone where these plants grow.
- Plant abundance appears to increase with water depth. Between 0-4ft, percent cover is less than 60%, only increasing to 100% in water deeper than 8ft., suggesting that native plants may have shifted to optimum growth below effect of the drawdown.

Examination of 2008-2015 water level records show;

- Each winter the lake level was regularly lowered to about 40 inches below spillway.
- Lake level lowering starts on or about October 1st.
- Target depth of 36 inches was reached in about 11 days (ranging between 7 and 18 days).
- Target depth of 36 inches below spillway typically reached by the mid October.
- Target depth of 96 inches below spillway typically reached by the mid November.
- In both cases, water level was held consistently at 40± inches below spillway until March.
- Refill after shallow drawdown was generally quick with water back to spillway level in 2-3 weeks.
    - However, refills in 2011-2012 and 2012-2013 were slower, taking between 8 and 12 weeks, with spillway level reached in late May and early June, respectively.
- Refill after deep drawdown takes about 15 weeks.
    - During refill of the most recent deep drawdown of 2014-2015, the water level was held at 40 inches below spillway until March when level was brought to spillway.
- The lake shoreline out to 3 feet of water depth was exposed each winter for these durations:
    - 0 to 1 foot = about 175 days.
    - 1-2 feet = about 161 days.
    - 2-3 feet = about 132 days.
- The lake shoreline deeper than 3 feet was not exposed each winter. Record of exposure deeper than 3 feet is:
    - 3-4 feet = 96 days occurring during 6 of 15 winters (2000-2014)
    - 4-5 feet = 71 days occurring during 5 of 15 winters
    - 5-6 feet = 60 days occurring during 4 of 15 winters
    - 6-7 feet = 49 days occurring during 4 of 15 winters

- 7-8 feet = 4 days occurring during only 4 of 15 winters

Analysis of the water quality record shows that lake has very good water quality;

- Water clarity was good to very good in 2016.
  - However, long-term trend in water clarity shows fluctuation between times of good clarity, >4 meters, and periods of reduced clarity <4 meters.
  - Between 2011 and early 2015 several readings were <3 meters.
    - Due to phosphorus/clarity relationship period of <3m occurred when phosphorus was 10-20ppb.
- Total phosphorus now ranges between 8ppb to 21ppb. During the period 2005-2013 phosphorus was lower, ranging between 4ppb to 10ppb.
  - The changes in top and middle depth phosphorus could be due to changing loading patterns from the drainage basin.
- Phosphorus in bottom waters shows large fluctuation and possible increasing trend in Middle Bay. Bottom phosphorus in the other two Bays shows fairly similar low values over time.
- Anoxic water tended to be less severe during the last few years with boundaries reaching 7 meters as opposed to higher in the water column at 6 meters.
- Total nitrogen is low in the lake and mostly in line with Oligotrophic lake condition.
- Ammonium nitrogen accumulates in bottom water of Middle Bay but may not interact with nitrogen levels nearer to the surface.
- Water clarity tends to be poorest during early spring and again in late fall suggesting that storm water or other watershed runoff sources are contributing higher levels of phosphorus to the lake.

Recommendation = Lake water monitoring program should be maintained at the present level of effort. Annual water quality reports should be prepared so that close tracking of the lake conditions can be made.

Recommendation = Storm water monitoring should be considered as part of the testing program. Due to a believed large number of drains that drain the perimeter lake road directly into the lake it will be a huge job to assess the water quality of each. Start by establishing the drainage area of each and sample the largest first. Prior conveyance studies can probably be used to determine which culverts to sample.

Winter Water Level Drawdown

Introduction

Highland lake, a 445 acre lake set in the northwest hills of Connecticut entirely within the town of Winchester, Connecticut, has had a water-level drawdown each winter since the early 1980's **Figure 1.**

Winter water-level drawdown has been used as a method of control over the growth of two species of milfoil; Eurasian Milfoil (*Myriophyllum spicatum*) and Variable-leaf Milfoil (*Myriophyllum heterophyllum*). Nearly 90%, of the shoreline of Highland Lake is masonry walled littoral zone, where the toe of the walls is almost always underwater at normal summer spillway level. Winter water level drawdown allows access to shoreline features and protects them from ice.

Typically, for every 100 feet of walled lake shore there is one masonry pier and/or dock and often one set of masonry stairs from lawn level (+1 foot lake level) to lake floor -3 normal summer water level (**Photo 1**-taken January 7, 2007).

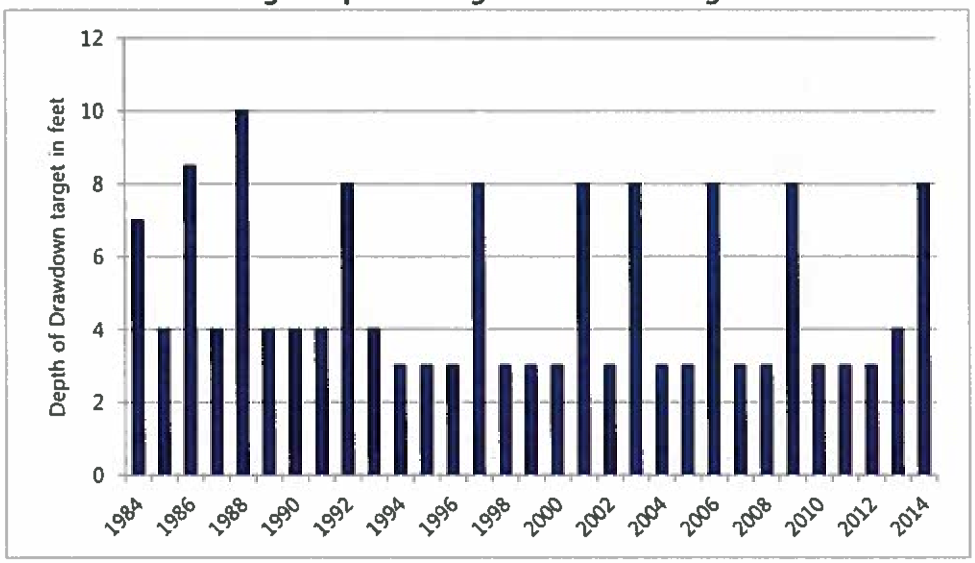
In a few locations the lake edge is also a foundation for a building (**Photo 2** taken January 7, 2007). Regular winter water level drawdown protects these structures from ice damage and allows maintenance to keep from disrepair. Concrete breaks down and crumbles when consistently exposed to water and freezing..

Photo 1- Masonry docks, walls, stairs below summer water level

Photo 2– Foundation below summer water level

Drawdown at Highland Lake is accomplished by opening a deep release gate located at the dam (north end of the lake). Lake level is drawn down to a maximum depth of 8 feet every fourth year, and to a maximum depth of 3 feet on intervening years. For the deep drawdown, the gate is opened on October 15; for the shallow drawdown, opened on November 1. The target level is maintained manually until January 1-15 when the gate is closed and the lake is allowed to refill to 40 inches below spillway, where it was held until ice-out, than allowed to refill to normal full conditions by mid-April.

Figure 1– Water level target depths during drawdowns at Highland Lake 1984 – 2014



Water level details

Winter water level drawdown target at Highland Lake has remained 3-4ft below spillway since records began in the early 1980s, interspaced with a deeper 8ft target--green shaded winters in **Table 1**. Details of water level trends during winters 2008-2014 are shown in **Figure 2** water level trends during winters 2000-2008 are shown in **Figure 3** for comparison.

Table 1– Early drawdown targets at Highland Lake (bold years examined in this report)

Beginning Winter Year	Target Drawdown Depth (Feet)	Records Available
1984	7	No
1985	4	No
1986	8.5	No
1987	4	No
1988	10	No
1989	4	No
1990	4	No
1991	4	No
1992	8	No
1993	4	No
1994	3	No
1995	3	No
1996	3	No
1997	8	No
1998	3	No
1999	3	No
2000	Shallow (actual=3.4 ft.)	Full
2001	Deep (actual=8 ft.)	Partial (January 1 on)
2002	Shallow (actual=3.3 ft.)	Partial (January 1 on)
2003	Deep (actual=8 ft.)	Full
2004	Shallow (actual=3.75 ft.)	Full
2005	Shallow (actual=3.5 ft.)	Full
2006	Deep (actual=8 ft.)	Full
2007	Shallow (actual=3.5 ft.)	Full
2008	**Shallow (actual=3.75 ft.)**	**Full**
2009	**Deep (actual=8 ft.)**	**Full**
2010	**In-between (actual=5.3 ft.)**	**Full**
2011	**Shallow (actual=3.6 ft.)**	**Full**
2012	**Shallow (actual=3.5 ft.)**	**Full**
2013	**Shallow (actual=4.3 ft.)**	**Full**
2014	**Deep (actual=8 ft.)**	**Full**

Figure 2– Trend in water level of Highland Lake during winters 2008-2014

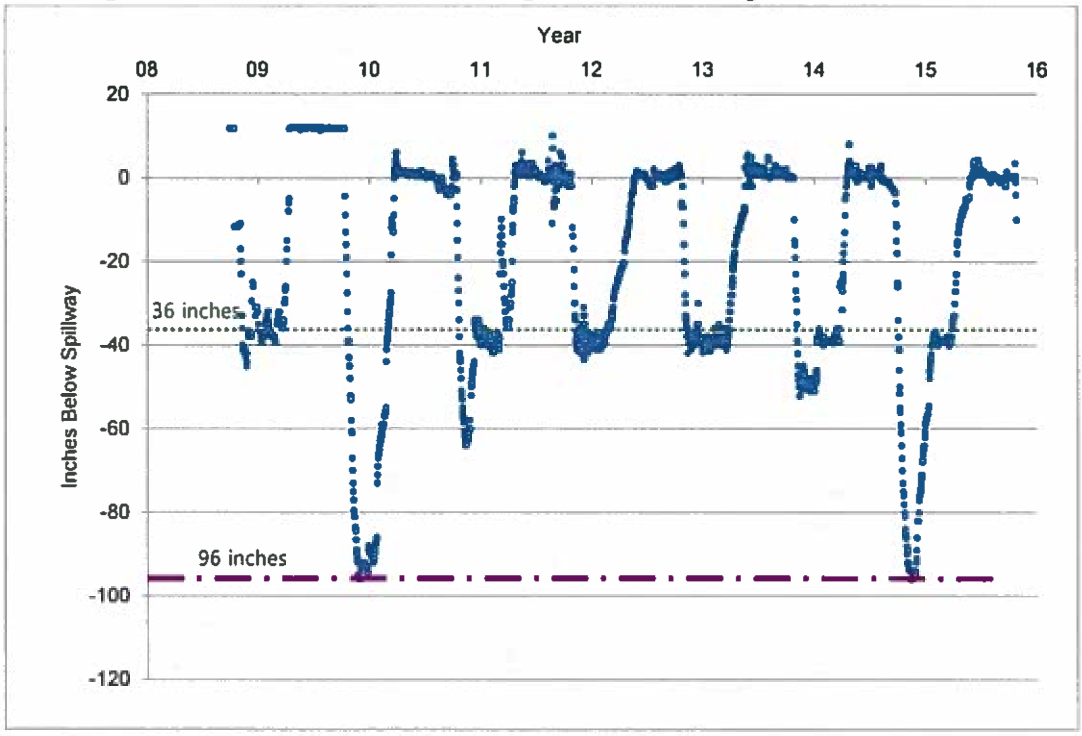
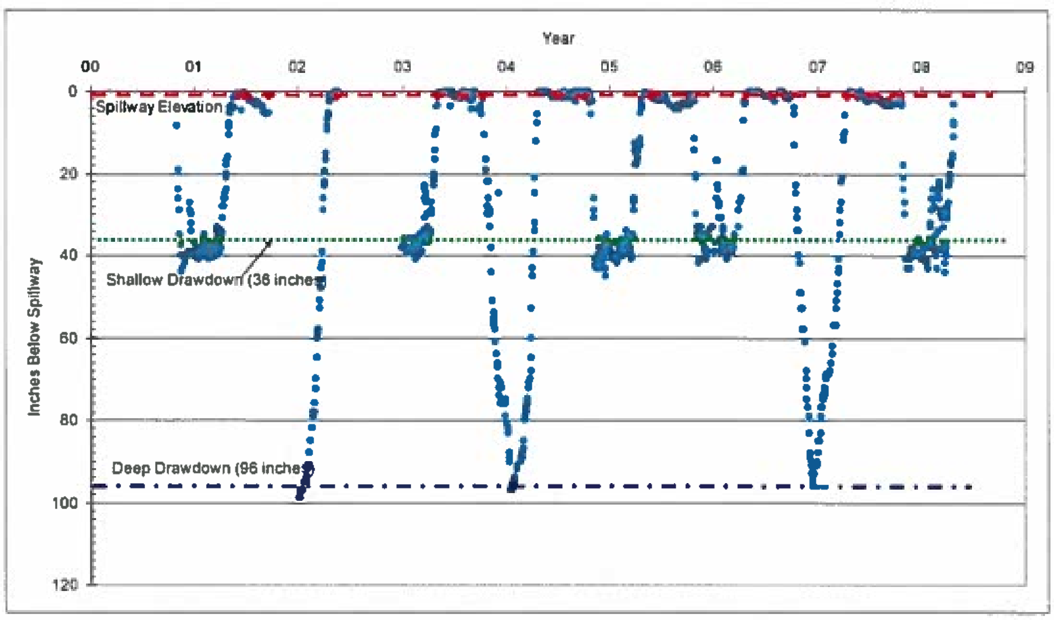


Figure 3– Trend in water level of Highland Lake during winters 2000-2008



Shallow drawdowns

Water level trends for the shallow drawdowns between 2008 and 2013 are shown in **Figure 4**. Trends show that water level drops quickly once the dam is opened in October. Target depth is reached by early November, held steady at 40 inches below spillway until late March. Refill is rapid in most years, although in 2011 and again in 2012, refill appears prolonged and did not reach the spillway until late May/early June. Drawdown trends between 2000 and 2008 show similar consistent winter water level of between 35 and 40 inches below spillway (**Figure 5**) between December and March.

Figure 4– Composite of water level trends during shallow drawdowns 2008-2013

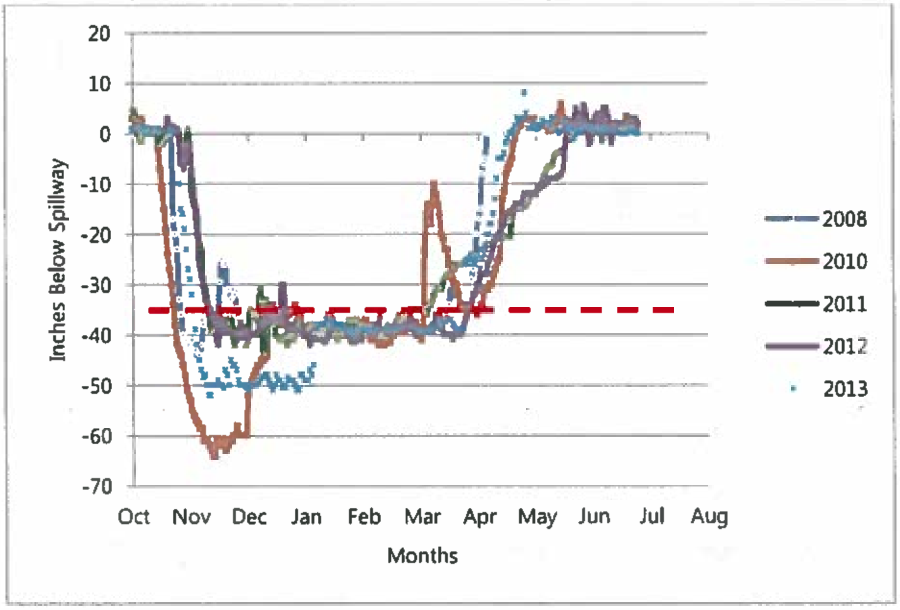
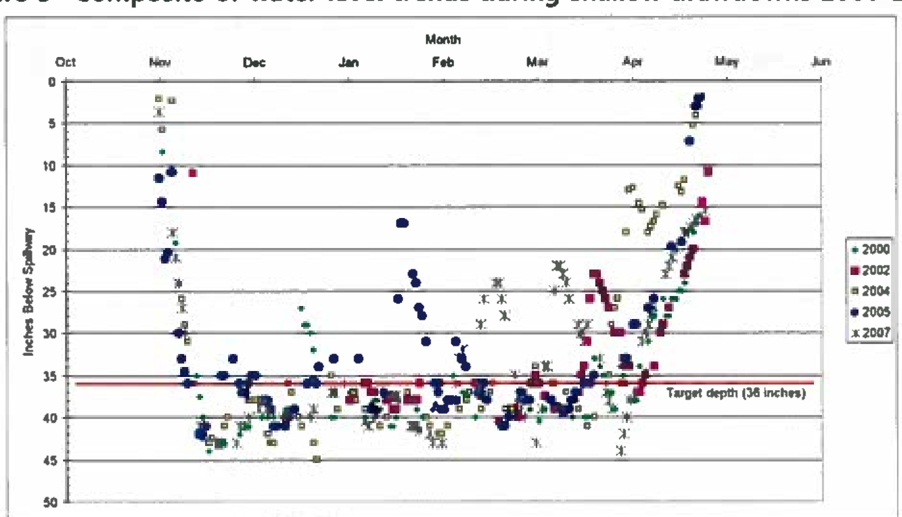


Figure 5– Composite of water level trends during shallow drawdowns 2000-2008



Deep drawdowns

Water level trends for the deep drawdowns 2009 and 2014 are shown in **Figure 6**. Trends show that water level drops quickly once the dam is opened in October, with target depth reached by early November, earlier than in 2001-2006 when target depth was achieved between early December and early January (**Figure 7**). In 2009, water level was held >90 inches below spillway until the end of December, then the lake was allowed to refill to spillway level. In 2014, target depth of 96 inches was kept for a shorter time, then allowed to refill to 40 inches below the spillway in January, where it was held until April.

Figure 6– Composite of water level trends during deep drawdowns, 2009 and 2014

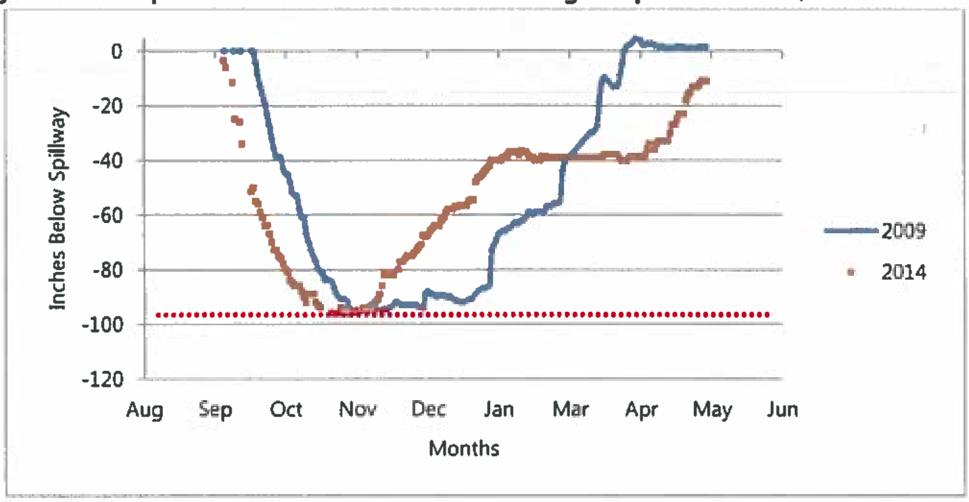
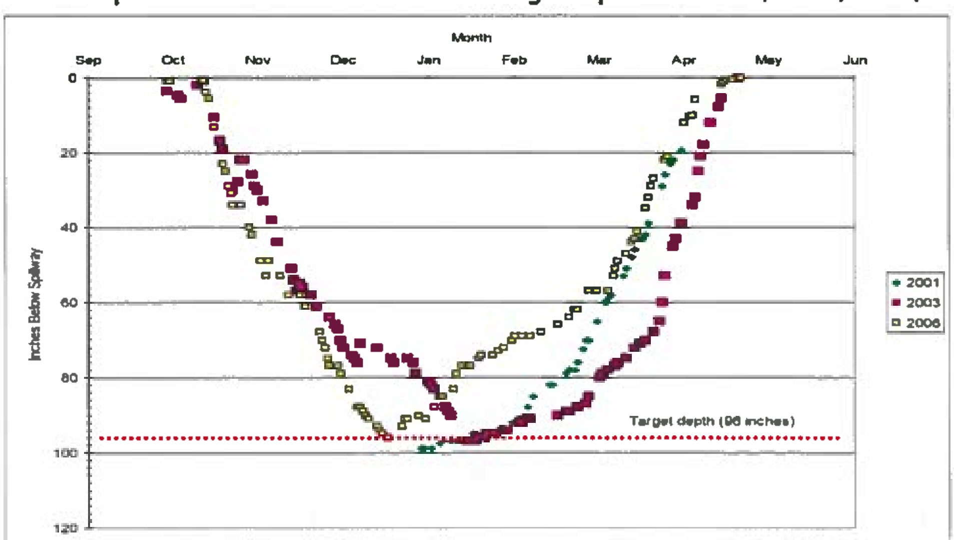


Figure 7– Composite of water level trends during deep drawdowns, 2001, 2003, & 2006



Drawdown and Refill Rates

Time to target level

The time in days to reach target level for each drawdown between 2000 and 2014 is given in **Table 2**. The shallow drawdown depth of 3 feet is reached quickly, typically between 7-18 days. All shallow drawdowns showed similar rates of 10-14 days to reach a target depth of 36 inches. Deep drawdowns of 2009 and 2014 took about 46 days to reach the target depth of 96 inches below the spillway, which was quicker than the 67-103 days in 2001, 2003, and 2006.

Table 2– Time reach target level

Year	Type	Target Level Inches	Days to reach target drawdown depth	Maximum Depth Achieved Inches
2014 – 2015	Deep	96	47	96
2013 – 2014	Shallow	36	10	52
2012 – 2013	Shallow	36	16	42
2011 – 2012	Shallow	36	18	43
2010 – 2011	In-between	36	11	64
2009 – 2010	Deep	96	44	96
2008 – 2009	Shallow	36	7	45
2007 – 2008	Shallow	36	14	43
2006 – 2007	Deep	96	67	96
2005 - 2006	Shallow	36	10	42
2004 – 2005	Shallow	36	14	45
2003 – 2004	Deep	96	103	96
2002 – 2001	Shallow	36	no data	38
2001 - 2002	Deep	96	no data	99
2000 - 2001	Shallow	36	12	44

Drawdown rates

The rate of water level lowering for each of the drawdowns reviewed in this report is combined with results from prior analysis in **Table 3**. The average rate of lowering during the shallow drawdowns studied here was 3.8 inches per day (**Figure 8**). Deep drawdowns had a slightly slower rate 3.2 inches per day during the first half of the lowering, decreasing further to 1.9 inches per day during the second half of drawdown (**Figure 9**). Prior data shows more variation with drawdown rates between 9.6 and 2.4 inches per day (**Figure 10**). Deep drawdown rates were slower at 1.0 inches per day (**Figure 11**).

Table 3– Rate of water level lowering for drawdowns at Highland Lake 2008-2014

Year	Target Level (Maximum achieved depth)	Initial Drawdown rate Inches / day	Final Drawdown rate Inches / day
2014 – 2015	Deep (8 ft.)	3.2	1.9
2013 – 2014	Shallow (4.3 ft.)	3.8	~
2012 – 2013	Shallow (3.5 ft.)	3.8	~
2011 – 2012	Shallow (3.6 ft.)	3.8	~
2010 – 2011	In-between (5.3 ft.)	3.8	~
2009 – 2010	Deep (8 ft.)	3.2	1.9
2008 – 2009	Shallow (3.75 ft.)	3.8	~
2007	36	2.9	3.0
2006	96	1.4	3.0
2005	36	3.7	9.6
2004	36	3.1	7.9
2003	96	1.0	1.4
2002	36	~	~
2001	96	~	~
2000	36	2.4	8.4

Figure 8– Water depths during shallow drawdown at Highland Lake 2008-2014

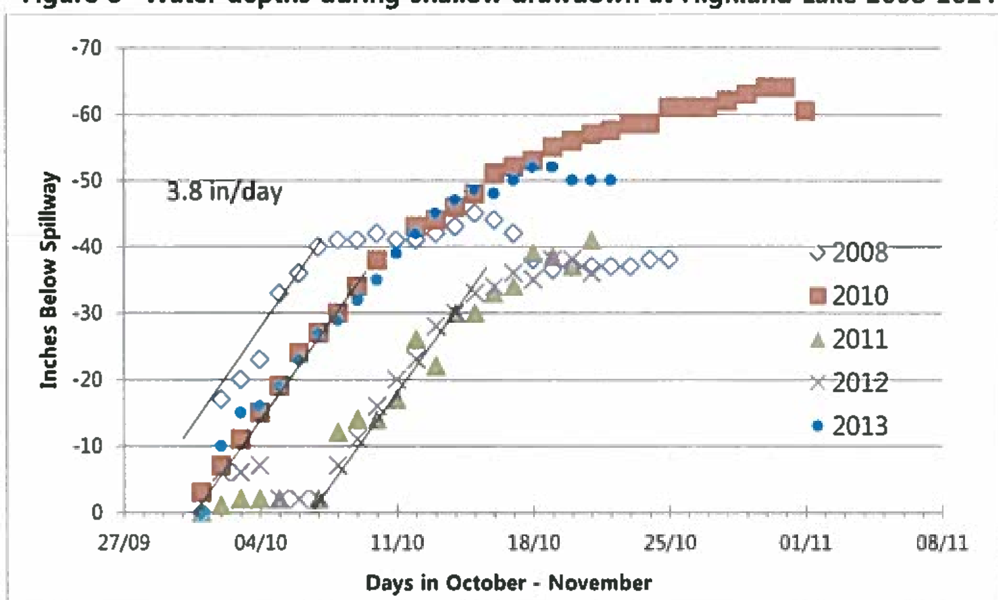


Figure 9 - Water Depths during deep drawdowns at Highland Lake 2009 & 2014

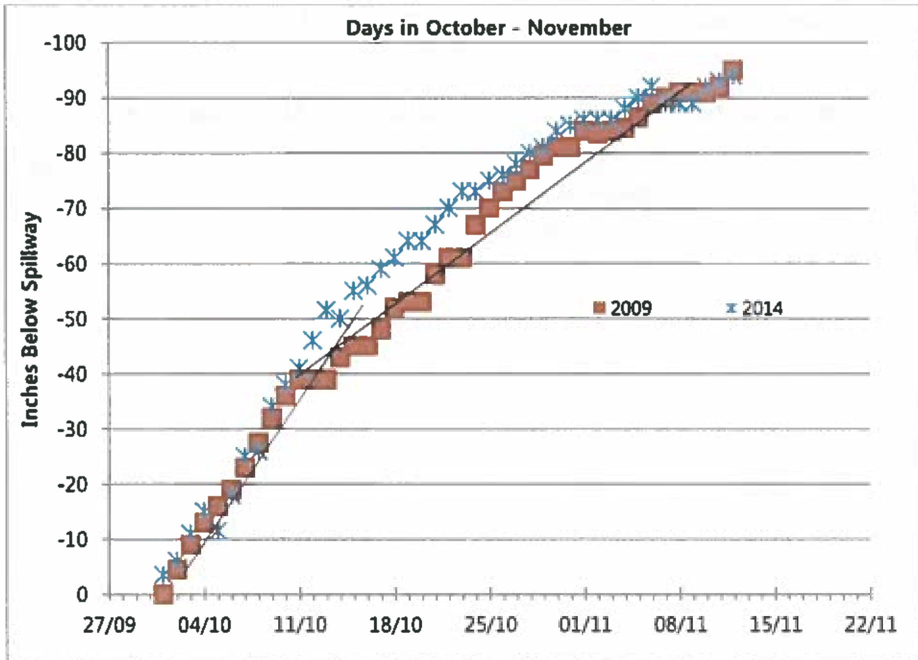


Figure 10– Water depths during shallow drawdowns at Highland Lake 2000-2007

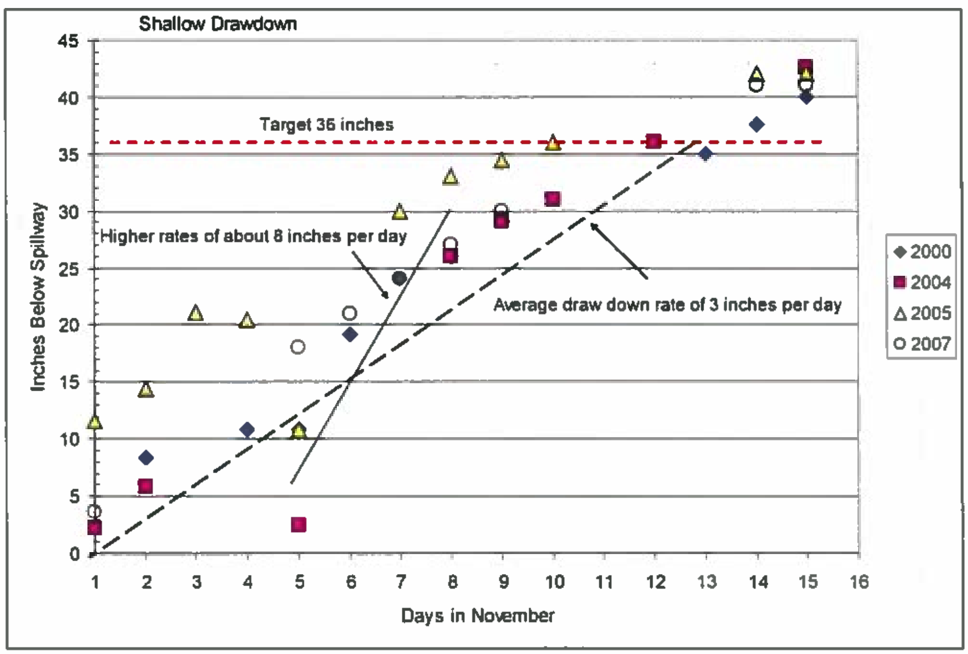
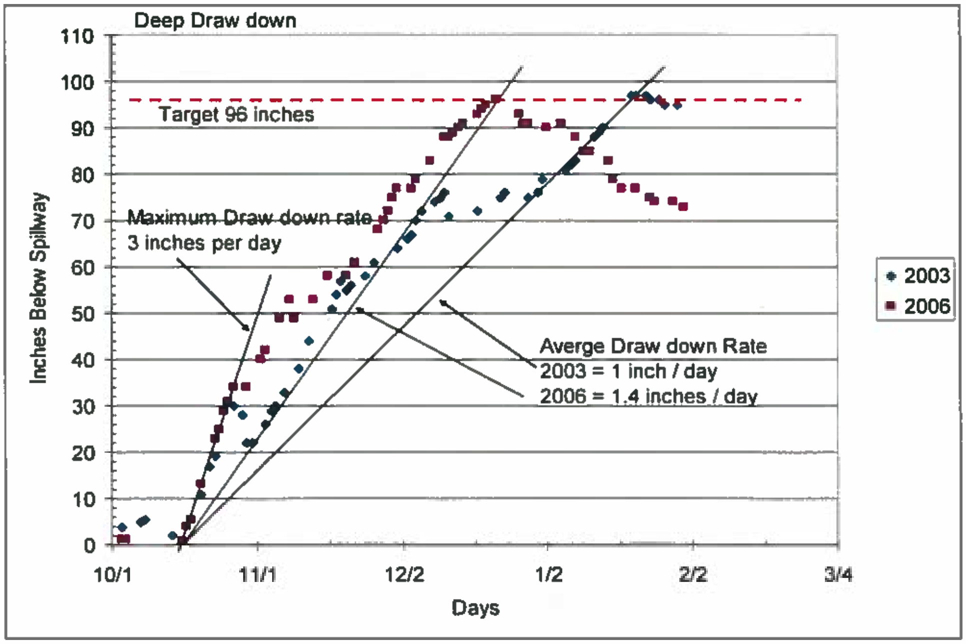


Figure 11- Water depths during deep drawdowns at Highland Lake 2003 & 2006



Refill rates

The rate of refill of the lake after drawdowns is given in **Table 4**. The time to refill during a shallow drawdown was between 13 and 32 days, while the deep drawdowns took between 69 and 171 days to refill. The spillway level was reached between March 25th at the earliest, and June 2nd at the latest. Refill rates are shown for shallow and deep drawdowns during the study period 2008-2014 in **Figure 12 and 13** and between 2000-2008 in **Figures 14 and 15**.

Table 4- Time to refill Highland Lake after drawdowns 2008-2015

Year Drawdown Began	Target Level	Target Level Inches below spillway	Time To Refill (Days)	Date Spillway Level Reached
2014 – 2015	Deep	96	171	6-4-15
2013 – 2014	Shallow	36	14	4-23-14
2012 – 2013	Shallow	36	58	5-25-13
2011 – 2012	Shallow	36	87	6-2-12
2010 – 2011	In-between	36	19	4-25-11
2009 – 2010	Deep	96	69	3-25-10
2008 – 2009	Shallow	36	23	4-16-09
2007	Shallow	36	32	5-2-08

2006	Deep	96	108	4-9-07
2005	Shallow	36	34	4-18-06
2004	Shallow	36	13	4-5-05
2003	Deep	96	84	4-19-04
2002	Shallow	36	21	4-28-03
2001	Deep	96	91	4-8-02
2000	Shallow	36	24	5-1-01

Figure 12– Refill rates for shallow drawdowns at Highland Lake 2008-2013

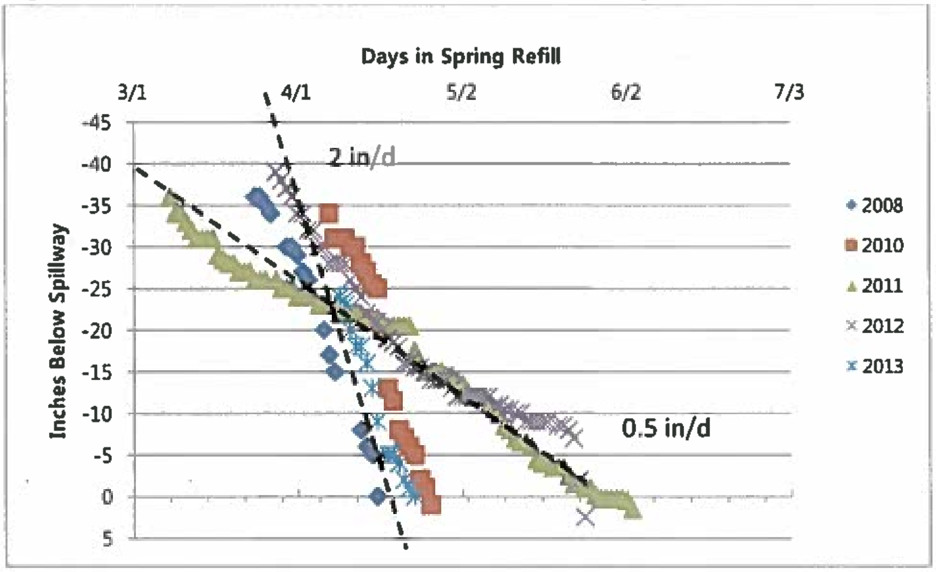


Figure 13- Refill rates for deep drawdowns at Highland Lake 2009 & 2014

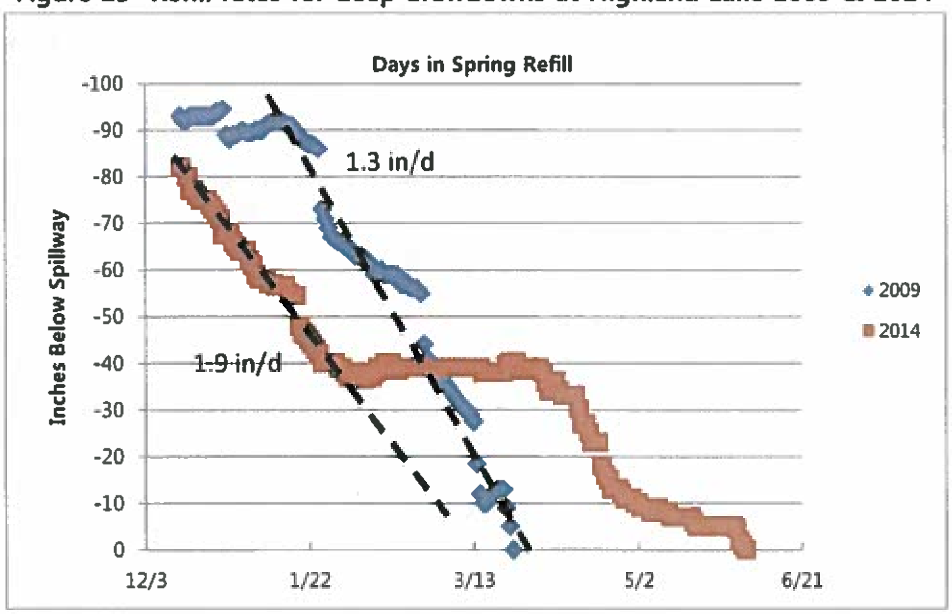


Figure 14– Refill rates for shallow drawdowns at Highland Lake 2000-2008

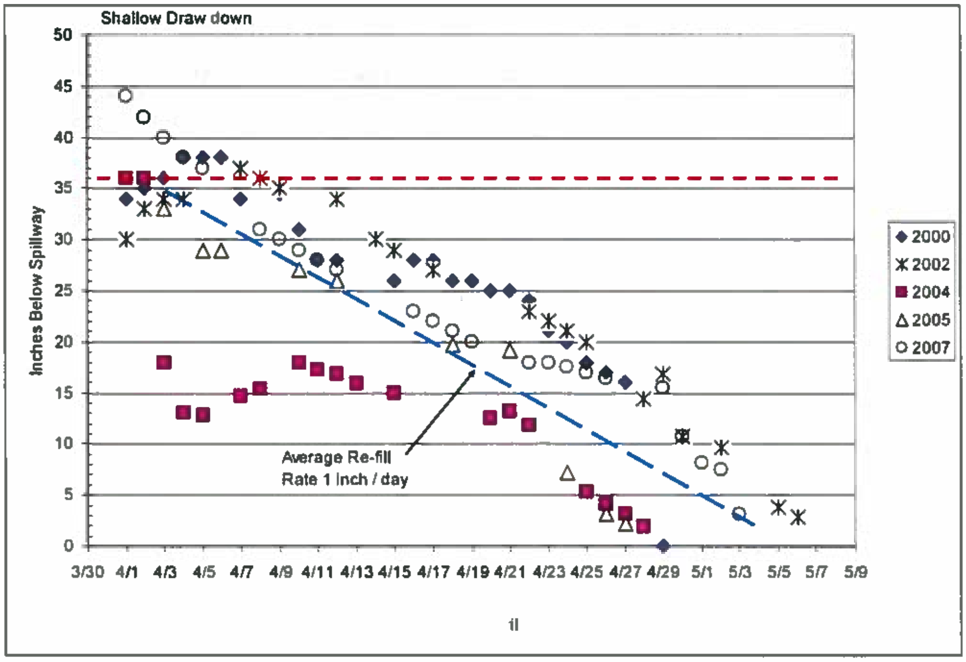
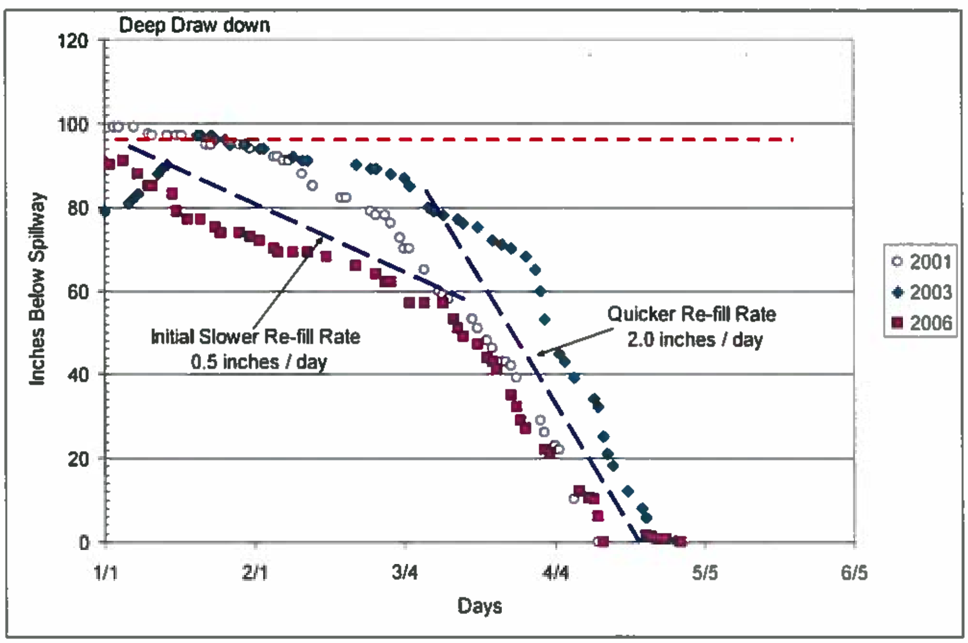


Figure 15 - Refill rates for deep drawdowns at Highland Lake 2001-2006



Inflow and Discharge Water Volumes

The values for lake surface area derived from the bathymetric map in A Fisheries Guide to Lake and Ponds in Connecticut (Jacobs and O'Donnell, 2002). The average runoff expected to refill Highland Lake between January and mid-April is estimated to be 3392 acre feet (**Table 5**).

Table 5– Lake water volume at different depths and expected inflow

Depth	Volume removed		Month	Expected inflow
3 feet	1,250 ac. ft.		January	754 ac. ft.
6 feet	2,530 ac. ft.		February	651 ac. ft.
8 feet	**3,200 ac. ft.**		March	1,320 ac. ft.
			April (until 15th)	685 ac. ft.
			Total average runoff	**3,392 ac. ft.**

The average volume of water discharged to Highland Lake between January 1st and April 15th is expected to be around 3,392 acre-feet, very close to the estimated volume of water between the surface and 96 inches.

Shoreline Exposure

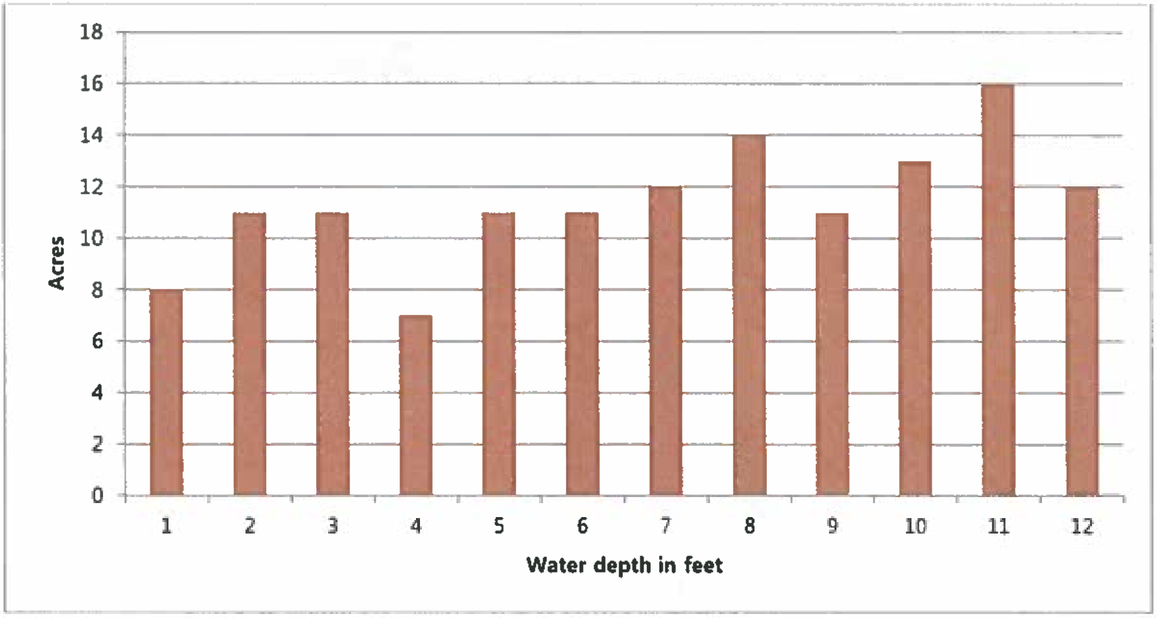
Bathymetric map of Highland Lake shows contour lines at each six feet of water depth (**Map 1**[2]). The surface areas of exposed lake bottom for each 1 foot depth increment and the cumulated area of exposed lake shoreline are given in **Table 6.** The total area exposed with a 3ft drawdown is 30 acres; total with an 8ft drawdown is 85 acres. Smallest incremental areas are in shallow water between 0-4ft deep (**Figure 16**).

Table 6– Lake surface areas for each 1 foot increment to 12 feet deep

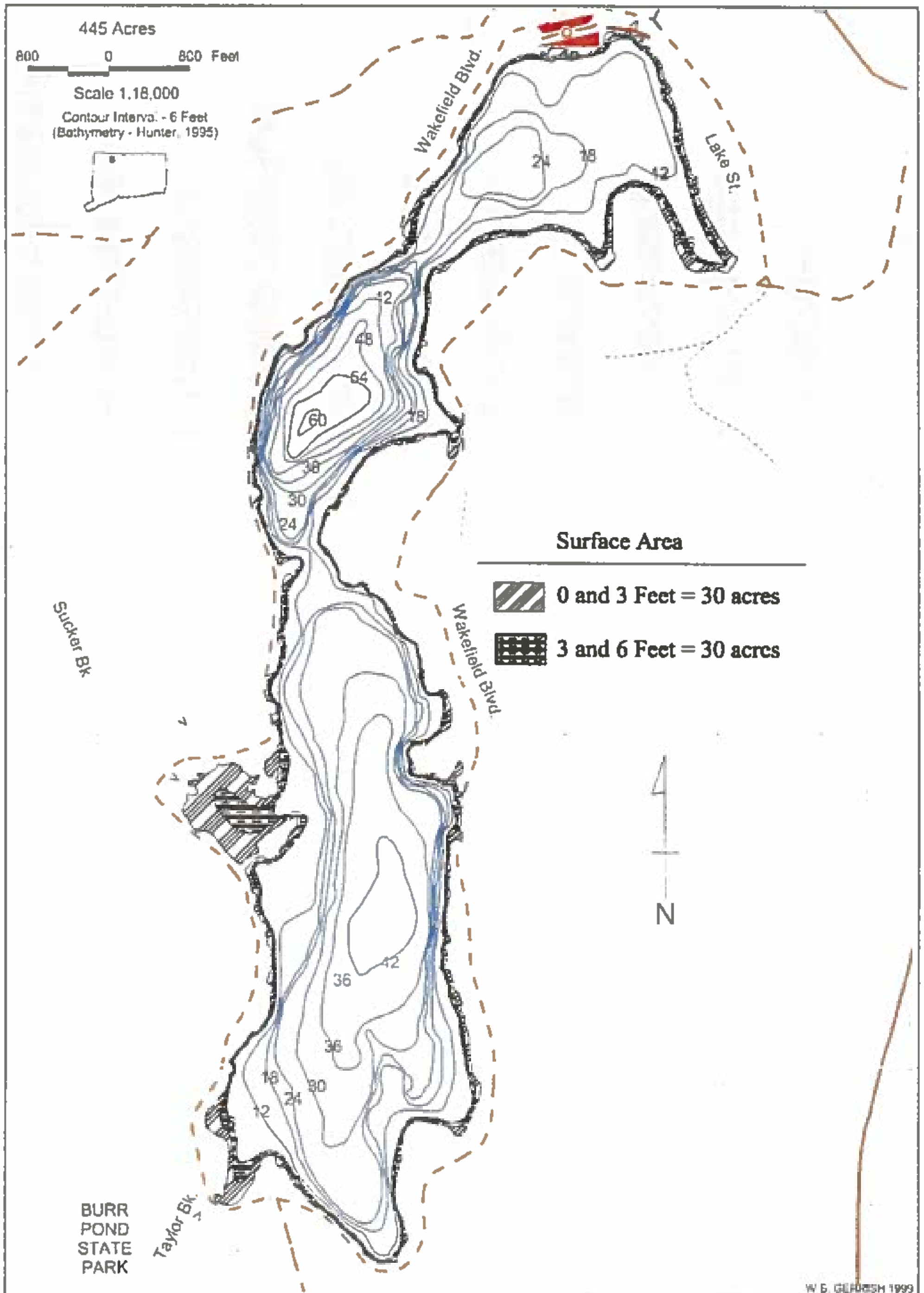
Depth In Feet	Surface Area At Depth Acres	Area within 1 Foot Increments in Acres	Cumulative Exposed Area in Acres
0	446		
1	438	8	8
2	427	11	19
3	416	11	30
4	409	7	37
5	398	11	48
6	387	11	59
7	375	12	71
8	361	14	85
9	350	11	96
10	337	13	109
11	321	16	125
12	309	12	137

[2] Jacobs and O'Donnell, 2002

Figure 16– Surface area of each 1 foot depth interval



Map 1 – Bathymetric map of Highland Lake (areas between 0 – 3ft and 3 – 6ft shaded)



Highland Lake, Winchester, CT	Depth Contours in Feet Showing shallow and deep exposure areas	Contour Map From CT DEP Jacobs and O'Donnell 2002

Exposure duration

The winter water level drawdown at Highland Lake exposes lake bottom sediments of different depths for varying periods of time. Each winter, the lake is lowered at least 36 inches (**Table 7** and **Figure 17**) exposing lake sediments between 0 and 2 feet of water depth for an average of 171 days each winter. The shallowest sediments, adjacent to shore, are exposed for the longest duration while, the deepest sediments at 96 inches for the shortest. The duration of exposure for each one-foot depth is shown in **Table 7**

Table 7- Days of exposure during drawdowns at Highland Lake

Depth (ft.)	1	2	3	3.5	4	5	6	7	8
Acres =>	9	19	30		37	48	59	71	85
2014	206	195	179		99	80	62	41	6
2013	168	154	140		59	0			
2012	186	158	140	2	0				
2011	186	147	102	4	0				
2010	183	177	161	44	36	22	0		
2009	151	144	132		119	99	79	68	2
2008	155	147	134	9	0				
Average =>	176	160	141	15	45	50	47	55	4
2007	177	159	100	13					
2006	172	160	145		127	99	65	34	1
2005	173	156	78	2					
2004	169	147	129	10					
2003	182	170	151		138	127	95	55	5
2002	164*	159	125	0					
2000	172	166	126	11					
	174	160	122	7	133	113	80	45	3

Duration of Exposure

The mean exposure time for 0-1 and 0-2 foot depth increments has been similar throughout the period examined 2000-2014. Trends in **Figure 17** and **Figure 18** show that the days of exposure of the 0-1ft and 0-2ft depth increment are nearly the same during both shallow and deep drawdowns (171-shallow and 185 days-deep). Shoreline between 2 and 3 feet deep is exposed for less than 150 days during a shallow drawdown but between 145 and 180 days during a deep drawdown. Shoreline deeper than 36 inches was exposed infrequently. Data from the four deep drawdowns shown in **Figure 18** indicate a linear decrease in duration between 4 and 8 feet, from 150 days at 4 feet, to about 2 days at 8 feet.

Figure 17- Duration (days) of exposure at each depth during shallow drawdown

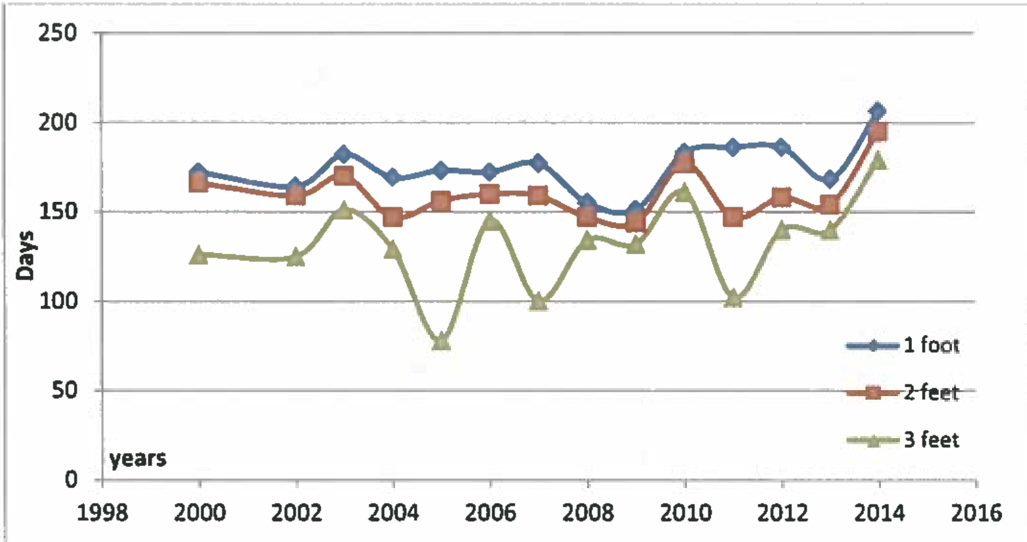
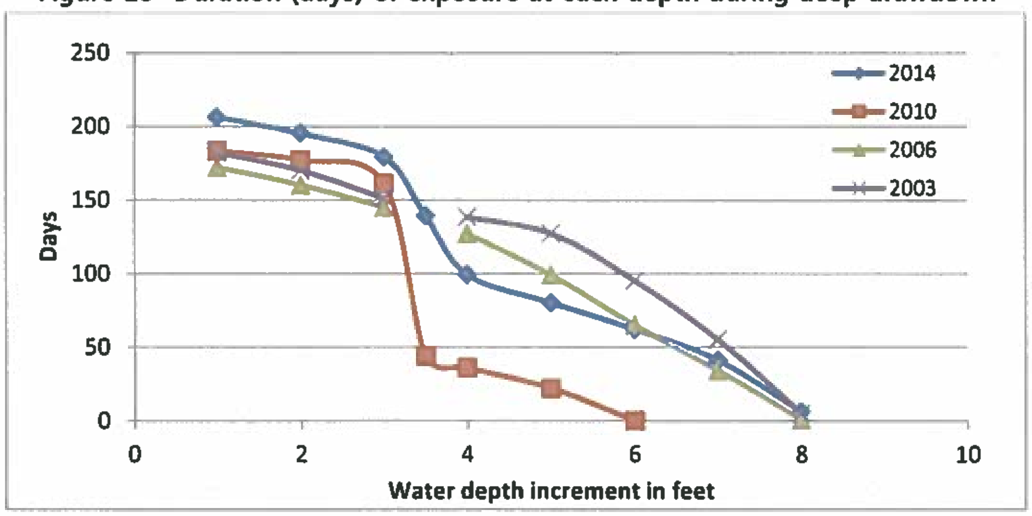


Figure 18- Duration (days) of exposure at each depth during deep drawdown



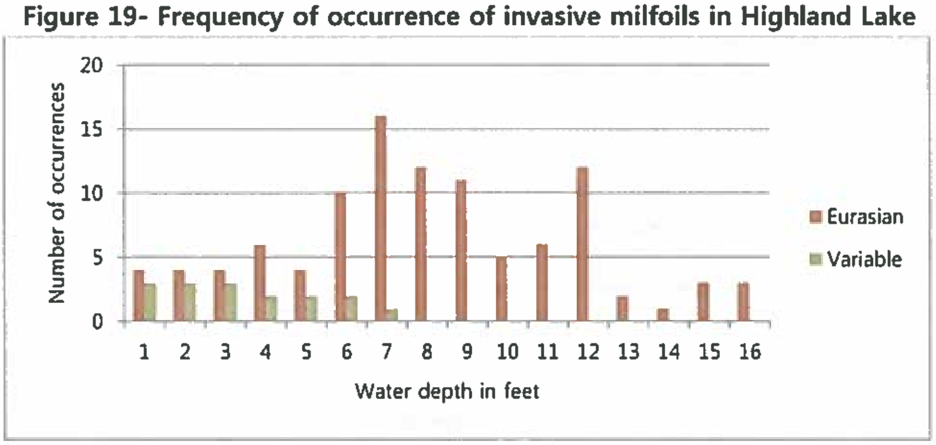
Aquatic Plants

Northeast Aquatic Research surveyed the distribution and abundance of aquatic plants in Highland Lake during the fall of 2015 and summer of 2016. Prior to these two surveys, NEAR's last survey of aquatic plants in Highland Lake was in 2009. We are not aware of other aquatic plant surveys having been conducted at Highland Lake between 2009 and 2015, and would be interested in adding any other survey results to our master list of plant distribution and abundance. Based on our survey data the following observations stand out regarding the invasive milfoils and native species.

Invasive Milfoils

- Eurasian and Variable-leaf milfoil occupy somewhat different water depth ranges (**Figure 19**). Variable-leaved milfoil inhabits shallow water from the shore to 7 feet, Eurasian milfoil is also present at the shore at about the same frequency, but it becomes more prevalent in water deeper than 5 feet. The highest frequency of Eurasian milfoil is in 7-12 feet of water, with deepest water observation at 16 feet.
- Low frequency of occurrence of Eurasian milfoil in shallow water 0-3ft is most likely due to annual drawdown and long duration of bottom sediment exposure.
- Significant quantities of Eurasian milfoil were found in water of 6-8ft. The deep drawdown of 96" shows little control of milfoil in that depth range.
- Eurasian milfoil growing in water deeper than 8 feet will be unaffected by a 96 inch drawdown.
- Higher frequency of occurrence of Eurasian milfoil at 6-9 feet suggests that is optimal depth range in Highland Lake.
- Presence of variable-leaf milfoil between the shore and 36" suggests this species is established in refuge areas that provide resistance to effects of drawdown.

Figure 19- Frequency of occurrence of invasive milfoils in Highland Lake



Native Species

- Twenty-six species of aquatic plants were noted in Highland Lake during our 2016 plant survey.
- Two protected species were not reported during either 2015 or 2016. These plants should be searched for in 2017.
- Floating-leaved plants were scarce and limited to single locations-reported at 1, or less than 1% occurrence.
- Species diversity was moderate across a wide range of water depths including the shallow exposed zone (**Figure 20**). Presence of aquatic plants in the exposed area indicates that some species exhibit good regrowth after the long exposure period. Because this area is exposed each winter for about 4 months per year, species selection pressures could be very high and would favor species that can withstand the freezing and desiccation as well as species that are limited to refuge areas sustained by winter inflows or subtle grade of the exposed lake bed that limits drying.
- Aquatic plant percent cover, an estimate of abundance, appears greatest in water depths between 8 and 12 feet (**Figure 21**), suggesting that although plants are present in the shallow drawdown depths (to 36") they are not abundant there. Full growth and/or maturity for some species may be limited to deeper water not affected by drawdown.
- Aquatic plants were found to a depth of 18.5 feet in Highland Lake during 2015 and 2016 surveys.
- Number and presence of species has not appreciably changed between 2009 and 2016, with a few more species found in 2016 than in 2009, and a few species not found in 2016 that were recorded in 2009 (**Table 8**).

Figure 20- Number of species found at depth

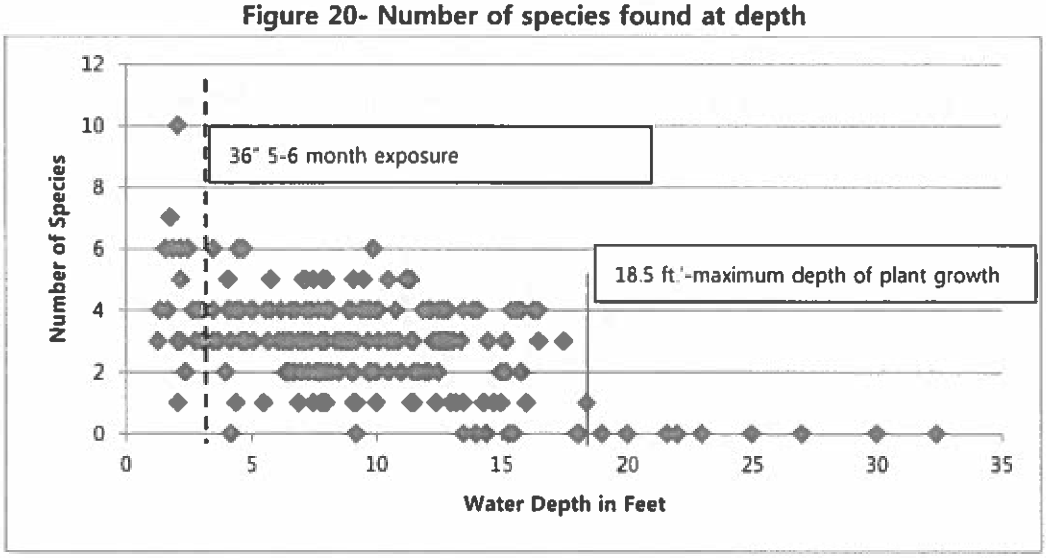


Figure 21- Average percent cover of aquatic plants at depth

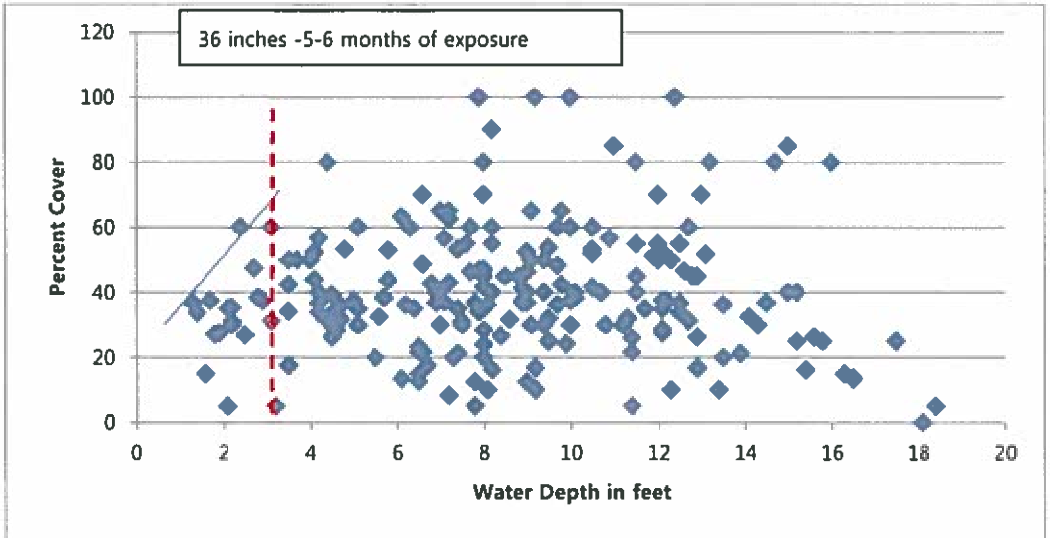


Table 8- Aquatic plants found by NEAR in Highland Lake

Bold Red are invasive species, bold green protected species

Species name	2016	2015	2009
Floating-leafed / Semi-Emergent species			
Creeping primrose	<1	~	~
Floating-leaf bur-reed	~	<1	~
Yellow Water lily	1	1	<1
Small, shallow water plants			
Waterwort	~	~	3
Tiny submersed spike-rush	1	1	4
Submersed arrowhead	6	3	~
Aquatic moss	1	1	<1
Qwillwort	<1	~	~
Large, deeper water, plants			
Southern naiad	42	52	38
Tape-grass	35	45	44
Stornwort (macro-alga)	27	32	17
Berchtold's pondweedi	24	89	<1
Large-leaf pondweed	23	13	17
Water naiad	16	6	3
Muskgrass (macro-alga)	11	4	13
Clasping-leaf pondweed	10	13	5
Eurasian milfoil	**6**	**46**	**1**
Coontail	6	6	<1
Berchtold's pondweed (gemmiparus)	~	~	**3**

Variable-leaf milfoil	**4**	**7**	**3**
Spiny naiad	**3**	**5**	**<1**
Filamentous algae	3	5	9
Common water elodea	2	5	~
Creeping bladderwort	2	8	<1
Ribbon-leaf pondweed	1	~	7
Robbin's pondweed	<1	1	~
Spiral-fruited pondweed	<1	~	2
Floating bladderwort	<1	4	<1
Snail-seed pondweed	~	<1	~
Twin-stemmed bladderwort	~	9	3
Purple bladderwort	~	1	~
Vasey's pondweed	**~**	**~**	**4**
Total species (invasives)	**26 (3)**	**24 (3)**	**23 (3)**

Water Quality Assessment

Water Quality Defined

Water quality of lakes is an elusive term that can mean different things to different people in different locations and situations, but typically for freshwater lakes refers to water clarity. Water clarity as measured by the Secchi disk is an indicator or the quantity of algae[3] growing in the lake. In most cases[4] the quantity of phytoplankton (algae) growing in the lake has been shown to be proportional to phosphorus concentration. Since algae are generally the cause of poor water clarity and the level of nutrients determines the level of growth of algae, the principal parameters of lake water quality are water clarity, phosphorus, and nitrogen.

Lake Trophic State is essentially a ranking of how much plant growth (mostly as algae) is occurring in a lake. Two broad categories have been used to group lakes that are very clear and very turbid. The clear lakes are known as Oligotrophic, while the turbid lakes are known as Eutrophic. The difference between the clear and turbid lakes is about 30 ppb of phosphorus. The term, Cultural Eutrophication, refers to the human induced increases in nutrient runoff to lakes that trigger and sustain higher productivity of algae in lakes.

CT DEEP Lake Trophic Categories

Using the quantity of phosphorus and resulting plankton and water clarity conditions, CT DEEP (1982) grouped lakes into 6 different lake trophic categories (**Table 9**). The Lake Trophic Categories[5] numbered 1-6 in this report, show lake characterization by quantity of phosphorus and resulting plankton growth. At the lowest trophic category 1, phosphorus is almost too low to measure, plankton too low to find easily, and cyanobacteria virtually nonexistent. At the highest trophic category 6, phosphorus is very high and plankton is exclusively cyanobacteria that form dense blooms all summer with scums on shore.

In 1982, CT DEEP classified Highland Lake as Oligotrophic based on data collected in 1979. Summer water clarity in 1979 was 6 meters, surface water phosphorus was 5 ppb, total nitrogen was 200 ppb, and chlorophyll-*a* was 2 ppb. Recent information from the lake shows the lake to be Mesotrophic, with water clarity between 3-4 meters, and phosphorus between 10-20 ppb.

---

[3] Algae are microscopic free floating single celled plants that live in the water column

[4] In some cases sediment, iron, or other minerals can cause non-plankton turbidity

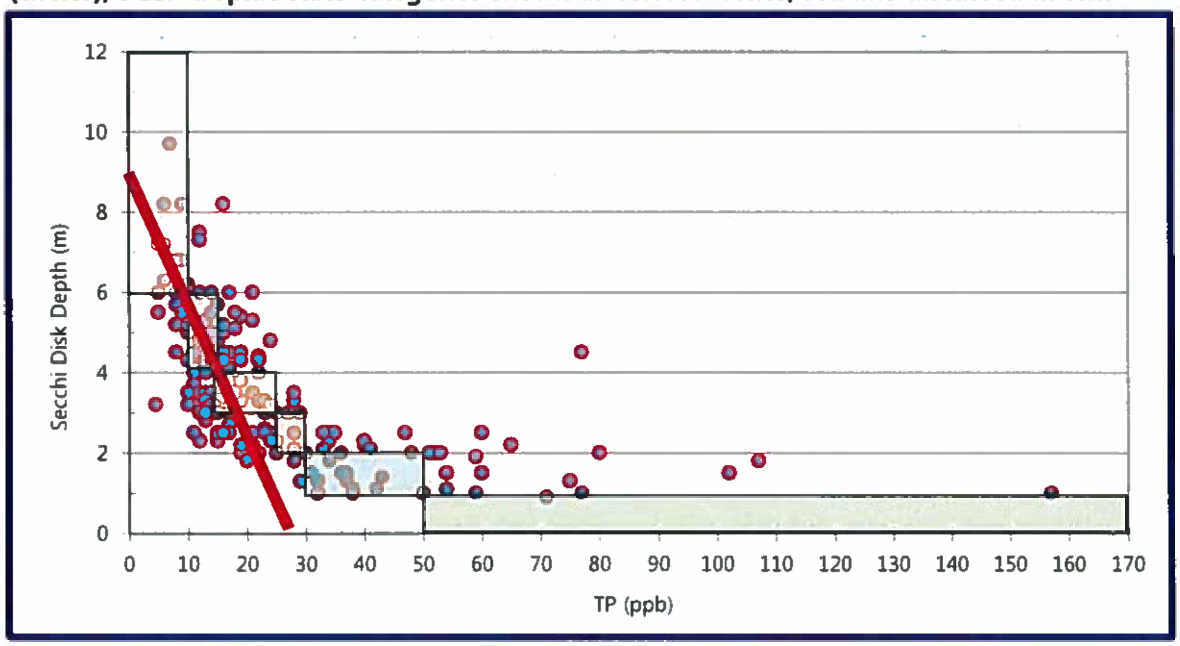
[5] Terms used interchangeably are Trophic-Level, Trophic-State, and Trophic-Status.

Table 9– CT DEEP lake trophic categories and defining ranges of indicator parameters

Trophic Category	Phosphorus (ppb)	Nitrogen (ppb)	Secchi Depth (meters)	Chlorophyll-*a* (ppb)
1-Oligotrophic	0 – 10	0 – 200	6 - 10	0 – 2
2-Oligo-mesotrophic	10 – 15	200 – 300	4 – 6	2 – 5
3- Mesotrophic	15 – 25	300 – 500	3 – 4	5 – 10
4- Meso-eutrophic	25 – 30	500 – 600	2 – 3	10 – 15
5- Eutrophic	30 – 50	600 – 1,000	1 – 2	15 – 30
6- Highly Eutrophic	50 +	1,000 +	0 – 1	30 - 50

The relationship between increasing phosphorus and declining clarity in a widespread sampling of Connecticut lakes conducted in the 1970's is shown in **Figure 22**. Three important aspects of the relationship are critical to the monitoring, preservation, and protection of Oligotrophic lakes such as Highland Lake, are elaborated below.

Figure 22 = Paired total phosphorus and Secchi depth data for CT lakes in 1970's (circles), DEEP trophic state categories shown as colored boxes, red line discussed in text



1) There is a very rapid, linear decrease in water clarity as phosphorus increases from zero to about 20ppb (red line in **Figure 22**).
    a. With very low phosphorus (<5ppb) water clarity can be 10m or more (light blue rectangle).
    b. With each increase of 5ppb phosphorus, the water clarity declines by about a meter, continuing until phosphorus reaches about 20ppb and water clarity averages 3m. Further increases in phosphorus cause water clarity to decline at a slower rate eventually leveling off at around 1.5 meters clarity when phosphorus is >30ppb.
2) When phosphorus is less than 20ppb, water clarity readings can vary considerably with the same phosphorus concentration.
    a. This means that although increases in phosphorus cause declines in clarity, trends are often not apparent due to large natural variability.
3) Phosphorus concentration can continue to increase past 30ppb with little further decline in clarity.
    a. With phosphorus concentrations >30ppb, water clarity remains between zero and 2m.
    b. Once phytoplankton reach growth rates of a full bloom (water clarity of about 1 meter) their numbers cause shading to those below causing general light limitation to the population but cause very high rates of dissolved oxygen loss.
    c. However, reclaiming lakes that have more than 30ppb phosphorus requires significant reductions before any increases in clarity can be realized.

Water quality monitoring protocol at Highland Lake

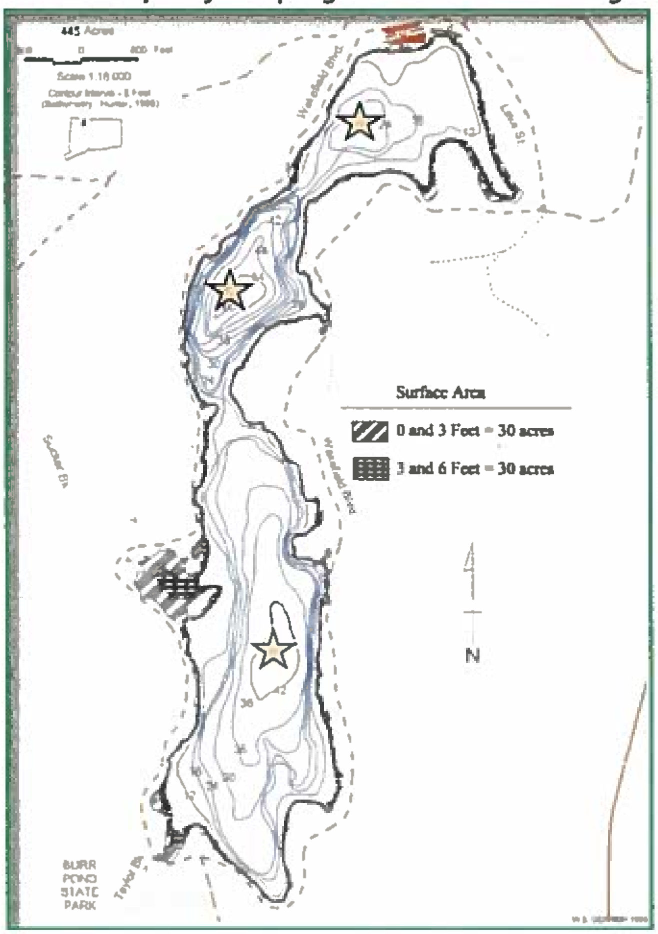
Water quality data at Highland Lake has been collected by residents each summer since 1998, with the exception of 2001. Typically, monitoring consisted of one or two sampling events each summer during the months of July, August, or September. In 2007, sampling frequency was increased to include monthly visits in April, May, June, October, and November. Water samples have been collected from three stations in the lake called; First (North) Bay, Second (Middle) Bay, and Third (South) Bay **Figure 23**.

At each station, three water samples are collected, one each from top, middle, and bottom depths. Top sample is always collected from 1 meter below the surface, the middle and bottom sample depths are collected from different depths due to varying total depths at each station (**Table 10**). At each station, water clarity, water temperature, and dissolved oxygen were measured at each meter depth increment from top to bottom.

Table 10– Water quality sampling depths in Highland Lake

Station	Middle sample depth -meters	Bottom sample depth -meters
First (north)	5	8
Second (middle)	7	17
Third (south)	7	12

Figure 23 = Water quality sampling stations—stars--in Highland Lake



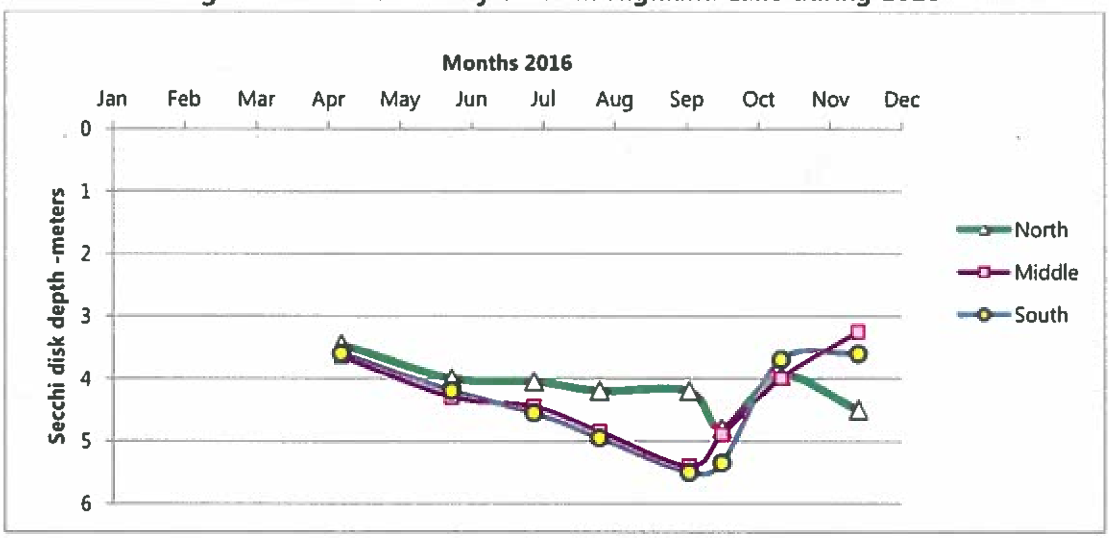
Water Quality Results

In this section, Highland Lake 2016 monitoring data results are discussed in the context of the long term data record and the DEEP water quality trophic categories listed above. The three parameters used to determine the trophic state at Highland Lake are water clarity, total phosphorus and total nitrogen. The fourth parameter, chlorophyll-*a*, has not been monitored.

Water clarity

Primary responsibility of a lake management program is tracking water clarity over time. Water clarity has been measured at several times each season at Highland Lake regularly since 1986, with a few readings made in 1979. In 2016, eight measurements were made between April and November (**Figure 24**). Chart shows clarity had seasonal variation from a low of 3.25 meters to a high of 5.5 meters at Second and Third Bay, but First Bay showed a lack of improvement, remaining at 4 meters during the season. Water clarity declined at all three stations between September and October with the three Bay's having differing conditions in November. The trend in clarity shown in **Figure 24** illustrates that the poorest clarity is in spring and fall, with best conditions in mid-summer. This pattern suggests watershed loading during wet months –October through May—is primary source of nutrients to the lake. The lack of clarity improvement in North Bay is probably due to storm water loading during the summer months. The smaller basin and shallower depths would mean lower capacity to absorb nutrient runoff during the summer. The maximum clarity was just shy of the 6 meter threshold for Oligotrophic lakes.

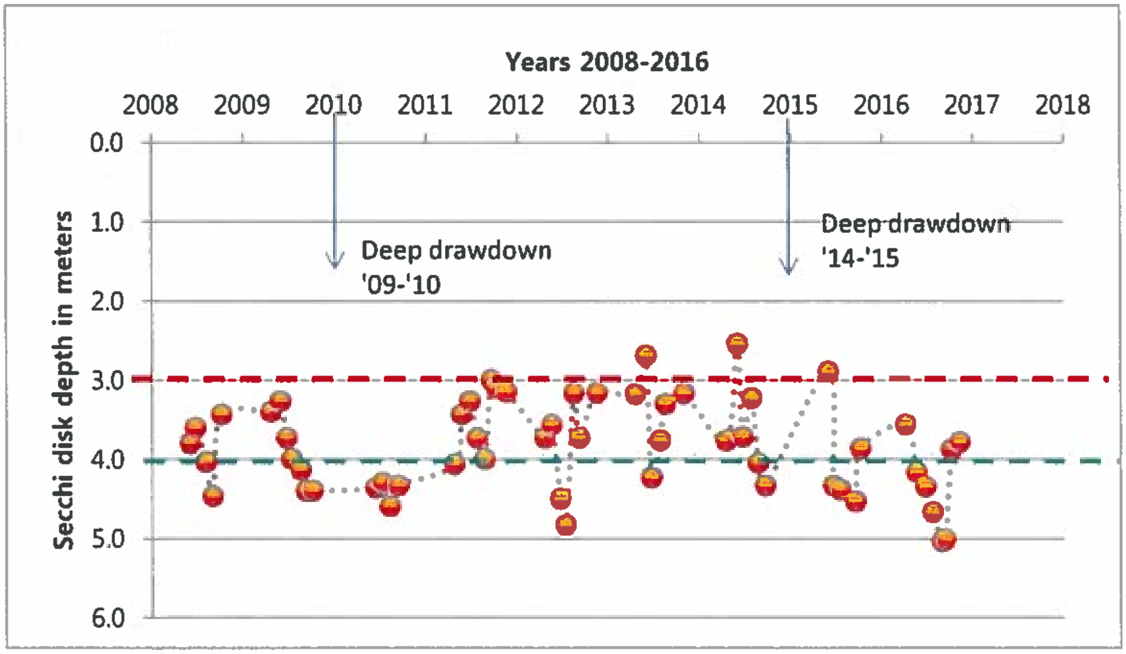
Figure 24 = Water clarity trend in Highland Lake during 2016



The range of water clarity readings during the study period 2008-2015 (drawdown evaluation) is shown in **Figure 25**. The chart shows averages of the three Bays during each monitoring visit. The measurements range between a low of 2.6 meters and a high of 5.0 meters. The bulk of the values are evenly split between 3-4 and 4-5 meters. Using ranges in **Table 9**, water clarity values between 3-4 meters means the lake is Mesotrophic, while values between 4-5 meters means better Meso-Oligotrophic conditions.

Water clarity appears to have been better after the deep drawdown of 2009-2010, as the 2010 clarity readings were above 4 meters all season. However, clarity was <4 throughout the 2011 season with some of the poorest recorded average values of 3.0 and 3.3 meters that summer. During the seasons of 2011-2014 most clarity readings were <4m. Beginning in 2015 most readings have exceeded 4m. Average water clarity readings of 5 meters occurred of the first time in summer of 2016.

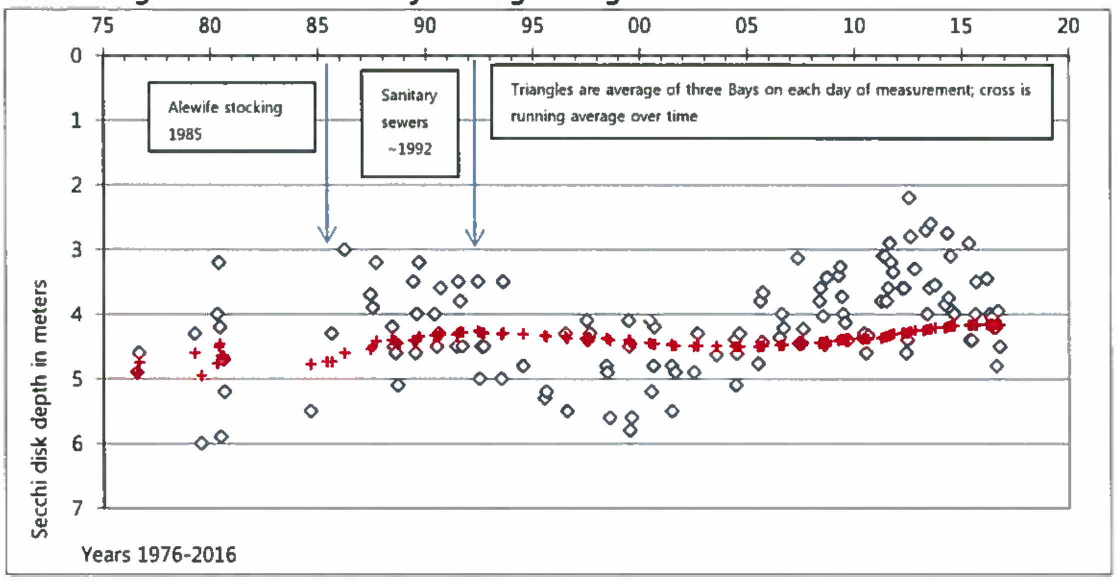
Figure 25 = Water clarity reading during drawdown study period 2008-2016, green line shows 4 meters, red line shows 3 meters



The full range of water clarity readings for Highland Lake is shown in **Figure 26**. Recorded data for the lake starts in 1976, and except for a few missing years in 1981-1983, has continued unbroken until today. Values range between a high of 6 meters (only one recorded value in 1979) to a low of 2.2 meters. The chart also shows the running average by red '+' marks. The long-term average clarity shows fluctuation between 4.7 and 4.1 meters, with poorest average values occurring in 2014 and 2015, due to the numerous readings of less than 3 meters between 2011 and 2015.

Water clarity readings made during the years 1976 and 1993 show a wide range between 3 and 6 meters (6 meter water clarity reading of 1976 has not been repeated since that time). During this time, readings of 4-5 are common and clarity values >5 meters are few with no readings less than 3 meters. Beginning in 1993 and continuing to 2004 water clarity was always better than 4 meters, with many readings >5m, although 6m was not attained. This second period appears to be coincident with the installation of the sanitary sewers around the lake. Beginning around 2005, clarity readings declined such that maximum clarity averaged between 3 and 4.5 meters, with several months having clarity between 2-3 meters.

Figure 26 = Water clarity readings in Highland Lake between 1976-2016

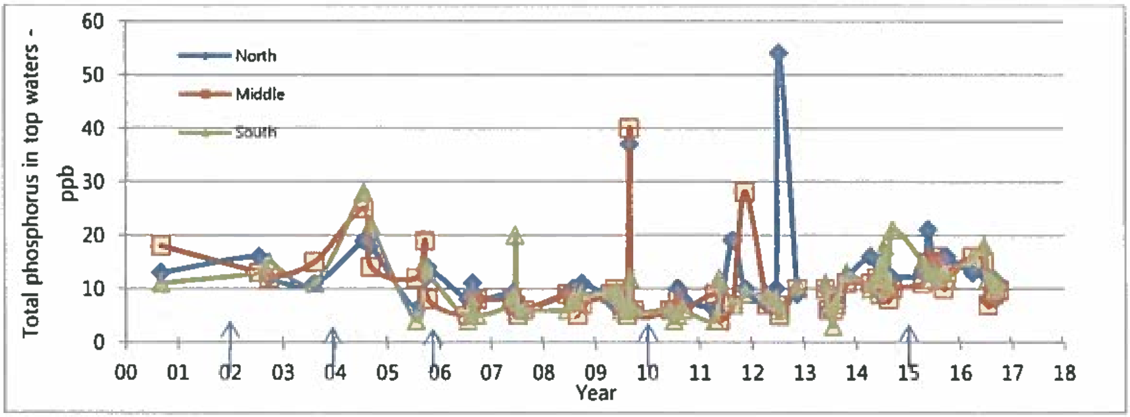


Total phosphorus

A second critical responsibility of a lake management program is tracking phosphorus concentration in a lake over time. Phosphorus gets into a lake from its drainage basin. Overtime, lake concentration increases causing a slow shift from Oligotrophic to Eutrophic conditions (10-30ppb).

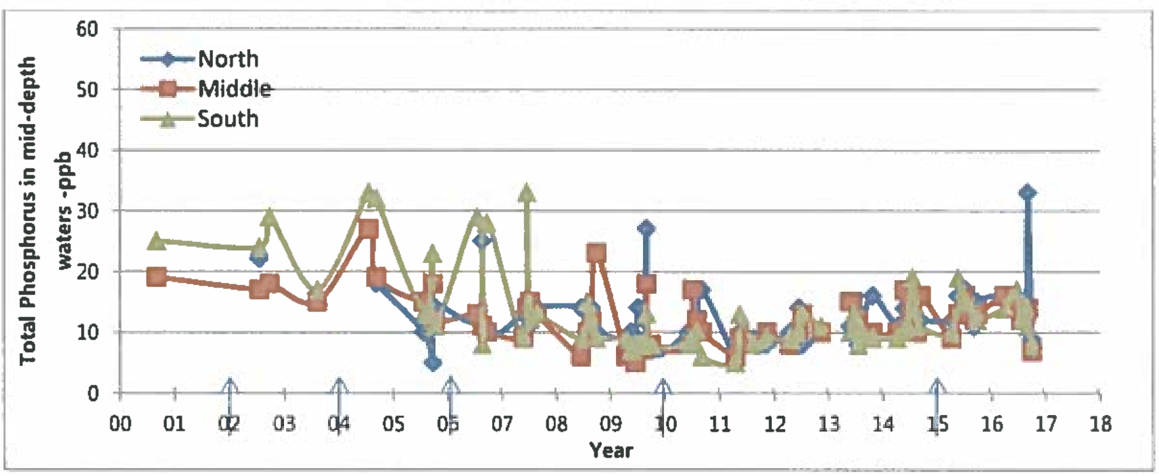
Total phosphorus seasonal monitoring started in 2000. Testing for total phosphorus at the three stations and three stratified depths per station has been continued almost unbroken to the end of the 2016 season (**Figure 27**). Limited testing was conducted in 1979 and 1993 from Middle Bay, with 8 total phosphorus results of between 7 and 19 ppb. Between 2000 and about 2004, phosphorus concentrations were between 10ppb and 20ppb. Between 2005 and 2012 phosphorus was rarely higher than 10pbb. Beginning in 2013, phosphorus has been higher in both the surface and mid-depth samples, ranging between 10ppb and 20ppb **(Figure 27)**. However, phosphorus data from 2016 showed the lowest values since at least 2013, reminiscent of 2005-2012 levels. Arrows show winters of deep drawdowns, some with spikes of phosphorus the following summer. However, increased phosphorus during summer months occurs regularly, and it would be inaccurate to make an association solely with deep drawdowns.

Figure 27 = Trend in phosphorus concentration at 1 meter in Highland Lake between 2000 and 2016



The trend in mid-depth phosphorus is shown in **Figure 28**. The mid-depth phosphorus shows a general declining trend between 2000 and 2008 from about 22ppb to 6ppb. Since that time, phosphorus in mid-depth water has increased to now be >10ppb. Phosphorus in South Bay was between 20-33ppb during summers following the successive 2 year apart deep drawdowns between 2001 and 2006. After lengthening frequency to 4-5 years between deep drawdowns the phosphorus in South Bay has remained below 20ppb.

Figure 28 = Trend in phosphorus concentration at mid-depth in Highland Lake between 2000 and 2016



Bottom water phosphorus concentration results for Highland Lake are demonstrated in **Figure 29** and are usually associated with the loss of dissolved oxygen and demineralization of dead algae falling from above and releases from bottom sediments. Trend in bottom phosphorous over time shows little association with the deep drawdowns, but seasonal maximum concentration shows a steady increase in Middle Bay (**Figure 30**), with maximum concentrations now always >50ppb with several values >100ppb.

Figure 29 = Trend in phosphorus concentration in bottom water at each station between 2000 and 2016

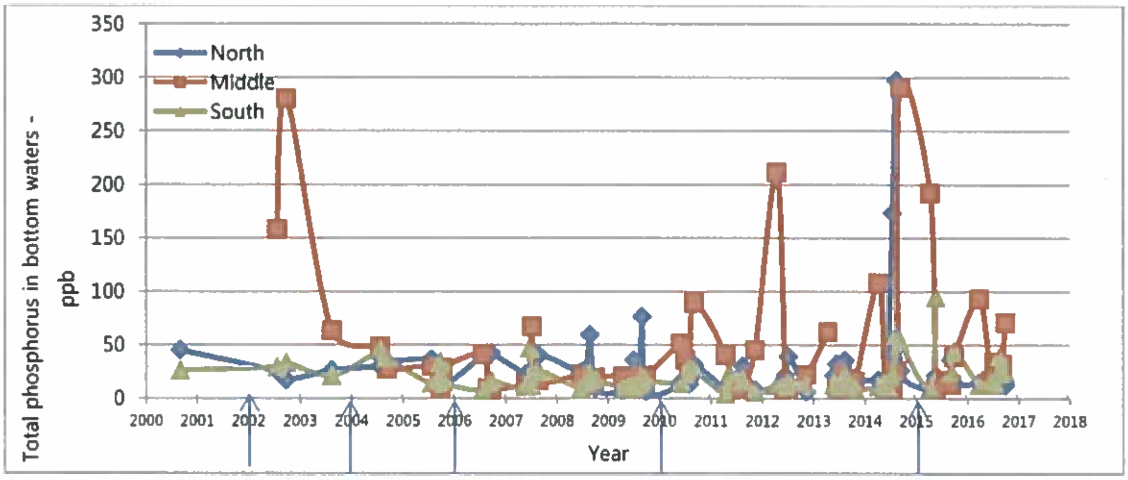
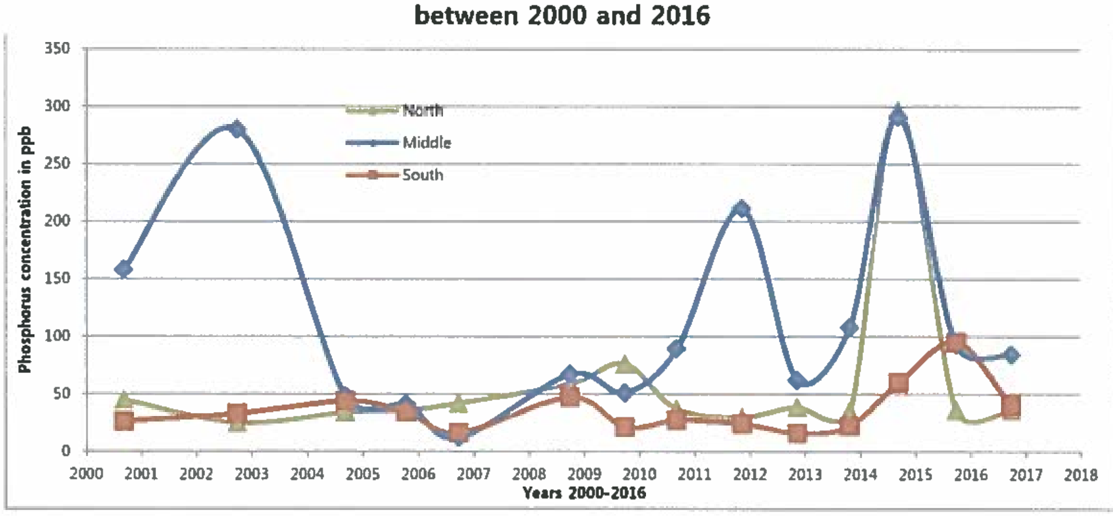


Figure 30 = Annual maximum phosphorus concentration in bottom water at each station between 2000 and 2016



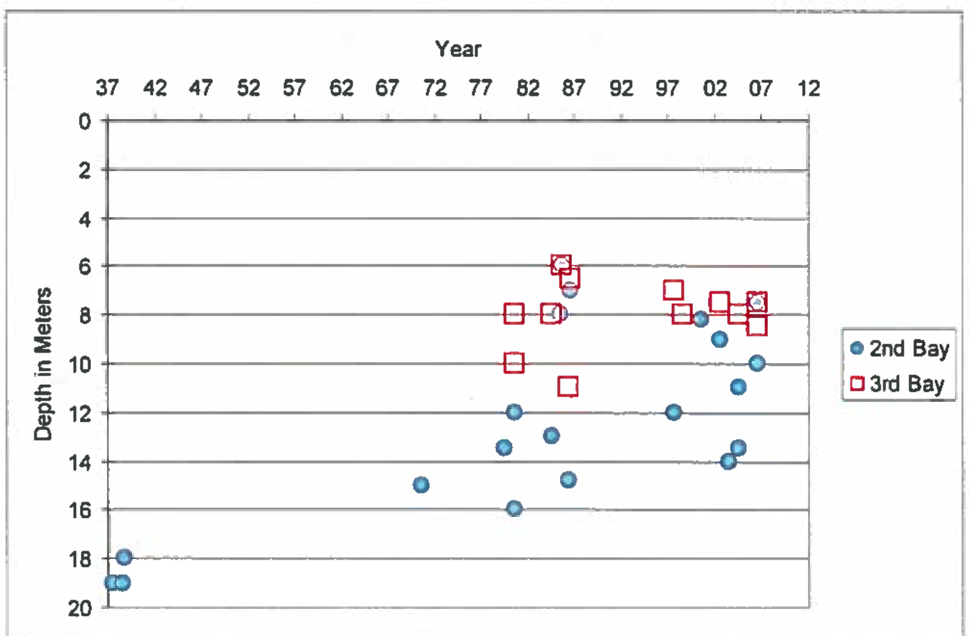
Dissolved oxygen

When lakes become enriched with nutrients and experience high algae growth rates, dead algae sink to the bottom where they are decomposed a process that consumes dissolved oxygen. The loss of dissolved oxygen in the bottom water of Highland Lake was documented in the prior drawdown report (2009). Historic values for anoxic boundary[6] (**Figure 31**) show that very old readings detected little anoxic water in the lake, but by 1980's boundaries commonly reached 8 meters in Middle and South Bays.

Anoxic boundary trends between 2008 and 2016 (**Figure 32**) show a regular seasonal loss of dissolved oxygen in each basin. Data show that anoxic water reaches 6 meters each season in North Bay but about 8 meters in Middle and South Bays. Higher volumes of anoxic water in North Bay are probably a function of its shallower depths and smaller volume.

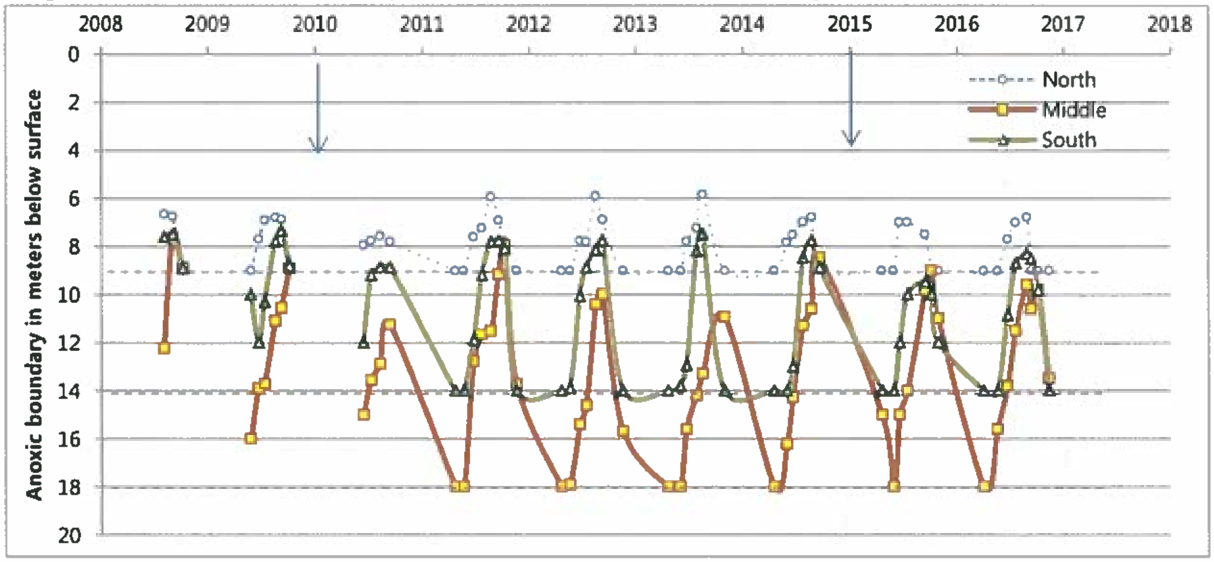
The data suggest a subsidence of anoxic water by about 1 meter in First Bay and possibly Third Bay. Middle Bay, however, shows a wide fluctuation in anoxic boundary from year to year, from a high of 8 meters to a low of 11.25 meters.

Figure 31 = Annual maximum ascent depths of anoxic bottom water in Highland Lake 1937-2007



[6] Anoxic boundary is measured down from the surface

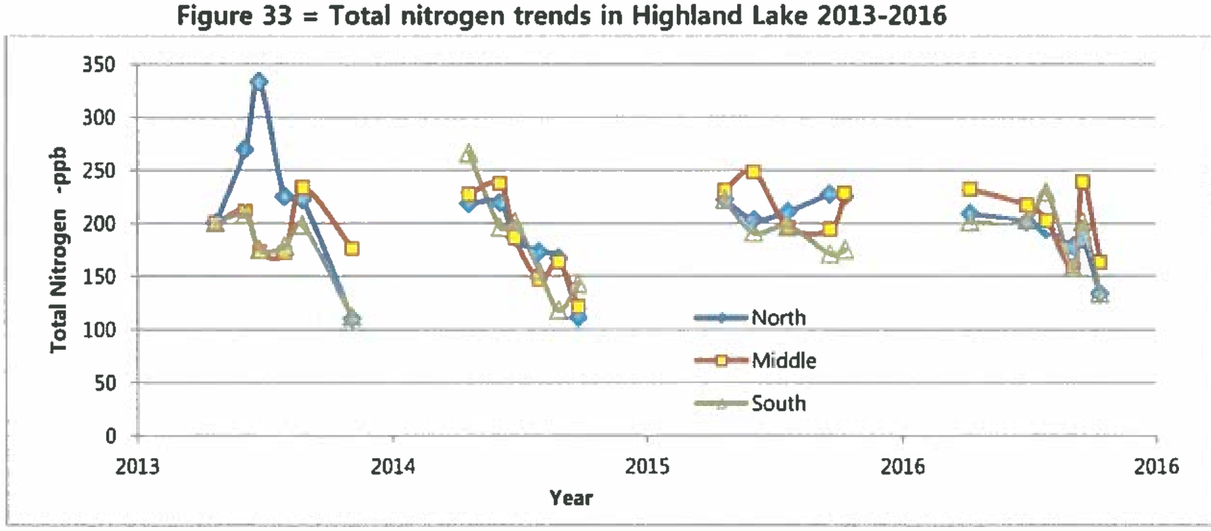
Figure 32 = Annual ascent depths of anoxic bottom water in Highland Lake 2008-2016



Nitrogen

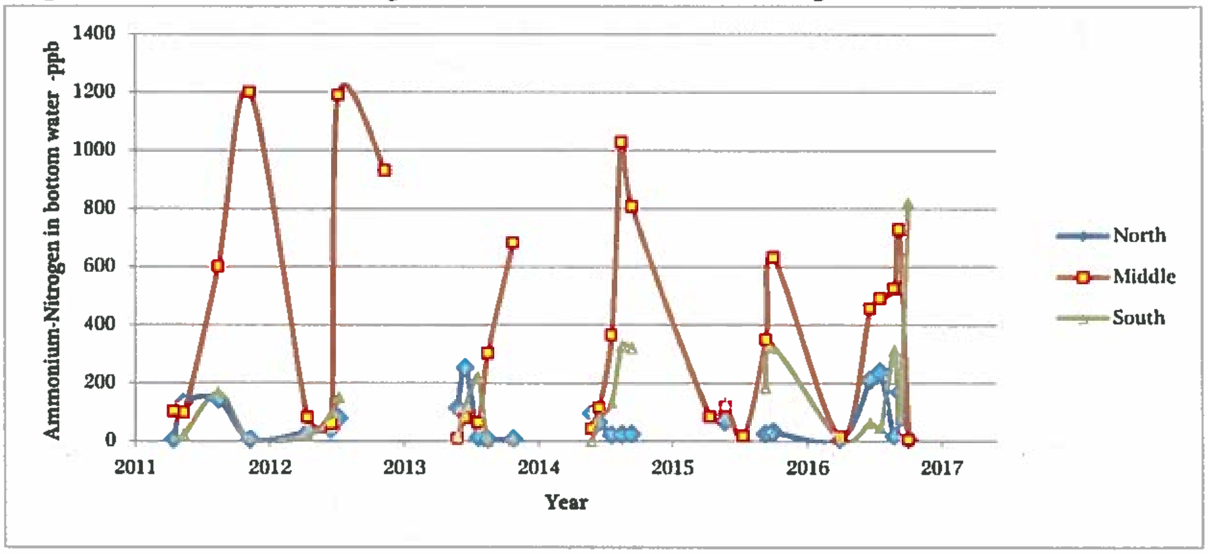
Total nitrogen is the second important algae-growth nutrient in lakes. Nitrogen occurs in different forms in lake water due to biological activity. Using the ranges shown in **Table 9,** total nitrogen in the lake has remained at low (mostly Oligotrophic), levels for the last five years, varying between 100-250 ppb (**Figure 33**). The trends shown in **Figure 31** illustrate that each season total nitrogen decreases from early spring higher values to fall lower values. This suggests that nitrogen in Highland Lake is primarily from watershed origin, entering the lake via runoff during the winter and spring months.

Figure 33 = Total nitrogen trends in Highland Lake 2013-2016



When bottom water is devoid of dissolved oxygen, nitrogen as ammonium will accumulate due to the leaching from anoxic sediments. Tracking the quantity of ammonium present in deep water gives an indication of the degree of anaerobic respiration and helps quantify the magnitude of the oxygen loss. The ammonium concentration from bottom water at each station is shown in **Figure 34**. Annual ammonium accumulation in Middle Bay has been large but not extreme as would be expected from such a deep site of the lake. The other stations showed only minor amounts of ammonium accumulations in bottom waters.

Figure 34 = Ammonium nitrogen trends in bottom waters of Highland Lake 2013-2016



Water Quality Conclusions

In 1982, DEEP classified Highland Lake as Oligotrophic due to results from sampling conducted in the late 1970's. Now 40 years later, the water quality has declined only slightly. Although no water clarity readings of 6 meters have been made at the lake since 1979, clarity is still good. In most years water clarity ranges between 3 and 5 meters. For a few years, 2011-2015, clarity readings dipped below the 3 meter threshold for Meso-Eutrophic lakes. Phosphorus in the upper waters has remained largely within the same bracket of values obtained in 1979 of 5-19ppb. For many years phosphorus was between 5-10ppb, but readings has recently been creeping up to where phosphorus values are now commonly between 10-20ppb and sometime exceed 20ppb. Phosphorus in the bottom waters may be higher than in 1970's but there is only one value from that time to compare with. Phosphorus at the bottom of Middle Bay now regularly exceeds 20ppb and has reached as high as 300 ppb. Total nitrogen data is less extensive as the clarity and phosphorus data but has shown consistently low levels.