Evaluation of the Effects of Winter Water Level Drawdown on the Ecology of Candlewood Lake, CT

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Town of New Fairfield
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Executive Summary

The Town of New Fairfield retained Northeast Aquatic Research to review available data in an effort to determine if winter drawdown has caused ecological harm to the Candlewood Lake. This report summarizes available information on aspects of lake ecology and winter water level drawdown as an invasive aquatic plant control method.

Northeast Aquatic Research (NEAR) looked for possible long-term trends in available data records for:

- water levels
- nutrient concentrations
- water clarity readings
- fisheries census numbers
- aquatic plant mapping results
- weather records

No new field data was collected as part of this study.

Analysis of Candlewood Lake ecological data shows deteriorating conditions since monitoring began in the early 1970's. Two sets of data available for review, 1973-1974 and 1984-2010, showed changes in three aspects of water quality.

- Water clarity has declined. Initial measurements collected in 1974 showed clarity to be 18 feet (5.5 meters). Measurements made during the last 10 years (2000 – 2010), show the clarity averaged 7.5 feet (2.3 meters) -- a 58% decrease.
- Dissolved oxygen is lost regularly below 7 meters during summer months. In some years 46% of the total lake volume is devoid of dissolved oxygen, while other years only 20% of the volume is without oxygen. A large annual variation of summer anoxia indicates year-to-year differences in loading of biological and chemical oxygen demand materials to bottom waters.
- Lake water phosphorus concentrations:
  - Are higher now than in 1973-74, and
  - Tend to be higher after deep drawdowns.
- Native aquatic plant species are rare to very rare in Candlewood Lake.

General Findings

1. Candlewood Lake has a surface area of 5,237 acres, with mean and maximum depths of 31 and 85 feet, respectively.
   - Water depths deeper than 55 feet occur in 1% of the lake area, located in the northeast (New Milford) arm.

2. Candlewood Lake has a shoreline length of 62 miles, including the shorelines of the largest islands. The two largest islands each have shorelines of about 1.5 miles; remaining islands collectively have less than 2 miles of shoreline.

3. Candlewood Lake is owned by a power utility, currently: FirstLight Hydro Generation Company, a subsidiary of GDF Suez Energy Generation North America, Inc.

- The lake is managed as a pump storage hydroelectric development through license by the Federal Energy Regulation Commission (FERC).
- Water-level elevation data for Candlewood Lake has been reported in two ways.
    - National Geodetic Vertical Datum (NGVD) used by Federal Energy Regulation Commission, and
    - Connecticut Light and Power Datum (CL&P) used by the utility. NGVD is converted to CL&P by adding 1.9 feet.
- All water levels reported in this report are in CL&P datum units unless specifically noted.

4. In 2004, Federal Energy Regulation Commission set two operating water levels for Candlewood Lake.
    - A summer level to remain between 427 and 429.5 ft. CL&P between Memorial Day and October 15, and
    - A winter level which can be anywhere between 425.9 and 417.9 ft. CL&P between October 15, and Memorial Day.
5. This report uses 428 ft. CL&P to represent normal summer level.

6. Winter water level drawdown has been used as a weed control strategy since 1983 when Eurasian Milfoil (<u>Myriophyllum spicatum),</u> a non-native invasive aquatic plant, was found to have infested the lake. Winter drawdowns have alternated between:
    - A shallow drawdown level -- between 4 and 8 feet below normal summer level, and,
    - A deep drawdown level -- between 8 and 10 feet below normal summer level.
    - Twenty-six annual winter water level drawdowns, thirteen deep and thirteen shallow, have been conducted since initial weed control drawdown during the winter of 1984/5.

Water Levels

7. The winter drawdown depth can be anywhere between 425.9 and 417.9 ft. CL&P -- that is, 2.1 to 10.1 feet below the normal summer level. Specific winter targets are determined by the utility in consultation with a Technical Advisory Committee comprised of representatives from the power utility, Connecticut Department of Energy and Environmental Protection, the U.S. Department of the Interior, and the Candlewood Lake Authority.

8. Deep drawdown level averaged 9.5 (range 8.2 – 10.7) feet below normal summer level, while shallow drawdowns averaged 6.1 (range 4.3 – 7.98) feet below the normal summer level. Ranges nearly overlap, indicating some drawdowns are difficult to categorize as deep or shallow.

9. Candlewood Lake basin shows a consistent increase of 50 acres of exposed shore with each additional 1 foot of water level decrease. This linear rate of increasing exposed surface area with depth holds to about 25 feet water depth.

- The linear change in surface area with drawdown depth allows exposed shore areas to be accurately estimated for each drawdown.
- Deep drawdown exposes about 463 acres (399 to 522 acres) of shore.
- Shallow drawdowns expose about 290 acres (205 and 387 acres) of shore.
- Approximately 205 acres are exposed during each drawdown, about 4.3 feet below normal summer level.
- Theoretical maximum exposure area, when the lake is at 417.9 ft. CL&P is 494 acres.

Specific Findings

Aquatic Plants

10. Aquatic plants in Candlewood Lake were first surveyed by CT DEEP during the summers of 1979 – 1982.

11. Recent surveys have been conducted by Connecticut Agricultural Experiment Station (CAES). CAES surveys have been conducted during six summers (2005, 2006, 2007, 2008, 2009, 2010) although results from 2005 and 2006 are often combined.
    - CAES report Eurasian milfoil coverage varies between a low of 221 acres and a high of 461 acres.
    - CAES found milfoil grows out to a maximum water depth of 15 feet, outer boundary of the littoral zone -- the part of the lake that can support plant growth.
    - The area of the lake to 15 feet of water depth is 753 acres.
    - CAES mapping estimates milfoil covers between 29% and 61% of the lake's littoral zone.
    - CAES mapping show milfoil beds extend along about 86% of the shoreline -- about 54 miles.

12. Native aquatic plants species are scarce in Candlewood Lake.
    - CT DEEP surveys of 1979-1982 found 8 native species; 5 of these have not been observed since that time.
    - CAES 2005 survey found 14 species of native submersed aquatic plants; none were common.
    - Recent (2009 and 2010) CAES surveys have found only 6 species of native submersed aquatic plants, with none common.
    - Species of floating-leaved and emergent plants species, both indicators of intact shoreline habitats, are very scarce indicating these habitats are rare in the lake.

Contiguous Wetlands

13. Wetlands contiguous to the shoreline of Candlewood Lake are naturally scarce. Only 14 sites where wetland soils were contiguous with the shoreline were found using USDA Web Soil. Thirteen of these are probably associated with stream channels on steep terrain. There are 2,281 linear feet of shoreline (about 0.7% of the total lake shore) with contiguous wetlands.

Water Clarity

14. Water clarity in Candlewood Lake has been consistently monitored at 4 stations by CLA since 1985.
15. Historical data exists from tests conducted by CAES in 1973-74.
16. Water clarity has decreased from an average of 5.7 meters in 1973-74 to an average of 2.3 meters between 2000 and 2010.
    - A change from 5.7 to 2.3 meters of water clarity represents a striking decline from very good to poor clarity.
    - Very poor clarity readings, less than 2 meters, now occur each season.
    - No differences in clarity after deep or shallow drawdowns could be identified.
    - Further declines in clarity will lead to dominance by blue-green algae and sustained periods of bloom conditions.

Dissolved Oxygen

17. Dissolved oxygen was found to be depleted in bottom waters during the summer.
    - The anoxic boundary ascends up into the water column beginning in May.
    - Measured down from the surface, the minimum depth reached by the anoxic boundary has varied between 10.7 meters and 5.9 meters. This is a large difference, representing the consumption of an additional 720,000 kg of O_2.
    - There does not appear to be a trend toward worsening oxygen conditions in the lake.
    - However, the large range in boundary position from year to year suggests an intermittent loading of oxygen demand material to the bottom of the lake.

Lake Mixing

18. A strong thermocline develops in May at a depth of 5 meters.
    - The thermocline is the boundary between warm water near the surface and cold water at the bottom.
    - Thermocline depth moves downward during the summer, intersecting the anoxic boundary in July,
    - Very poor water quality occurs when the thermocline and anoxic boundary meet in July.
    - Increased oxygen demand in bottom water will intensify blue-green algae blooms caused by the boundary intersection.

Phosphorus Concentrations

- Lake phosphorus concentration has increased from 13 ppb in 1974, to 22 ppb averaged from the last several years.
- The current range of lake phosphorus concentration is between 8 and 31 ppb. Concentrations high enough to cause blue-green algae blooms -- between 22 and 31ppb -- occur frequently.

- Phosphorus concentration reaches highest values after deep drawdown.
    - All values of 40 ppb or more have occurred after a deep drawdown.
    - Most values between 30 ppb and 40 ppb occurred after a deep drawdown.

Fisheries Populations

19. CT DEEP Inland Fisheries Division manages Candlewood Lake as a Trout Management Lake with 14,000 -16,000 catchable brown and rainbow trout stocked annually.
    - CT DEP Inland Fisheries Division set gill nets in 1976–1978 to monitor pelagic fish species populations and has conducted electroshocking during 9 years between 1988 and 2010.
    - Gill nets captured 19 species of fish.
    - Chain pickerel, caught in gill nets abundantly, has not been caught since those surveys.
    - Electroshocking surveys have collected a total of 29 fish species: eleven species have been caught in each of the 9 surveys, thirteen species have been caught between 2 and 8 times, and five species have only been caught once.
    - Comparing catch records after shallow and deep drawdowns reveals some minor differences in numbers of certain size fish. Mostly, there were slightly more fish of smaller sizes after shallow drawdowns than seen after deep drawdowns.

Vertebrate and Invertebrate Communities

20. Invertebrate information is limited to one set of collections from three near-shore sites in 2010
    - Very few species of invertebrate were found.
21. No data on vertebrate populations was available for review.

Weather and Milfoil Lethality

22. Minimum air temperatures of 24ºF have been implicated as a lethal threshold for milfoil shoots and roots during controlled laboratory experiments conducted at Western Connecticut State University.
    - Temperatures of 24ºF and below typically occur starting in mid-December.
    - However, some years showed that threshold temperatures may not occur until January, or even February.
    - Duration of lethal temperatures may be short.
23. Winter snow cover may be an important factor, insulating milfoil roots and shoots from experiencing lethal temperatures.
    - Snow cover has varied significantly between each of the last 5 years.
    - The winter with the lowest duration of snow cover, 2007, was followed by the summer with least milfoil.

24. Drawdown water elevation targets and durations have been erratic; the last three deep drawdowns have had inconsistent timing and duration during the window of critical temperatures.
    - 2005-2006 target 8 feet reached 12/23 sustained for 23 days
    - 2006-2007 target 8 feet reached 12/28 sustained for 81 days
    - 2008-2009 target 8 feet reached 1/17 sustained for 51 days

Suggestions for future management and data collections

1. To better understand the effect of drawdown on milfoil beds, areas of dense stands of milfoil should be surveyed in spring between May and June in addition to the summer survey.
    a. Summer fragmentation and colonization suggest that surveys conducted in August into September measure new beds formed that season, or regrowth of existing beds in exposed areas.

2. Standardize, as much as possible, the timing and duration of each deep drawdown. There appears to be variably in remaining milfoil after deep drawdown that may be due to differences in the date the target depth is reached and the duration of time the water level is at the target depth.

3. On-site weather records should be kept to track local air temperatures and snow cover during drawdown period. Some investigation should be carried out to link air temperature to sediment temperature.

4. Milfoil coverage appears to extend out to 15 feet of water. Drawdown results indicate that milfoil remains intact between 10 and 15 feet of water. Specific mapping results are needed that characterizes the areas where milfoil has been controlled and where it persists despite drawdown. Deeper waters should be scanned for colonies of milfoil that might exist out to 19 or 20 feet.

5. A wider survey for existing native species should be conducted.

6. Data suggest that milfoil re-colonizes all drawdown exposed areas within one year. This rapid proliferation should be investigated to determine the mechanism that causes milfoil to re-grow in drawdown cleared areas.
    a. If re-growth is caused by fragments, future investigations should consider indexing milfoil topped-out coverage and boat traffic to determine if specific areas require alternate control to limit boat-induced fragmentation.
    b. Boat-induced fragmentation suggests that there is significant boating occurring within the no-wake zone of 100 feet from shore. Determine if boats are responsible for milfoil fragmentation during the summer.

7. Continue experimentation with required lethal temperatures and drying duration.

8. Survey exposed areas slopes, sediment types, and groundwater influx in order to better characterize likelihood of drawdown success.

9. Continue collecting water-quality data with possible refinements:
    a. Collect mid-depth water samples during the summer to verify if phosphorus diffuses into the upper water from across the thermocline.
    b. Characterize the summer deep-water oxygen loss in order to determine why the anoxic boundary fluctuates so much.
    c. Explore reasons why phosphorus in surface water is higher after deep drawdowns, and phosphorus in deep water is higher after shallow drawdowns.

10. Characterize the invertebrate community in the lake -- specifically these three littoral zone sub sections:
    a. consistently exposed zone of 0 – 5 feet,
    b. the biennially exposed zone between 5 and 10 feet,
    c. the perpetually submersed zone between 10 and 15 feet.

11. Collect data on young-of-year fish after shallow and deep drawdowns.

12. Investigate vertebrate population status.

13. Investigate function and structure of contiguous wetlands to determine wetland viability.

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Introduction

The Town of New Fairfield retained Northeast Aquatic Research, LLC to review available information on Candlewood Lake to determine if winter drawdown has caused ecological harm to the lake. Candlewood Lake is owned by a power generation utility currently, FirstLight Hydro Generation Company -- a subsidiary of GDF Suez Energy Generation North America, Inc. Water level of Candlewood Lake has been lowered each winter since 1983 to control Eurasian milfoil infestation. No evaluation of possible changes in the ecology of Candlewood Lake due to drawdown has been done since 1985 when Siver et al. (1986) found no adverse effects to water quality. This report summarizes and examines existing Candlewood Lake water quality, fisheries, and aquatic plants data for evidence of long-term impacts. Resources were provided by the following sources **Table 1**.

Table 1 - Sources of data used in this report

Volumes and Morphometry	FirstLight Hydro Generation, CT DEEP
Water Level Records	FirstLight, Candlewood Lake Authority
Water Quality Trends	Candlewood Lake Authority, T. Simpkins
Contiguous Wetlands	USDA –Web Soil Survey, Google Earth
Aquatic Plants	CT Agricultural Experiment Station
Fisheries Electro-shocking Records	CT DEEP Inland Fisheries Division
Invertebrates	North East Naturalists Services
Vertebrates	None found
Precipitation Records	WeatherSource data from Danbury station

Study Suppositions

Changes in the ecology of Candlewood Lake due to winter water drawdown are assumed in this report to be due primarily to exposure of lake littoral zone sediments during the winter, although other indirect effects are also possible. The duration and magnitude of the exposure will likely determine the significance of the changes -- with shorter duration and shallower lowering have less effect than longer, deeper ones. Both positive and negative effects of winter lowering have been reported to occur. Results are expected to show increasing positive or increasing negative effect due to increasing duration and deeper drawdown. The list of positive and negative drawdown effects presented below is taken largely from recent publications in the lake management literature *Eutrophication and Aquatic Plant Management in Massachusetts. Final Generic Environmental Impact Report* by Mattson et al. in 2004, and *Restoration and Management of Lakes and Reservoirs*, Third Edition, by Cooke et al. in 2005. However, several additions to the list come from NEAR records and observations.

Positive Effects

A. The most significant positive change is the reduction in growth of rooted aquatic plants. Winter drawdown kills rooted aquatic plants that grow in exposed areas by subjecting root systems to freezing and drying. Areas that are exposed have fewer plants during the following growing season. Winter water level drawdown can provide good control of rooted aquatic plant growth in high-recreation-use shallow waters along the perimeter of the lake.
   a) Fewer plants in littoral zone allows for more fish nesting sites that were unavailable due to dense beds of plants.
   b) Thinning of extremely dense stands of aquatic plants can provide mixing of dissolved oxygen into areas that have become stagnant due to thick plants.

B. Winter water level drawdown allows access to the shoreline areas for maintenance of structures, debris clean–up, and removal of accumulated sediment.
   a) Winter water level drawdown provides for protection of shoreline structures by keeping ice formation below the masonry.

C. Freezing and drying of peaty sediments causes shrinkage due to oxidation of organic material during the exposure period.
   a) Drawdown causes compaction of loose sediments by allowing small and tiny grains to settle deeper in sediments or be washed out. However this is also a negative effect, due to transport of sediments into deep regions of the lake.

b) The compositions of exposed sediments become coarser grained, as fine grain sediments are removed.

D. Drawdown also increases the flood storage capacity of the lake. In some cases this is the primary benefit of winter water level drawdown and may be mandatory because spring runoff would cause extreme flooding, otherwise.

Negative Effects

A. Winter drawdown may cause changes in the vegetation that are counter to intended goals. Plant growth can increase instead of decrease. Some species may tolerate or even favor a winter water level drawdown.

   a. Target species may expand or shift to deeper waters due to repeated drawdowns.
   b. Non-target plant community may show species shifts as drawdown-tolerant species replace sensitive species. Sometimes tolerant species become nuisance plants.
   c. Overall aquatic plant species diversity may decline as drawdown sensitive species become scarce.
   d. Target plants surviving in deeper water, beyond the reach of the drawdown, control can be first to recolonize exposed areas following re-fill.

B. Contiguous shoreline wetlands dependent on the lake level for hydrology may experience excessively dry conditions during a winter. Water-level drawdown could cause shifts in wetland plant species abundance, disrupting wetland structure and function.

C. Several negative changes in water quality are possible due to lowering the water level during the winter. Primarily, drawdown exposes the lake area of highest biological production where sediments are rich in nutrients and organic material. Exposure allows transport of these rich sediments into lake water.

   a. Nutrient rich sediments and organic material exported to the open water during a drawdown potentially increases nutrient and suspended solids the following spring. Higher nutrient levels will lead to degraded water clarity the next summer.

b. Nutrients released from decaying plants killed by drawdown can cause an increase in nutrient concentration of shallow water following a refill.
c. Winter water-level drawdown may increase draining of groundwater into lake waters. Groundwater is typically rich in nitrate, from water leaching out of septic systems. Flows of high nitrate concentration groundwater into a lake can be increased as the lower lake level permits enhanced draining of the near-shore areas.
d. Sediments that erode from the exposed shore accumulate and cause extensive filamentous algae growth after refill, because typically these sediments contain sufficient quantities of both nutrients and dissolved oxygen demand substances.
e. Organic material exported from exposed areas to the lake bottom increase oxygen demand in the water during the following summer. Declines in supply lead to a greater amount of water devoid of dissolved oxygen during the summer.
f. Exposed shores are subject to erosion due to rain events and melting snow during the wettest months of the year. Erosion of exposed lake sediments can become severe as partial ice cover forces runoff flows into gullies. All sediments eroded from the exposed area are carried directly to the lake.
g. Water discharged to the lake from street drain culverts can provide continuous runoff that erodes deeper channels in exposed lake sediments. Continuous higher water flows transport sediments further into the lake.
h. Dried and now buoyant organic sediments can float during refill. Large peat islands can be moved by winds and currents to become beached on shorelines transporting nutrients and oxygen demand material to new areas. These grounded peat island are often unwanted and need to be removed.
i. Transport of rich decomposable material to deeper waters causes more severe dissolved oxygen loss during the following summer. The new material represents an increased load to the respiration occurring

at the bottom of a lake, causing an increase in anoxic water during the summer.

D. Drawdown exposes the area of the lake with the highest biological productivity to drying and freezing during the winter, subjecting all animals using that area to excessive environmental conditions. The combination of loss of habitat, increased distance required to move to find favorable habitat, and the general shift to conditions outside tolerable ranges make it more difficult for these organisms to survive.
   a. Water-level lowering can impact animals such as snails, mussels, benthic insects, and crayfish by requiring migration with the changing water conditions.
   b. Removal of standing beds of aquatic plants may impact the macro-invertebrates, such as insects, that use the habitat provided by the vegetation.
   c. A water level drawdown may expose and harm hibernating reptiles and amphibians buried in lake sediments.
   d. Active winter aquatic mammals may lose foraging habitats that require a lake edge. Dormant mammals may suffer mortality if the absence of lake causes harsher environmental conditions.
   e. Compaction of benthic sediments may be a detriment to some types of aquatic macro-invertebrates that require pore space in the sediment grains. Since compact allows settling these pore spaces become scarce.

E. Winter water-level drawdown can also impact fisheries in a variety of ways.
   a. Lower water level during the winter can move fish that require vegetation for concealment out to deeper water where they are susceptible to predation.
   b. Lower winter water level concentrates prey fish in smaller volume allowing for higher rates of predation.
   c. Loss of necessary vegetation cover may affect survivorship of spring young of year fish.
   d. If water levels are not returned to normal conditions in time, certain fish species may not be able to reach spring spawning areas.

   e. If remaining water volume under the ice is a small fraction of the total pre-drawdown water volume, dissolved oxygen can become depleted, stressing fish.

F. Water level drawdown can also negatively affect human use of the lake during the winter.
   a. Shallow wells located near the shoreline can lose water supply during a deep drawdown.
   b. Winter water-level drawdown limits human access to open water by forcing crossing of extensive soft sediments.
   c. Limits availability of near-shore ice cover for skating.
   d. Delayed refill will limit boat access because boat ramps will be above water line.

Summary of Possible Negative Effects

From the list above, a number of key aspects of lake ecology were considered to be indicators of lake change over time. Ecosystem characteristics examined in this report are:

1. Shifts in aquatic plant species shifts
2. Impacts to water quality through
   a. Increases in nutrient concentration
   b. Declines in water clarity
   c. Declines in dissolved oxygen content
3. Changes in fisheries populations
4. Identification of areas of wetlands contiguous to the lake shore
5. Impacts to littoral zone animals

Limited information was available on shallow-water organisms, and semi-aquatic mammals. Also, it is important to note that changes in some values, such as the water quality changes, may have been caused by increased development and larger percentage of impervious surface cover in the watershed, and structural changes such as shoreline armoring, road improvements, and storm-water conveyance changes.

Background

Control of Eurasian Watermilfoil in Candlewood Lake

Candlewood Lake has been infested with the invasive, non-native, aquatic plant Eurasian watermilfoil (Myriophyllum spicatum) since the early 1980's. Eurasian watermilfoil (EWM) is a very troublesome weed that spreads rapidly, displacing native aquatic plants through competition and affecting water quality. Impairments are due to dense stands of plants establishing a surface canopy that effectively shades and suffocates habitats below (Grace and Wetzel 1978). An early study by Western Connecticut State University (Siver et al. 1986) found that EWM had become well established in shallow waters of the lake between 1979 and 1983. By 1982, the proliferation of EWM in Candlewood Lake was causing extensive recreational and aesthetic problems.

Initial use of winter water level drawdown to control the growth of EWM was during the winter of 1983–1984, when the lake was lowered to 6.6 feet below normal summer levels. The following winter (1984–1985) the level was drawn down to 8.9 feet below normal summer levels.[1]

During each drawdown aquatic plant growth and water quality data was collected by facility and students from Western Connecticut State University. The results of the work were published in the Journal *Lake and Reservoir Management* as proceedings of the 5th annual conference of the North American Lake Management Society, titled *The effects of winter drawdown on macrophytes in Candlewood Lake, Connecticut*. The paper reached three important conclusions that were landmark at the time:

1) "Based on the reduction in M. spicatum plants in Candlewood Lake after two drawdowns, we believe that drawdowns will effectively control this macrophyte,"

2) "Without continued drawdowns, Myriophyllum plants from the deep populations may re-infest shallow areas, especially since they grow rapidly early in the season."

3) "In summary, since the drawdowns appeared to have no adverse effects on the lake (either on phosphorus or chlorophyll concentrations, phytoplankton

[1] normal summer level can range between 427 and 429.5 feet above sea level CL&P datum

levels, or water clarity), they seem the most logical means of controlling M. spicatum populations."

These three statements provided strong evidence that winter water-level drawdown:

1. controls Eurasian watermilfoil
2. prevents re-colonization from beds of deeper water milfoil, and
3. does not harm the water quality of the lake.

The importance of the work was cited in the book *Restoration and Management of Lakes and Reservoirs* (Cooke et al. 2005) as a case study with strong evidence that drawdown "eliminates" milfoil.

These conclusions provided validation to use winter water level drawdown as the primary EWM control technique at Candlewood Lake since that time. Collaboration between the Candlewood Lake Authority (CLA), the power utility who owns the facility, and CT Department of Energy and Environmental Protection (CT DEEP) established EWM control to consist of biennial deep water-level drawdowns targeting 10 feet below normal summer level, with shallower alternate-year drawdowns about 6 feet below normal summer levels.

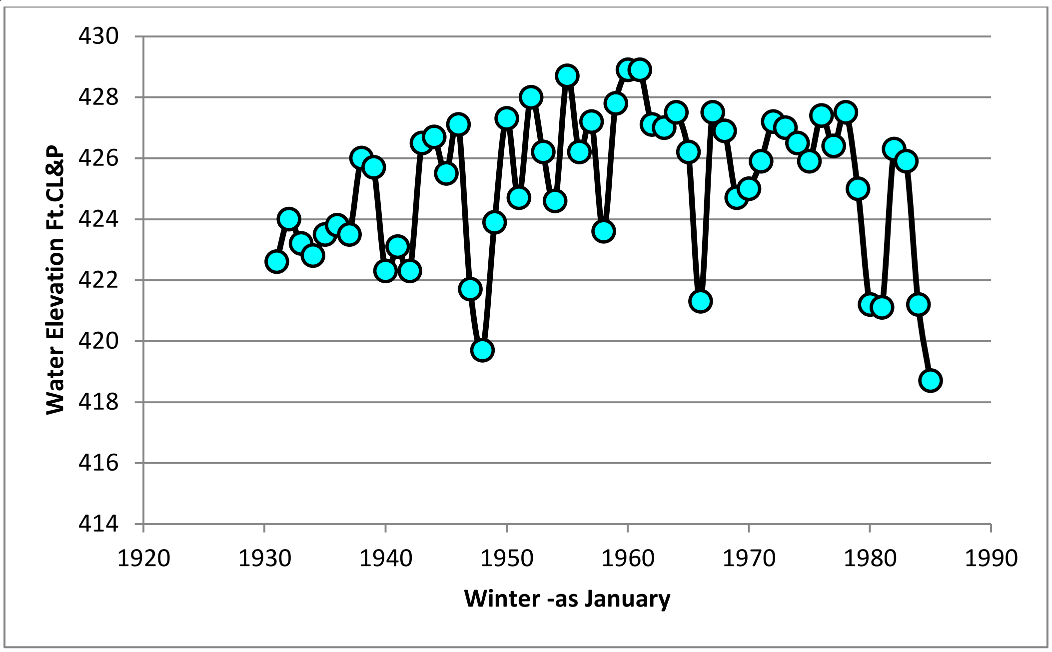
The water level of Candlewood Lake is regulated by the Federal Energy Regulatory Commission (FERC) in Article 403 of the license issued June 23, 2004 and Order of Rehearing dated November 23, 2004. The license states that the summer level between Memorial Day and October 15 shall remain within the range 427–429.5 ft. CL&P. This report uses the elevation of 428 as the normal summer level throughout in order to simplify calculation of lowering distances. However, it should be kept in mind that whenever "feet below normal summer level" is used in the report, such as when the lake is 6 feet below normal summer level, the water level could actually be within a 1.5-foot range of that value (421-423.5 ft. CL&P).

A winter drawdown is allowed between October 15 and Memorial Day when water level can be within the range 425.9–417.9 ft. CL&P; annual targets are determined by the utility with recommendations from a technical committee comprised of the representatives from the licensee, CT DEEP, U.S. Department of the Interior, and CLA.

Drawdown Record

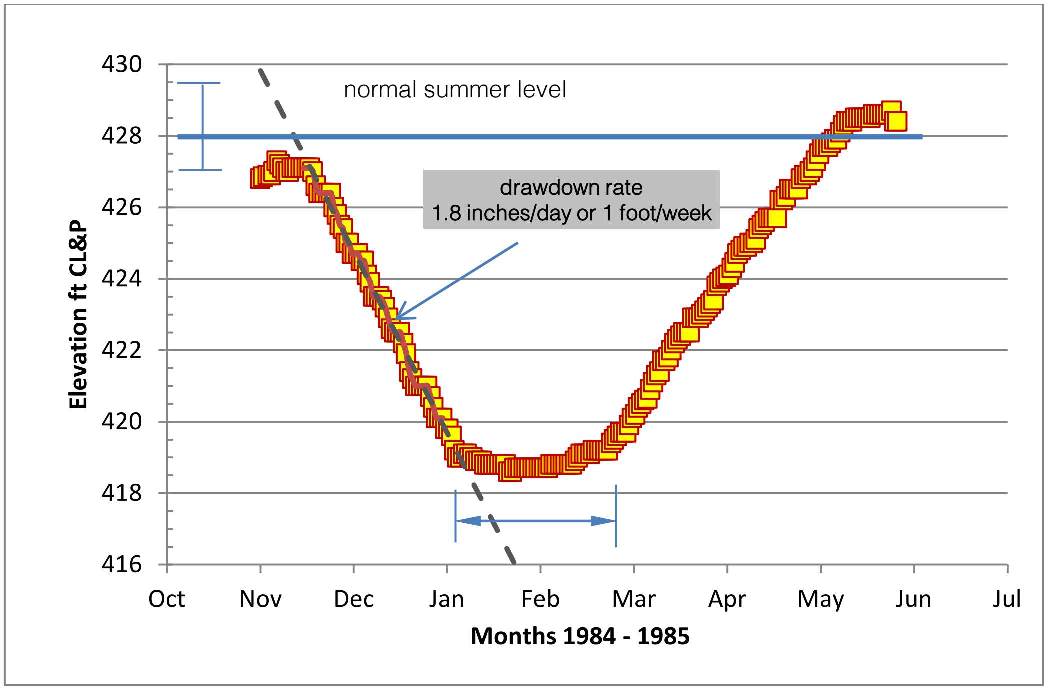
The water level of Candlewood Lake fluctuated wildly between 1931 and 1985 (**Figure 1**). The chart shows minimum winter levels between 1931 and 1985 were generally not deeper than 422 ft. CL&P or about 6 feet below normal summer level. Deepest winter drawdown was 419.7 ft. CL&P occurring during the winter of 1948. Last two winter levels shown on the chart in **Figure 1,** 1984 and 1985, are the first drawdowns used to control EWM. Throughout this report the year of the drawdown will be referred to by the January in which it occurred; for example the drawdown occurring over the winter 1984-1985 is called the drawdown of 1985.

Figure 1 – Minimum winter water level of Candlewood Lake between 1931 and 1985



Winter drawdowns at Candlewood Lake look much like the trend in water level during the winter of 1984-1985 shown in **Figure 2**. The chart shows the water elevation at the beginning the drawdown period, October 15, at 427 ft. CL&P, within the range of the summer level. Between November and January the lake level was lowered 8.5 feet, at a rate of about 1 foot per week. The chart shows that water level remained 8.5 feet down at elevation 418.5 ft. CL&P until the end of February. Between March and April water lever was raised at about the same rate of 1 foot per week. Water returned to normal summer level in early May. Similar charts showing water level trends for each winter drawdown between the winter of 1984-1985 and the winter of 2009-2010 are given in **Appendix 1.**

Figure 2 – Water level trend at Candlewood Lake during the winter 1984-1985



The minimum water level attained during each drawdown between 1985 and 2010 is shown in **Figure 3**. The chart shows the 26 drawdowns have had minimum winter water levels, ranging from elevation 423.7 ft. CL&P, the shallowest, to 417.3 ft. CL&P, the deepest. To facilitate differentiation of possible effects, the 26 drawdowns have been split into 13 shallow and 13 deep drawdowns. Shallow drawdowns have had a wider range of minimum winter levels but have not exceeded 8 feet below normal summer level or elevation 420 ft. CL&P. Deep drawdowns are defined as having a minimum level exceeding 8 feet below normal summer level or lower than elevation 420 ft. CL&P (see **Table 2** for minimum elevation during each of the 26 drawdowns).

Figure 3 - Minimum winter water levels during winters of 1985 to 2010

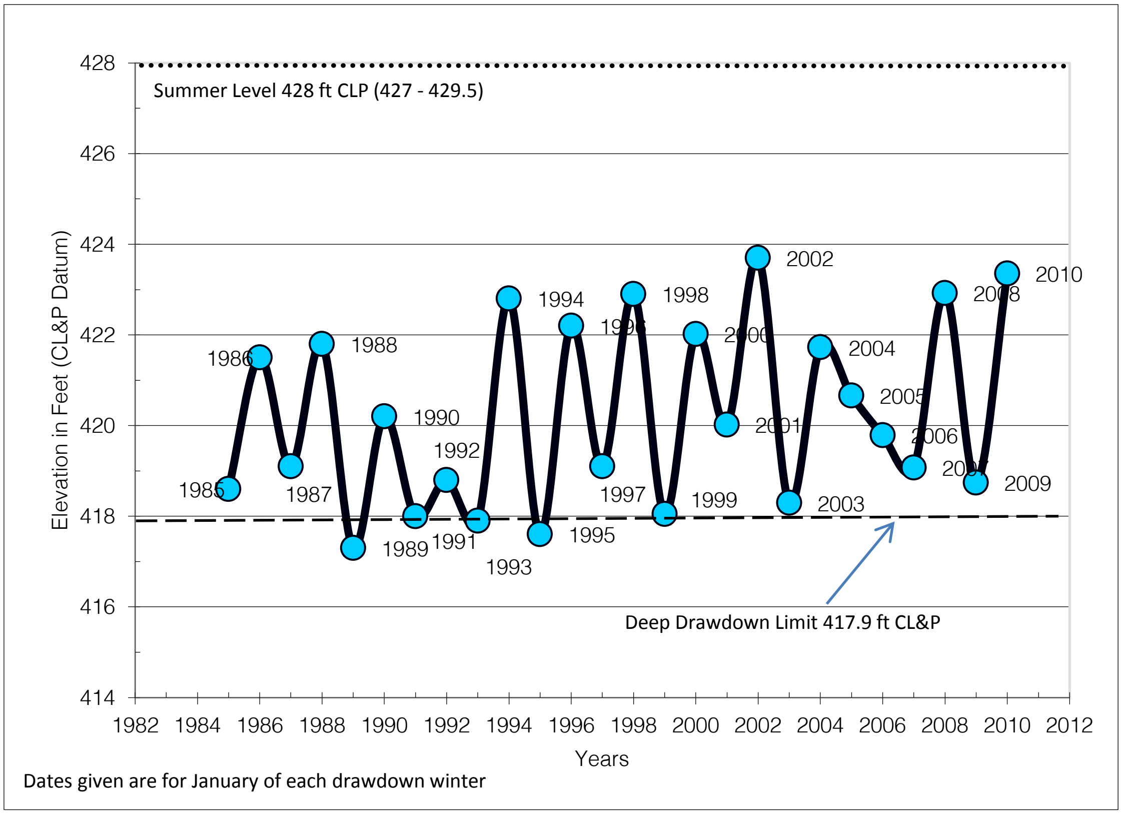
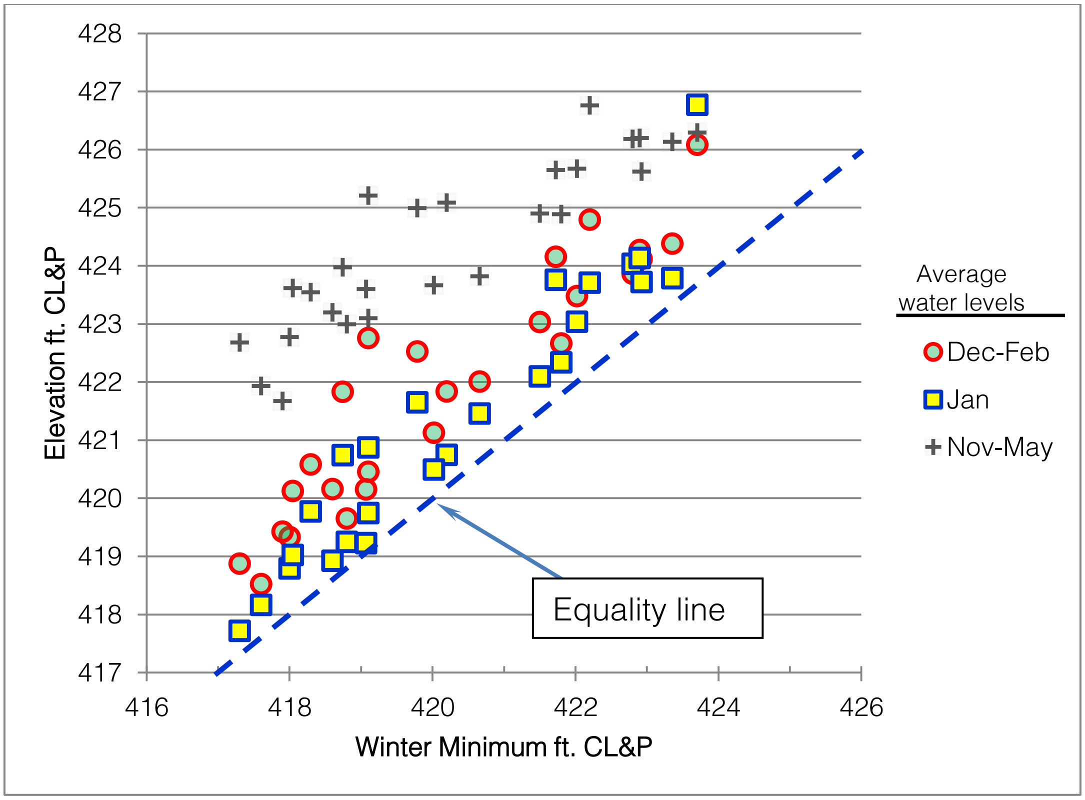


Table 2 –Drawdown winters and minimum water elevation ft. CL&P

Deep Drawdown Dates			Shallow Drawdown Dates		
Beginning Nov	End May	Minimum Elevation	Beginning Nov	End March	Minimum Elevation
1984	1985	418.6	1985	1986	421.5
1986	1987	419.1	1987	1988	421.8
1988	1989	417.3	1989	1990	420.2
1990	1991	418.0	1993	1994	422.8
1991	1992	418.8	1995	1996	422.2
1992	1993	417.9	1997	1998	422.9
1994	1995	417.6	1999	2000	422.0
1996	1997	419.1	2000	2001	420.0
1998	1999	418.1	2001	2002	423.7
2002	2003	418.3	2003	2004	421.7
2005	2006	419.8	2004	2005	420.7
2006	2007	419.1	2007	2008	422.9
2008	2009	418.7	2009	2010	423.4
Average Min Elevation ft. CL&P		418			422
Range Elevation ft. CLP		419.8-417.3			423.7-420
Average ft.		9.52			6.02

The minimum winter water level was found to closely agree with the average level for the month of January and the average level between December 1st, and Feb 29th as shown in **Figure 4**. The chart shows the average water levels for the month of January as squares, and the average between December 1st and February 29th as circles. Averages for each year are plotted against the minimum elevation of the drawdown. The equality line is the value that each average is plotted against. Values close to the equality line are near minimum elevation. The closer the value is to the dashed line, the longer the lake level was near minimum level. The chart shows that most January levels are near minimum level, while the average for Dec-Feb follows about 2 feet above the minimum level. The '+' symbols show average water levels between November 1 to May 31. These data indicate that using the minimum winter water level correctly describes the duration of minimum water level occurring during each drawdown. In other words, the minimum recorded water level was representative of water levels experienced during the duration of the exposure period.

Figure 4 - Average lake elevations during different winter periods



Basin Structure

Candlewood Lake has a surface area of about 5,237 acres when at the normal summer level of 428 ft. CL&P. The lake has a 10-mile long basin along a north-south axis. The lake consists of two 5-mile-long arms extending northward, the Sherman Arm to the west, and New Milford Arm to the east; a central area composed of several large north/south bays; and a 2.5 mile long southern arm (Danbury Bay). Although long, each of the arms is narrow; the widest areas are in the range of 0.6 miles, while many constrictions exist where width is only 0.1 miles. The lake contains at least 35 islands -- the largest is 63 acres. Candlewood Lake has a shoreline length of 65 miles.

Candlewood Lake is a pump storage hydroelectric development that uses natural watershed flows and water pumped up 250 feet from the Housatonic River (captured at the Rocky River Station) and discharged into the extreme northern end of the northeast (New Milford) arm. Electricity is generated during release of lake water back to the Housatonic River.

The lake has a maximum depth of 85 feet, although this is a very small, 75-acre-deep hole located in the northern reach of the New Milford arm. The remainder of the lake has a flat bottom with maximum depths between 40 and 55 feet deep. The volume of the lake is 167,059 acre-feet (55 billion gallons) when at an elevation of 428 ft. CL&P.

Table 3 gives morphometric information of Candlewood Lake between the surface (at 428 ft. CL&P) and 15 feet deep. The table gives the surface area of the lake as it is sequentially lowered by 1 foot depth increments to 15 feet. The table also gives the surface area of each exposed 1 foot of shoreline. For example, the surface area of the lake when lowered to 1-foot below summer normal is 5,192 acres, yielding 45 acres of exposed area between 0 depth (the shoreline), and the new waterline 1 foot down. The average exposed area for each 1-foot water lowering is 50.7 acres, ranging between 45 and 59 acres. The theoretical maximum area of exposed shoreline when the lake is at 417.9 ft. CL&P is 539 acres, or about 10% of the total lake surface area. **Table 3** ends at 15 feet, marking the outer edge of the littoral zone, or that part of the lake that can support rooted plant growth. The surface area between the shore and 15 feet of water depth is 753 acres, the theoretical size of the littoral zone of Candlewood Lake.

Table 3 - Candlewood Lake water basin statistics

Surface Area	5,237	Acres	21,195,540	Square meters
Total Volume	167,059	Ac-Ft	206,151,263	Cubic meters
Maximum Depth	85.0	Feet	25.91	Meters
Mean Depth	31.9	Feet	9.72	Meters

DEPTH		SURFACE AREA Cumulative From Bottom	SURFACE AREA Of Each Stratum	
Feet	CL&P	acres	Depth interval	Acres
0	428	5,237	0 – 1	45
1	427	5,192	1 - 2	47
2	426	5,145	2 – 3	45
3	425	5,100	3 - 4	50
4	424	5,049	4 – 5	51
5	423	4,998	5 – 6	50
6	422	4,948	6 – 7	47
7	421	4,901	7 – 8	50
8	420	4,851	8 – 9	52
9	419	4,799	9 – 10	51
10	418	4,748	10 – 11	51
11	417	4,698	11 – 12	52
12	416	4,646	12 – 13	47
13	415	4,599	13 – 14	57
14	414	4,542	14 – 15	57
15	413	4,484	15 – 16	59

There is a linear increase in volume between 0 and 10 feet of about 5,000 acre-feet per foot, or 3% of the total lake volume with each 1 foot of depth. The total volume of water between 428 feet CL&P and 418 feet CL&P is 49,976 acre-feet, (about 16.5 billion gallons) or about 30% of the total lake volume.

The monthly flows from the direct watershed of the lake, that area surrounding the lake that supplies natural runoff but not including the drainage basin of the Housatonic River, is given in Table 4. The annual average water runoff to the lake is about 55,195 acre-feet per year. Of that total, about 38.5% or 21,257 acre-feet, enters the lake between February 1st and May 31st, -- the months of lake re-fill. These data are estimated by assuming half the average precipitation falling on the watershed becomes runoff.

Table 4 – Average monthly water flows entering Candlewood Lake during re-fill months

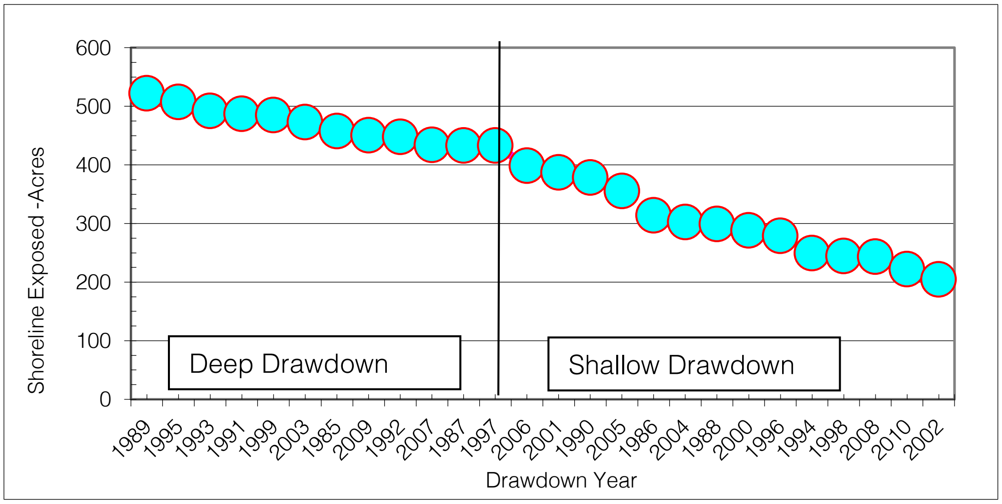
Month	Acre-feet / month
February	3,688
March	6,031
April	6,034
May	5,502
Total	21,257

The volume of water contained in the top 10 feet of Candlewood Lake when at normal summer level is 49,976 acre-feet, meaning that on average, less than half the volume evacuated for a deep drawdown enters the lake naturally as runoff between February 1st and May 31st. This indicates that, on average, about 28,718 acre-feet of water needs to be pumped up from the Housatonic River during each deep (10 foot) drawdown in order to achieve a full lake by Memorial Day.

Shoreline Exposure during Drawdown

The estimated areas of exposed shoreline during each drawdown are shown in Figure 5. Deep drawdown exposes an average or 469 acres, with a range of 432 and 522 acres, while shallow drawdowns expose on average 298 acres, with a range of 204 and 399 acres. The minimum of 204 acres indicates that area of lake shore exposed during every winter drawdown, about 4.3 feet below normal summer level.

Figure 5 - Maximum surface area of exposed shoreline during each drawdown 1985 - 2010



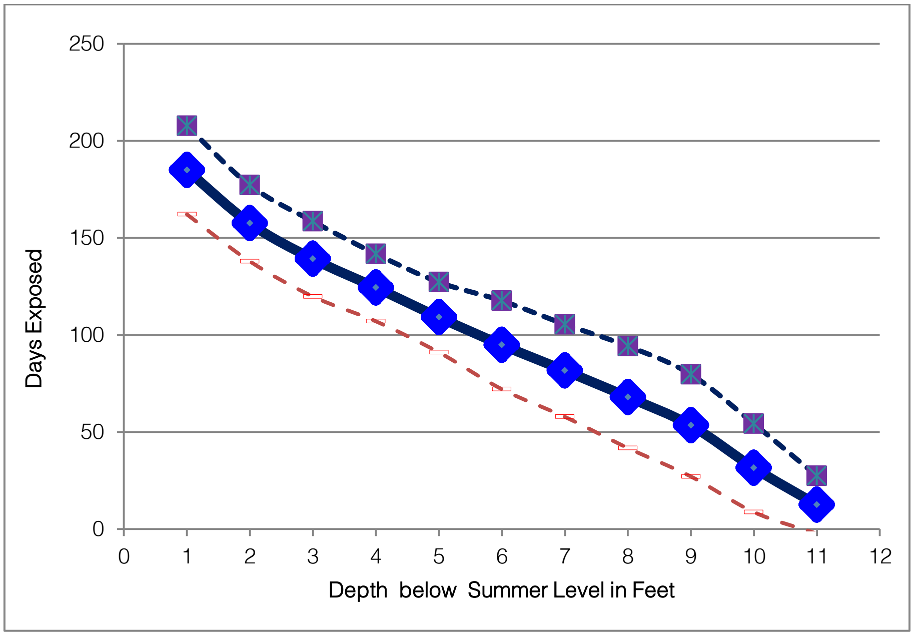
The average exposure duration in days for each 1-foot depth increment is given in **Table 5**. The table gives the cumulative acres exposed with lowering water level, and the percent of drawdowns that exposed that depth of shore. The average exposure duration at 1 foot is 174 days, decreasing linearly to 86 days at 5 feet. Shore areas down to about 5 feet are exposed every year. Areas between 6 and 8 feet have had equal exposure durations of about 66 days, while exposure of 9 and 10 feet has been 53 and 32 days, respectively. Areas deeper than 9 feet have been exposed only 10 times or during 39% of the drawdowns

Table 5 – Average duration of shoreline exposure for each 1 foot depth increment

	Average number of exposure days at each 1-foot depth increment									
Depth in Feet	1	2	3	4	5	6	7	8	9	10
Cumulative Acres	45	93	138	188	239	289	336	386	438	489
Days	174	143	119	103	86	69	66	64	53	32
Percent of drawdowns	100	100	100	100	100	92	73	62	50	39

Using the entire data set of drawdowns (1985-2010) the mean number of exposure days for each 1 foot of drawdown depth was calculated. There is a significant linear relationship between declining number of exposure days and deepening drawdown depth as shown in **Figure 6**. The chart shows the mean number of days that areas at that depth are exposed. For example, the area of the lake between 6 and 7 feet is exposed an average of 82 days, despite the depth of drawdown, provided it is at least 7 feet down. The confidence intervals are shown (dashed lines above and below the solid line) giving the expected range. For example, the days of exposure of the area between 6 and 7 feet ranges between 58 and 105. The relationship predicts the number of days exposed during each drawdown.

Figure 6 – Average duration of shoreline exposure in days with each 1 foot drawdown increment, solid blue line. Graph also shows 1 standard deviation around mean shown as dashed lines.



Aquatic Vegetation

Early Survey Results

The earliest record of aquatic plants in Candlewood Lake obtained by NEAR for this analysis was from surveys conducted by the CT DEEP during the summers of 1979, 1980, and 1982 (CT DEP 1983). Eleven species of aquatic plants were noted (**Table 6**). Three species of milfoil were observed: Myriophyllum spicatum, Myriophyllum exalbesense, and Myriophyllum brasiliense. Myriophyllum brasiliense is now called M. aquaticum or Parrot-feather and Myriophyllum exalbesense is now called M. sibiricum or northern milfoil). These were probably misidentified specimens of M. spicatum because the presence of these species in the lake has not been confirmed since that time.

The DEEP survey found eight native species -- 4 pondweeds: Potamogeton robbinsii, P. amplifolius, P. gramineus, and P. richardsonii; and 4 additional natives species: tape-grass (Vallisneria americana), bushy pondweed (Najas flexilis), coontail (Ceratophyllum demersum), and waterwort (Elatine sp.).

Table 6 – Aquatic plants observed in Candlewood Lake by CT DEP during surveys conducted between 1979 and 1982

Common Name	Scientific Name	
Eurasian Milfoil	Myriophyllum spicatum	
Northern Milfoil	Myriophyllum exalbesense	now M. sibiricum
Parrot-feather	Myriophyllum brasiliense	now M. aquaticum
Richardson's pondweed	P. richardsonii	
Grassy pondweed	P. gramineus	
Robbins pondweed	P. robbinsii	
Large-leaf pondweed	P. amplifolius	
Coontail	Ceratophyllum demersum	
tape-grass	Vallisneria americana	
Bushy pondweed	Najas flexilis	
Waterwort	Elatine sp.	

Although milfoil was dense in some areas, the report lists other species as being dominant or co-dominant in several areas. Brookfield Bay was dominated by tape-grass and Robbins pondweed, Lattins Cove was dominated by coontail. The

Northwest arm was noted to have tape-grass as a co-dominate with milfoil, and along the west side of Candlewood Isle tape-grass and large-leaf pondweed were present with milfoil. The New Milford arm was found to have areas of moderate growths of large-leaf pondweed and tape-grass.

The CT DEEP survey further reported that Eurasian milfoil grew to depths of 11, 12, 13, and 15 feet generally, and to 19 feet at one location in the New Milford arm. Some areas had dense coverage in areas less than those depths. The New Milford arm was reported to have dense beds of milfoil that extended out to 15 feet. Siver et al. reported that Eurasian milfoil had rapidly expanded by 1983. The plant had formed monocultures (single species stands) in many places, completely replacing coontail in Lattins Cove for example.

CT Agricultural Experiment Station Survey Results

The next full scale aquatic plant survey of Candlewood Lake was conducted by the Connecticut Agricultural Experiment Station (CAES) in 2005 using transects to sample the vegetation community. A transect is a sampling method designed to obtain data along a line crossing a specific habitat. CAES collected plant data at about 10 points spaced evenly along each of 105 transects, for a total of 783 observation points. Transects began at the shoreline and ran about 300 feet out into the lake. During surveys conducted in 2008–2010, 10 transects were used with about 100 observation points each year (see Table 7 for actual number of observation points used in 2008-2010 surveys).

Frequency data for each species observed by CAES (Table 7) confirms that Candlewood Lake contains few native plant species. Rooted aquatic plant community in Candlewood Lake appears to consist of only 6 species: Eurasian milfoil, spiny naiad, coontail, tape grass, waterwort, and sago pondweed. Eleven additional species (those shaded in blue) are shown to be so scarce as to be almost undetectable. The larger data-set of observation points used in 2005 (783) does not proportionally increase the frequency of occurrence of most native species, further indication that native plants are rare in Candlewood Lake. However, it may also be possible that native species are being replaced by milfoil exemplified by the three species of pondweed (Potamogeton richardsonii, P. robbinsii, and P. amplifolius) noted by the CT DEEP in 1979-1983 that have not been found by CAES during any of their surveys.

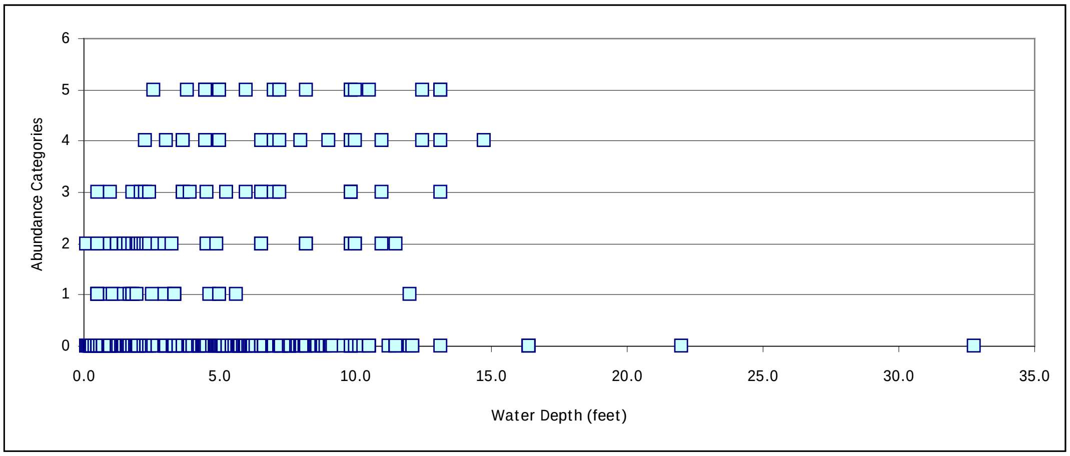
Table 7 – Aquatic Plant Species Observed in Candlewood Lake by CAES

		2005	2008	2009	2010
	Number of transects =>	105	10	10	10
	Number of observation points =>	783	100	97	96
Common Name	Scientific Name	% Occurrence			
Submersed Plants					
Eurasian Milfoil ^^	Myriophyllum spicatum	51	79	65	71
Spiny Naiad ^^	Najas minor	12.5	6.3	8.2	11.5
Coontail	Ceratophyllum demersum	31	33	11	23
Tape-grass	Vallisneria americana	2.1	2.1	4.1	4.1
Waterwort	Elatine	0	1	3	2
Grassy Pondweed	P. gramineus	2.1	0	0	0
Pondweed	P. bicupulatus	0	1	0	0
Curly-leaf Pondweed ^^	P. crispus	12.5	1	0	0
Clasping-leaf Pondweed	P. perfolatus	1	2.1	1	0
Pondweed	P. foliosus	3.1	0	0	0
Pondweed	Potamogeton pusillus	3.1	1	0	0
Horned Pondweed	Zannichellis palustris	11.5	3.1	0	0
Common elodea	Elodea nuttallii	4	0	0	0
Bushy Pondweed	Najas flexilis	7.3	1	1	0
Water Starwort	Callitriche sp.	1	0	0	0
White Water lily	Nymphaea odorata	1	1	0	0
Sago Pondweed	Stuckenia pectinata	6.3	1	0	4
Tiny Floating-Leaf Plants					
Duckweed	Lemna minor	2.1	6.3	1	4.2
Giant duckweed	Spirodela polyrhiza	1	0	0	1
Emergents ? unclear					
Rush	Eleocharis	0	0	3	1

^^ = Invasive aquatic plant

The outer boundary of the littoral zone of Candlewood Lake is indicated by the plant occurrence vs. water depth relationship shown in **Figure 7** below. Milfoil was found at all densities to water depths of 13 feet, and one observation of milfoil at abundance category 4 at 15 feet. Squares shown for zero abundance in deeper water indicate that no plants were found at those depths. The cluster of points shown in **Figure 7** ends abruptly at 13 feet of water depth, suggesting that the littoral zone, or the area of the lake where plants grow, has an outside boundary marked by the 13-foot water depth contour. Occasional plants found at 14 feet and references to plants found at 15 and 16 feet (CAES 2010) suggest that littoral zone extends to at least 15 feet of water depth, or about 753 acres (see **Table 3,** page 23).

Figure 7 – Eurasian Milfoil presence vs. water depth as determined by CAES 2005 survey data. Abundance categories determined in the field by CAES denote increasing density of milfoil, with 5 indicating extremely abundant.



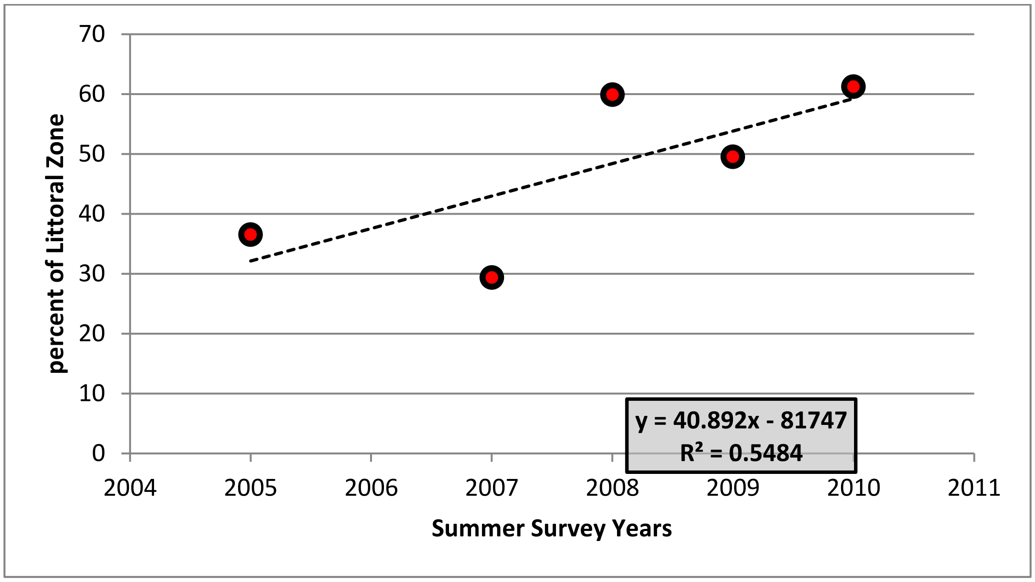
Estimates of surface area coverage of Eurasian milfoil in Candlewood Lake have been reported by CAES for each of the last 5 years Table 8. Coverage refers to the area of the lake that contained stands of milfoil as mapped by CAES. Mapping results given for 2005-2006 are a composite of two CAES surveys -- one from each year -- so it may not be usable for comparisons against latter surveys when the whole was observed in one year. The coverage of milfoil has varied between a low of 221 (2007) acres and a high of 461 acres (2010), for a range of 240 acres, between 29 and 61% of the littoral zone, or 4% to 9% of the total lake surface area.

Table 8 - Surface area coverage of two invasive species in Candlewood Lake

Year =	2005/2006	2007	2008	2009	2010
Acres					
Eurasian milfoil	275	221	451	373	461
Spiny naiad	ND	12	11	26	21
Percentage of Littoral Zone					
Eurasian milfoil	36	29	59	49	61
Spiny naiad		2	1	3	3

Milfoil coverage as percentage of littoral zone (753 acres) appears to be increasing (Figure 8). However, the suggested rate of increase represented by the dotted regression line in Figure 8 is not statistically significant, meaning that not enough data has been collected to correlate coverage changes over time.

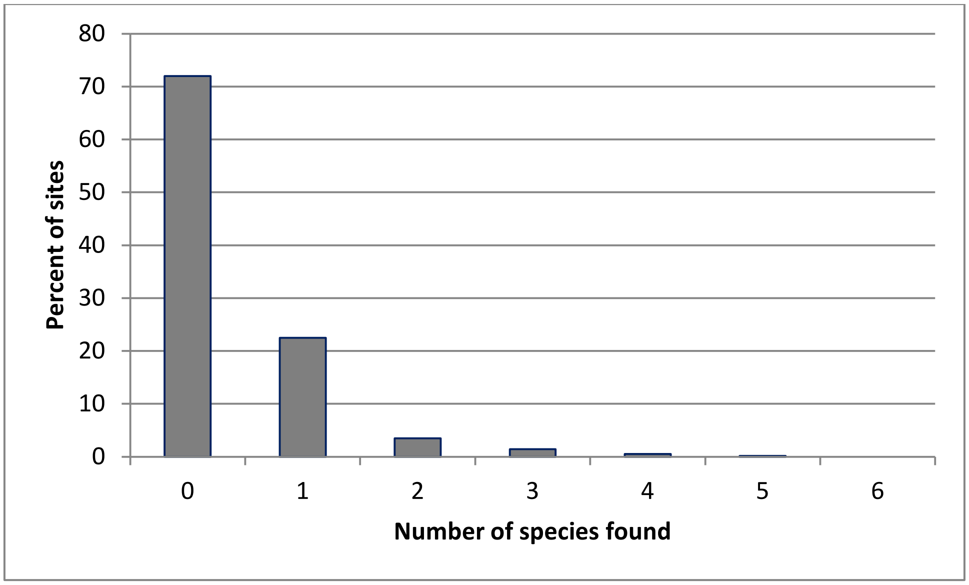
Figure 8 – Percentage of littoral zone dominated by milfoil



The increase in surface area covered by EWM shown in Figure 8 suggests that the species is not being controlled by drawdown because despite deep drawdowns that occurred during the winters of 2007 and 2009, there was still more milfoil in the lake in 2010 than there was in 2005; however, this graph doesn't account for possible changes in density of milfoil.

Plant occurrence data from the CAES 2005 survey (783 observation points) shows that 73% of the observation points (574 points) had no plants (Figure 9). Only 23% of the points (173 points) had one species, which was mostly always milfoil. These data indicate that a large portion of the littoral zone had no plant growth at the time of the survey. This suggests that milfoil has a significant area into which to expand. Although some of the 783 points may have been located in water depths deeper than 15 feet, most were within depth range that milfoil occurred (0 to 15 feet deep). The data also corroborate that the lake has mostly a one-species aquatic plant community consisting of Eurasian milfoil. Only small isolated pockets showed other species. The two abundant native plants -- coontail and tapegrass -- were found at only 1 or 2 percent of the observation points.

Figure 9 – Percentage species richness (number of different species occurring at each point) during CAES 2005 survey



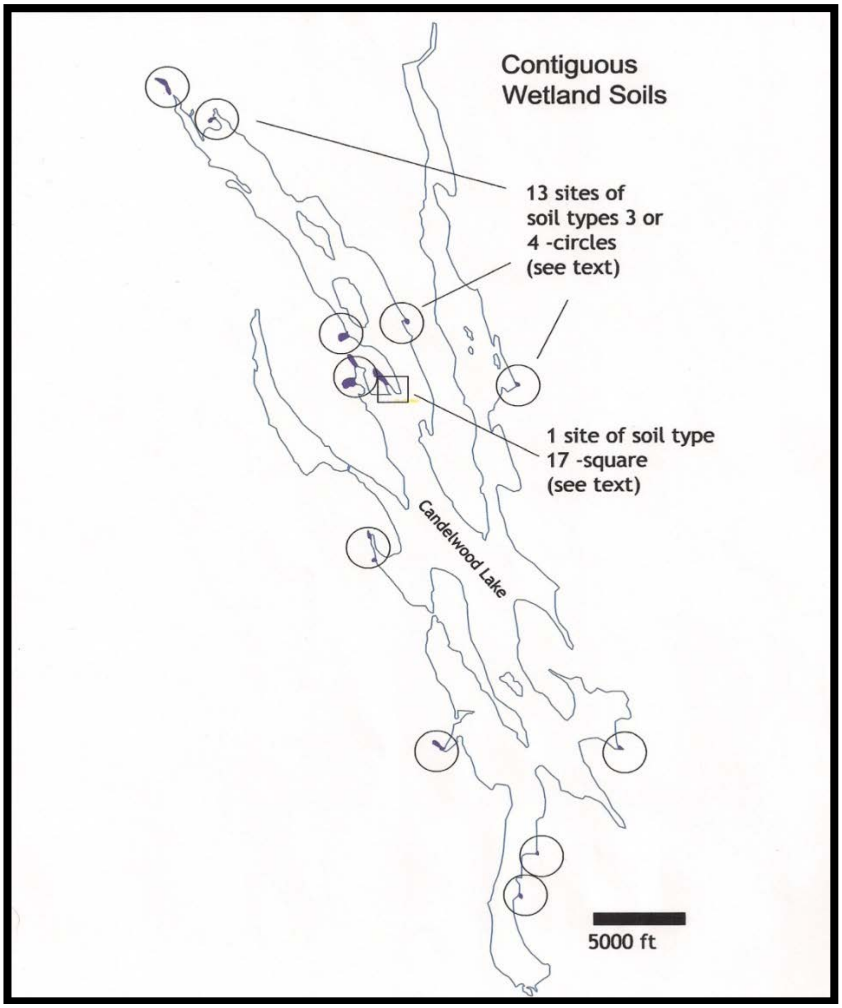
The aquatic plant surveys provide evidence that the rooted aquatic plant community in Candlewood Lake has changed since early CT DEEP surveys. Growths of large-stature, robust native plants (Potamogeton richardsonii, P. robbinsii, and P. amplifolius) have been replaced by Eurasian milfoil as a single species. Other native species are found very rarely in the lake, including floating-leaved and emergent plants. The CAES surveys also indicate that that Najas minor, an invasive aquatic plant, is becoming more abundant in the lake.

Little information is available indicating that milfoil grows in water deeper than 15 feet. However, differences in the estimate of distribution, using either percent occurrence or polygons from CAES mapping hint at milfoil growing in water deeper than 15 feet. Whereas percent occurrence suggests that only 23% of the littoral zone contains milfoil (173 acres), polygon mapping shows that milfoil coverage is actually between 221 and 461 acres (29-61% of the littoral zone). The large estimate of coverage from polygon mapping indicates that outer edges of many polygons may be in water deeper than 15 feet. Some select areas may support milfoil in water as deep as 19 feet, based on CT DEP surveys from 1978-1983.

Contiguous Wetlands

Wetlands contiguous to shoreline are dependent on the lake level for hydrology and may experience species shifts or losses during winter water-level drawdown. Very few areas of wetland soils contiguous to the shoreline of Candlewood Lake exist and are shown in **Figure 10**.

Figure 10 – Contiguous wetland soils to the shoreline of Candlewood Lake



The acreage of contiguous wetland areas that could potentially be impacted by drawdown is very small -- 38 acres, or 0.7% about 2,280 linear feet of the shoreline. Thirteen of the fourteen wetlands are Ridgebury / Leichester wetland soils, which are generally surface wetlands associated with rocky stream corridors typically occurring on slopes. These wetlands probably will not be seriously impacted by water level lowering in the winter because of the upland surface water flows, moving through these wetlands to the lake. One wetland, about 6.5 acres in size, shown by the square in **Figure 10**, consisted of Timakwa / Natchaug wetland soils, which are deep peat and muck may be more sensitive to water loss during the winter. Each of the wetlands needs to be field inspected to determine current wetland structure and viability.

Water quality

Introduction

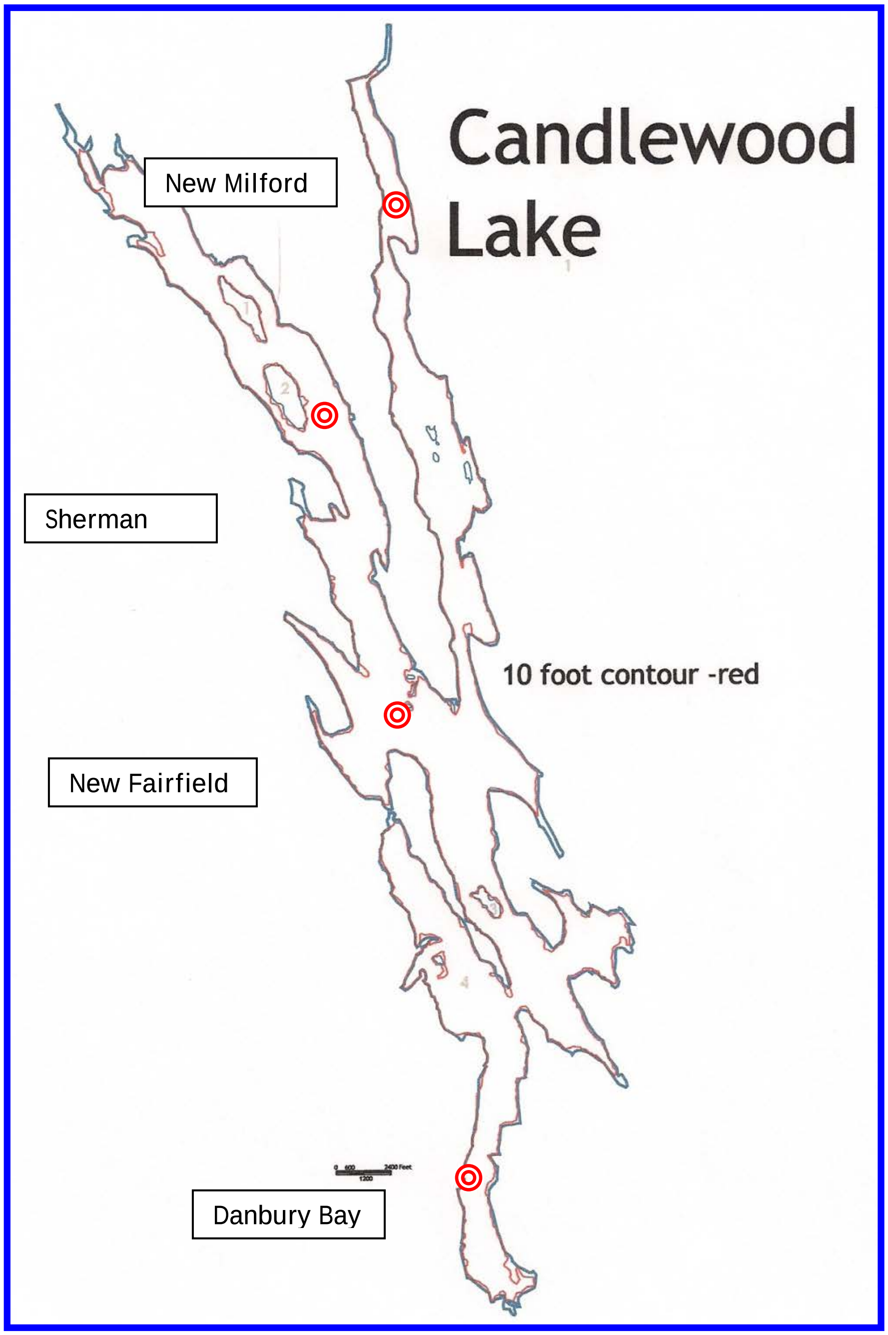
Winter water-level drawdown may cause a number of water quality changes in a lake. Two primary mechanisms for water quality declines are increasing nutrient levels, and decreasing dissolved oxygen content in bottom water. Increases in nutrient content of the lake water have been directly linked to decreases in water clarity (Wetzel 2001). Decreases in dissolved oxygen in bottom water lead to a number of impacts, including loss of fisheries habitat, increases in phosphorus release from sediments, increases in the recycling rate of phosphorus and nitrogen from decomposing organic matter raining down from the epilimnion, increased rate of transformation of nitrate, and an increase in the diffusion of nutrient from bottom waters to surface waters.

Monitoring of water quality parameters has been conducted by the Candlewood Lake Authority (CLA) since 1985. Four water-quality stations were established early in the program and have been visited several times a year to measure water temperature, dissolved oxygen, and water clarity; and to draw water samples for nutrient chemistry analysis (Figure 11).

This analysis reviews the water clarity, dissolved oxygen, total phosphorus and total nitrogen record for possible long-term trends. Water clarity, presented first, is measured with a Secchi disk, an 8 inch disk with the surface divided into quarters with 2 opposing sides painted black. The disk is lowered into the water until it disappears from view, with that distance, measured from the water surface, being the Secchi disk depth. Water clarity measurements were typically made monthly between May and October at each of the 4 stations.

The water temperature and dissolved oxygen content was measured at each 1 meter depth increment from the top to the bottom at each of the 4 stations. These measurements were made on the same dates the water clarity was measured. In addition, one water sample was drawn from both top and bottom depths at each station on the same dates as the clarity and profile measurements.

Figure 11 – Approximate locations of water quality sampling stations shown by red circles

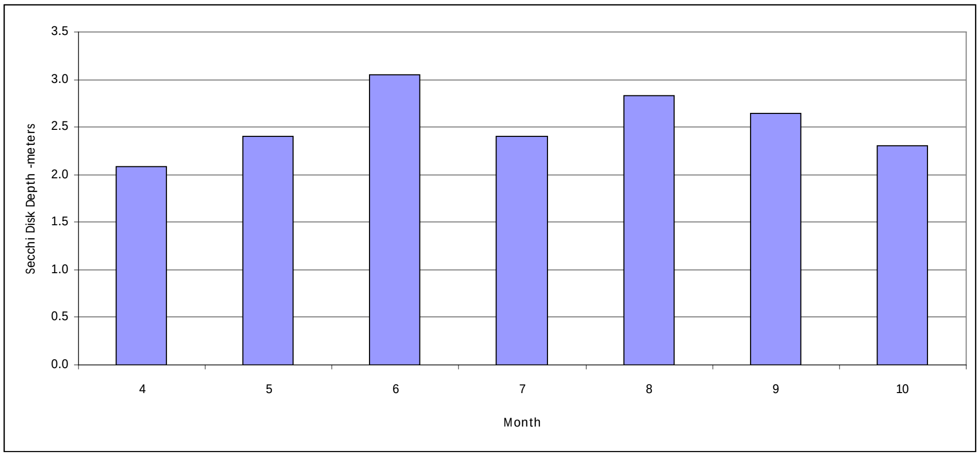


Water Clarity

Water clarity has been measured in Candlewood Lake 6 or 7 times annually, at each station, since 1986. In addition to this data set, CAES measured water clarity in 1973 (1 reading) and 1974 (4 readings).

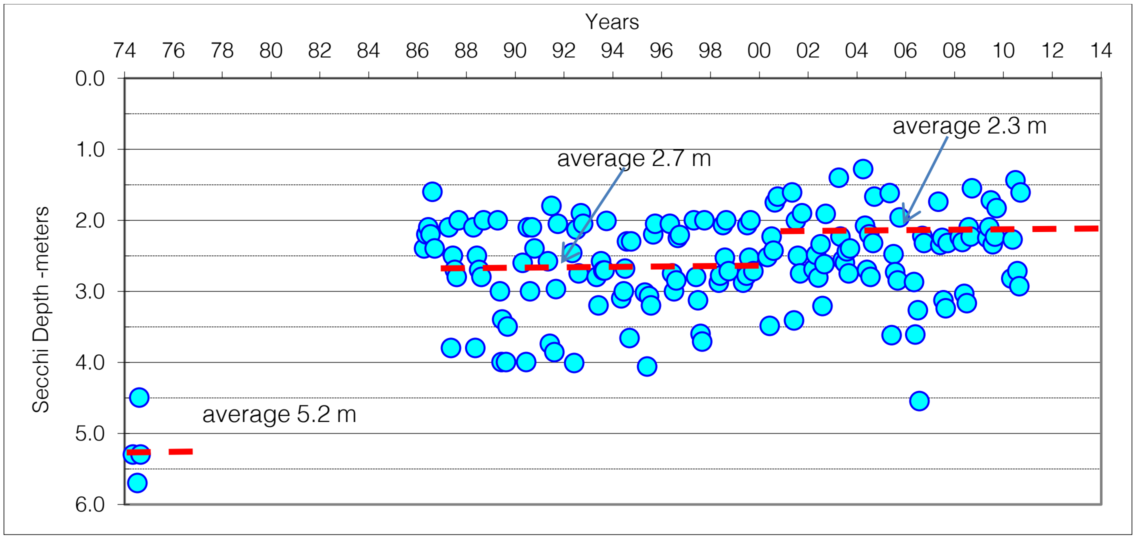
Average monthly water clarity for Candlewood Lake, shown graphically in **Figure 12,** indicates that clarity is generally between 2 and 3 meters (6.6 to 10 feet) during each season. Clarity is poor in the spring, increases to become clearest in June, but is followed by poorer readings in July and variable but declining conditions in the fall.

Figure 12 – Average monthly water clarity in Candlewood Lake



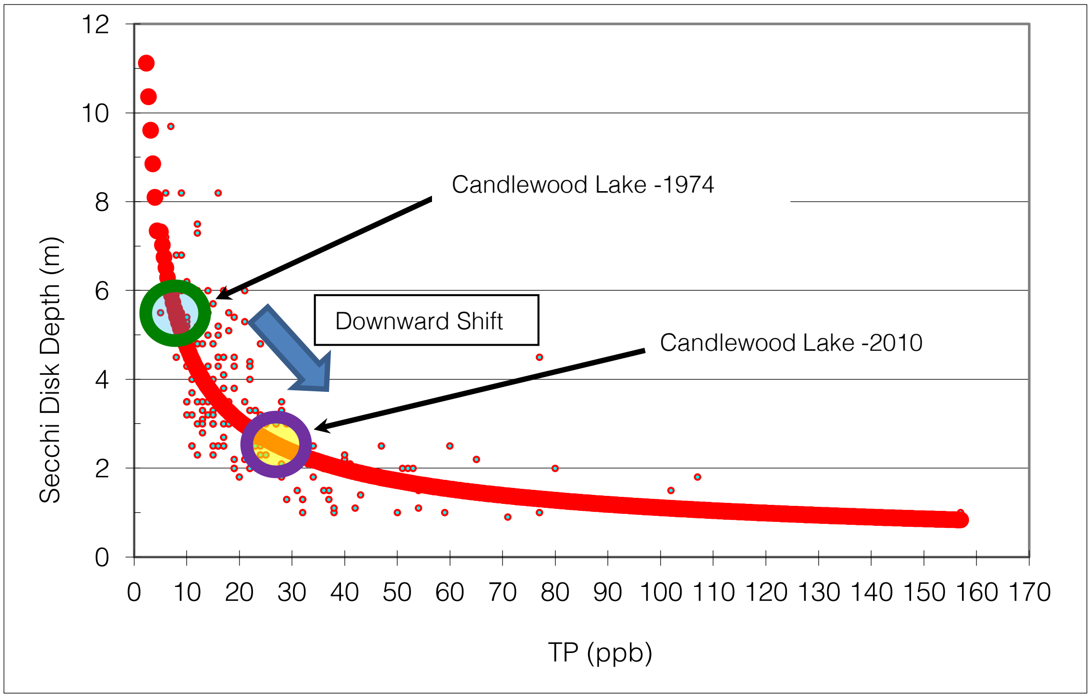
Water clarity readings measured at the New Fairfield station by CLA are shown in **Figure 13** together with measurements made in 1974 by CAES. Water clarity has declined significantly since the 1974 readings, when transparency averaged 5.2 meters. Data collected between 1984 and 2000 indicate that the lake had average clarity of 2.7 meters, while beginning in 2000 clarity has averaged 2.3 meters.

Figure 13 – Secchi disk depth values measured at New Fairfield station



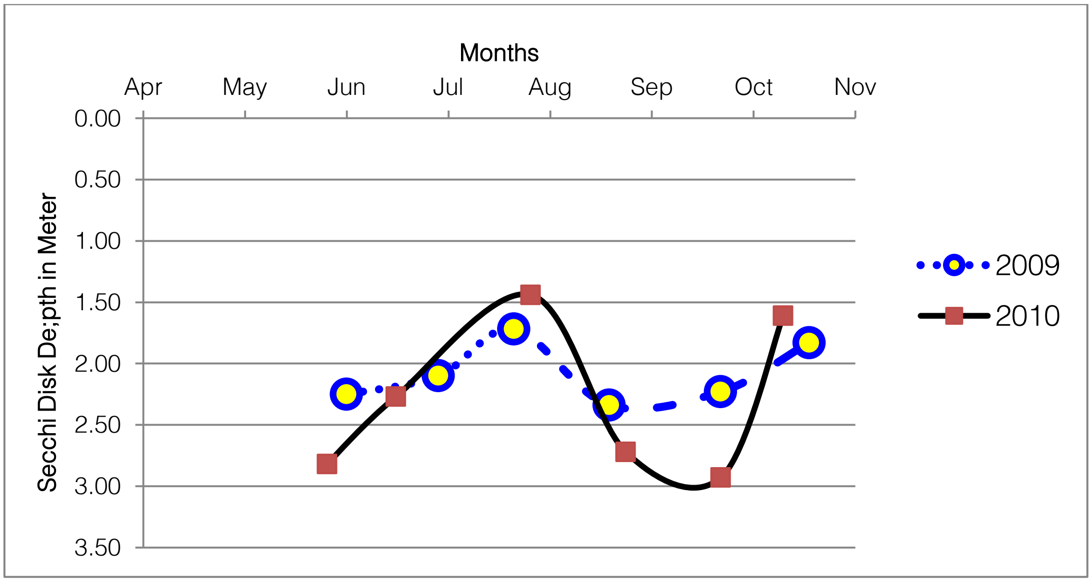
A decline in water clarity from 5.2 meters to 2.3 meters represents a significant change in lake condition. An empirical relationship of phosphorus and water clarity from a CAES survey of Connecticut Lakes conducted in the 1970's is shown in **Figure 14** (Frink and Norvell 1986). Clarity values show a non-linear decrease with increasing phosphorus concentration. The dotted line shows the approximate center of the data. Placing Candlewood Lake water clarity readings on the trend line suggests that phosphorus has more than doubled, from less than 10 ppb to nearly 30 ppb. The curve shown in **Figure 14** indicates that water clarity does not decline much below 1 meter (lowest data on the chart is 0.9 meters), even with greatly increasing phosphorus concentration. When phosphorus is greater than 30 ppb, blue-green algae (cyanobacteria) tend to dominate by forming surface blooms that self-shade their production, thereby limiting their growth. This creates a dangerous predicament for lake management because phosphorus concentration ceases to be perceived as the problem, i.e. moderate decreases in phosphorus concentration show no effect on the tenacious bloom conditions. The purple circle on **Figure 14** shows recent condition of Candlewood Lake suggesting that water clarity impairments will increasingly be caused by blue-green algae blooms.

Figure 14 – Empirical relationship between phosphorus and water clarity with data from Candlewood Lake superimposed over a dashed line showing the general trend



The water clarity readings for 2009 and 2010 at the New Fairfield station show wide fluctuation in transparency during each of the two seasons (**Figure 15**). Both years show an early summer and late summer decline to 1.5 meters Secchi disk depth, indicating blue-green blooms. The poor clarity in July was coincident with overlap of the thermocline and the anoxic boundary -- explained next.

Figure 15 - Trend in water clarity in Candlewood Lake during 2009 and 2010

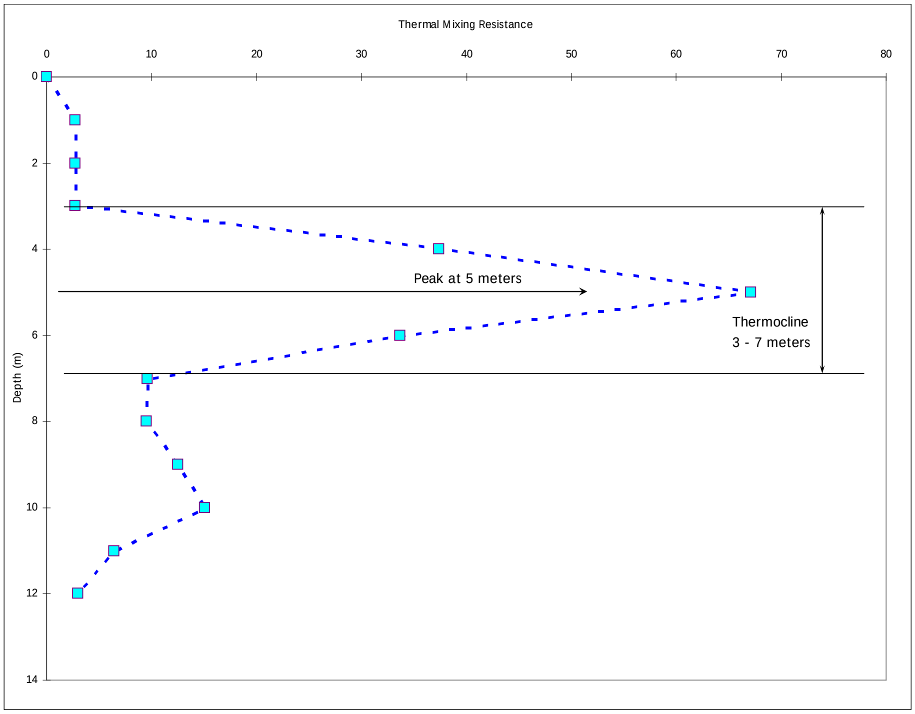


Thermocline

Each season is marked by warming of upper waters of a lake. Once ice leaves the lake, strengthening sunlight warms the surface water, causing water to become more buoyant, as water becomes less dense with increasing temperature. The penetration of the sun's rays into the water determines what depth the warmer buoyant will develop. This now-buoyant water floats over the cooler water below. During summer, the warm upper water becomes significantly less dense than deeper water. The large difference in density can be measured by calculating mixing resistance.

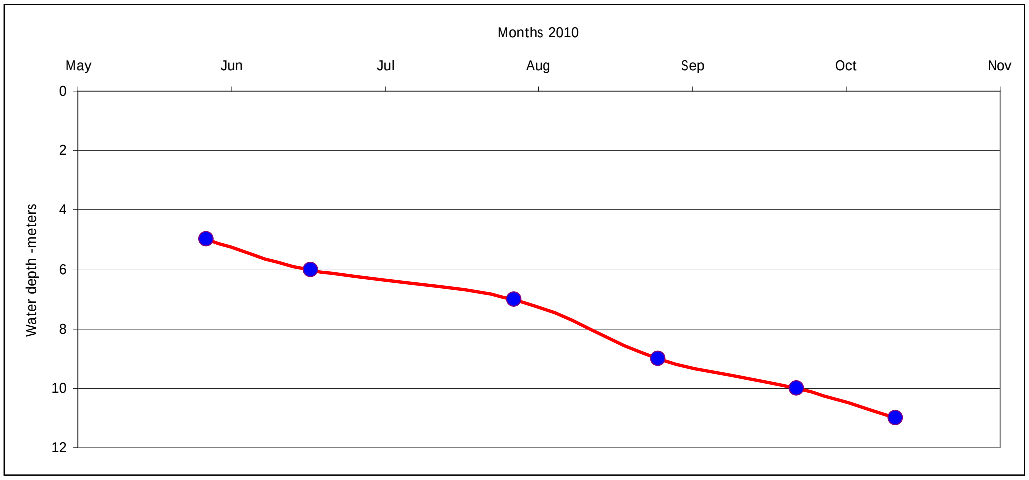
A profile of Candlewood Lake water temperature measured on May 27, 2010 at the New Fairfield station shows mixing resistance values at each 1-meter depth increment from top to bottom (**Figure 16**). The graph shows low mixing resistance between the surface and 3 meters of water depth (where water temperatures were equal) and very high values between 4 meters and 7 meters where there was a large decline in water temperature with depth. The peak resistance value of 68 occurred at 5 meters, indicating the position of the thermocline in the water column.

Figure 16 – Thermal resistance to mixing values in Candlewood Lake on May 27, 2010 at New Fairfield station



The depth of the thermocline steadily deepens during the season (Figure 17). The long 3–6 mile north-south wind fetch of the lake allows sufficient wind energy to force the thermocline to gradually descend during the summer.

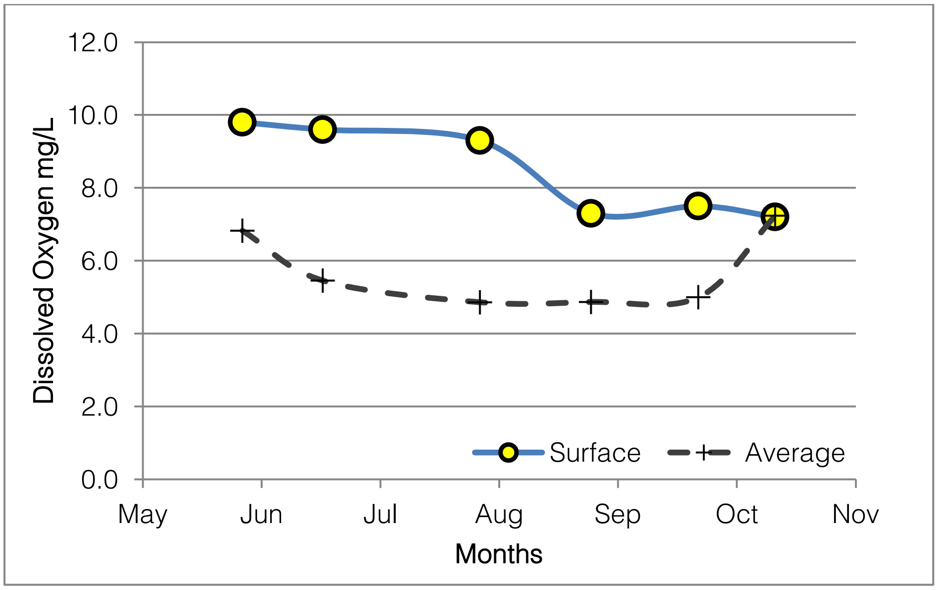
Figure 17 - Seasonal thermocline progression in Candlewood Lake measured at the New Fairfield station



Dissolved Oxygen

Oxygen diffuses into lakes from the atmosphere, becoming dissolved in water at much lower concentrations than in air. Whereas the atmosphere has 210,000 mg DO/L, water typically has only 8–9 mg DO/L. Dissolved oxygen can also become dissolved in water as a bi-product of photosynthesis by aquatic plants and phytoplankton. The chart in **Figure 18** shows dissolved oxygen content at the surface (circles) and an average of the whole water column (crosses). During the 2010 season, the dissolved oxygen in the surface of the lake averaged about 8.5 mg/L, while the water column average was closer to 5 mg/L, indicating the loss of oxygen from deeper waters.

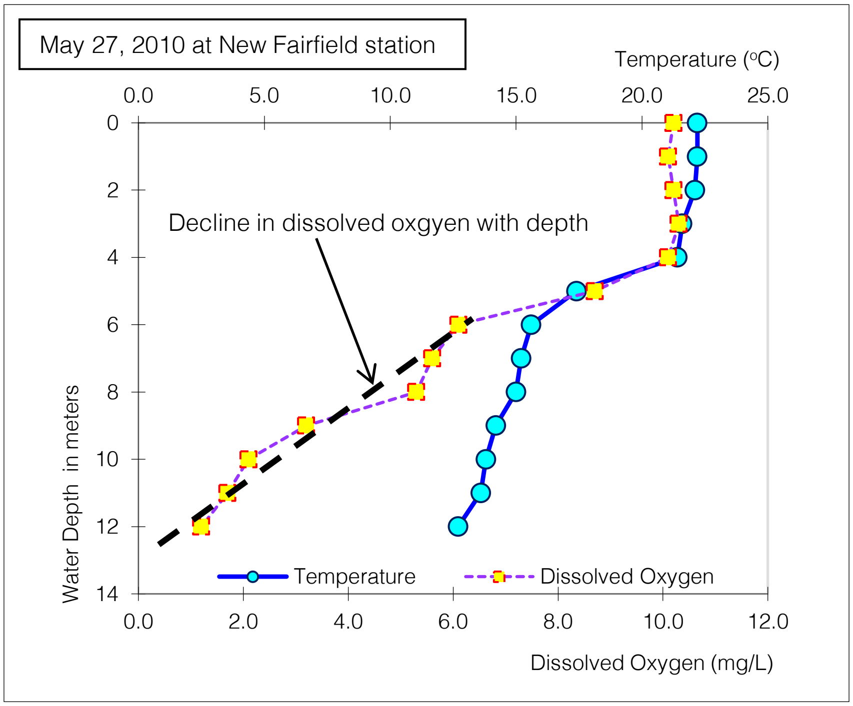
Figure 18 – Dissolved oxygen content in surface water (circles) and whole water column average (crosses) in Candlewood Lake at the New Fairfield station



Dissolved oxygen supply in deepest water is cut off from the atmosphere once the lake stops mixing and a thermocline develops in May. Isolation of deep water from sources of new dissolved oxygen leads to its depletion by bacterial decomposition of organic matter. Oxygen consumption begins at the sediment surface in deepest water in spring as the lake warms. Dissolved oxygen content at the New Fairfield station on May 27, 2010 is shown in **Figure 19**. The dissolved oxygen content between the surface (0 depth) and 4 meters was very similar at about 10 mg/L.

Between 4 meters and the bottom the amount of dissolved oxygen slowly declines, becoming depleted at the bottom at 12 meters.

Figure 19 – Profile of water temperature and dissolved oxygen measured at the New Fairfield station on May 27, 2010

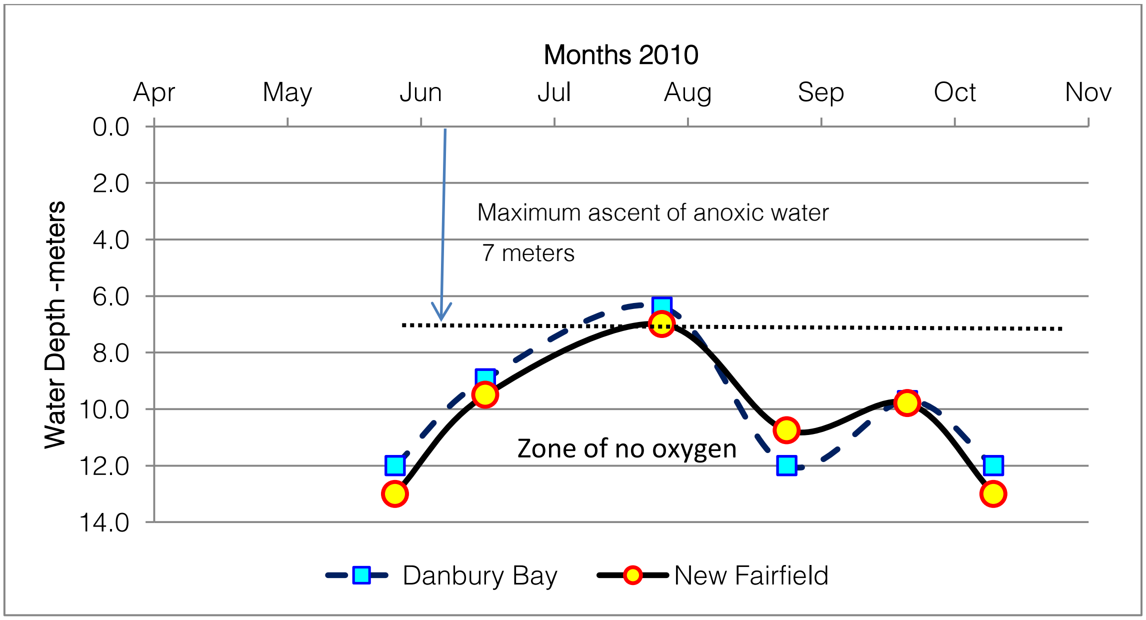


With progression of summer, more and more bottom water is stripped of its supply of dissolved oxygen. A boundary develops separating water with oxygen above, from water without oxygen below. The location in the water column where water with oxygen meets water without oxygen is termed the anoxic boundary and is measured as depth down from the surface.

Each summer the anoxic boundary reaches a minimum distance from the surface, representing the equilibrium between the oxygen consumption force from below and the rate of diffusion and re-supply from the atmosphere above. As the demand for oxygen in bottom sediments increases, the boundary between oxygen and no oxygen is forced upward, closer to the water surface.

The pattern of oxygen loss in Candlewood Lake during 2010 is shown in **Figure 20**. The chart shows the boundary between water with dissolved oxygen and water without dissolved oxygen. The maximum volume of the lake devoid of dissolved oxygen occurs when the anoxic boundary is at a minimum distance from the surface. During 2010 this occurred at the end of July when all water below 7 meters was anoxic. The chart in **Figure 19** shows the lake early in the season when the anoxic boundary was at 12 meters below the surface or just over the bottom.

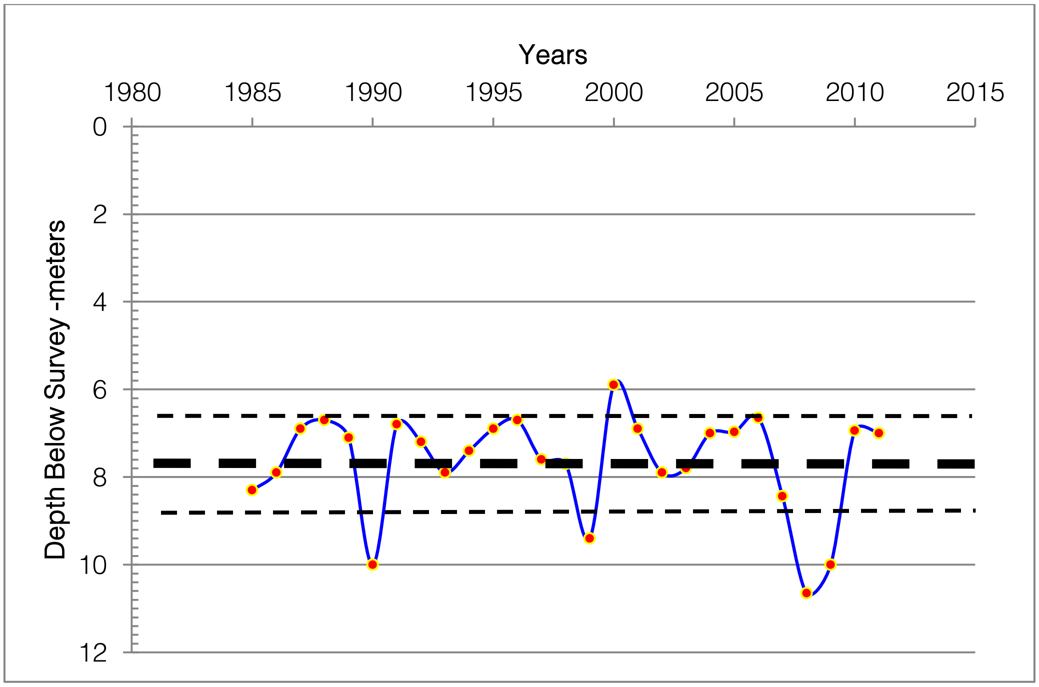
Figure 20 – Seasonal trend of anoxic boundary during 2010 at two stations in Candlewood Lake



The minimum depth from the surface that the anoxic boundary reaches each year is shown as a time series in **Figure 21**. The long-term average minimum depth in the water column of anoxic water is 7.6 meters. About 68% of the annual minimums fall within an upper and lower confidence interval of 1.2 meters (dashed lines in **Figure 21**). This means that a majority of the years of record showed the anoxic boundary to reach minimums of between 6.1 and 9.5 meters below the surface.

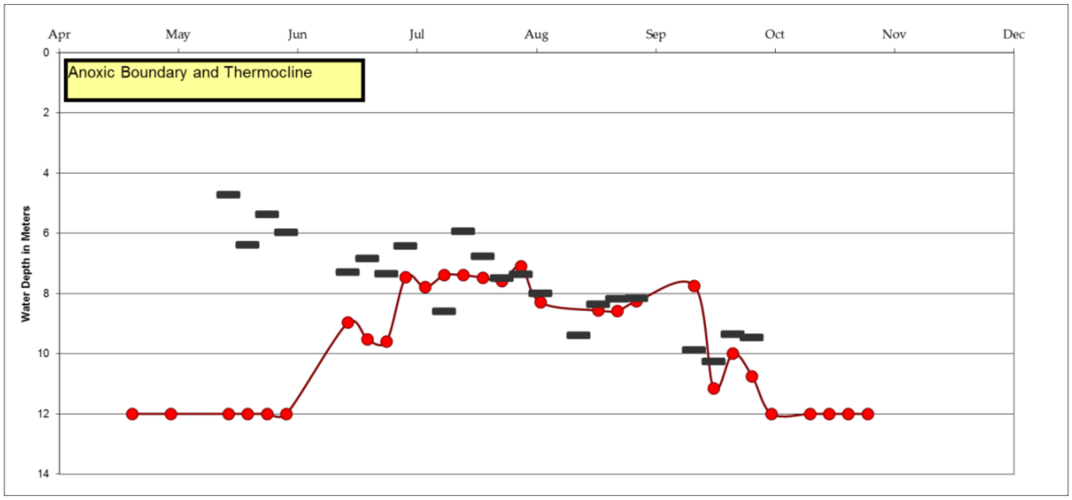
This range in annual minimums represents a difference in oxygen consumption of about 335,000 kg O_2. In other words, 335,000 kg more dissolved oxygen is consumed when the anoxic boundary reaches 6.1 meters than when it only reaches 9.5 meters. This is a large difference in oxygen consumption from year to year, implying that the load of oxygen demand material to the lake bottom varies seasonally. Variation in volume of anoxic water from year to year could be due to variations in lake mixing, variation in water temperature, differences in water clarity, fluctuations in air temperature, changes in the quantity of algae in the water, and/or changes in the amount of biological oxygen demand in the water.

Figure 21 – Minimum depth of anoxic water, measured down from the surface, at New Fairfield station



A composite of all years of data, shows thermocline migration downward and anoxia upward in Figure 22. The chart shows the two boundaries meet in July corresponding to the timing of the first period of poor clarity shown in Figure 15 (page 42).

Figure 22 – Seasonal trends of thermocline (black bars) migration downward and anoxic boundary (red circles) ascension upward in Candlewood Lake



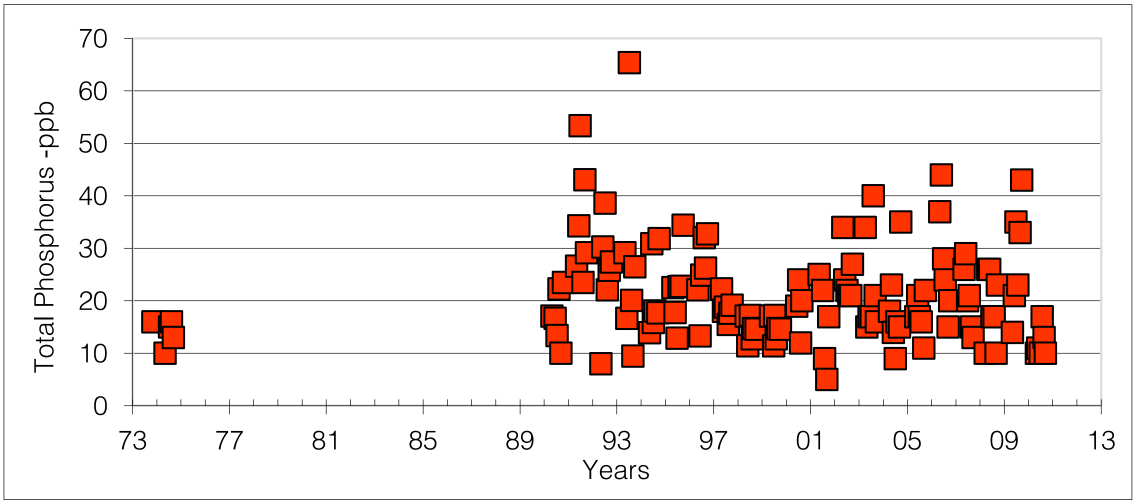
Phosphorus

Total phosphorus has been linked to decreased water clarity in lakes because this nutrient is generally in the shortest supply to phytoplankton growth, triggered by increased phosphorus in the water (Wetzel 2001). When phosphorus is below 10 ppb the water is very clear, usually averaging 6-meter transparency. Lakes with more than 10 ppb in the upper water have decreased water clarity; those with more than 30 ppb have significantly poorer clarity, with a higher chance of blue-green algae (cyanobacteria) blooms.

Surface or Epilimnion Phosphorus

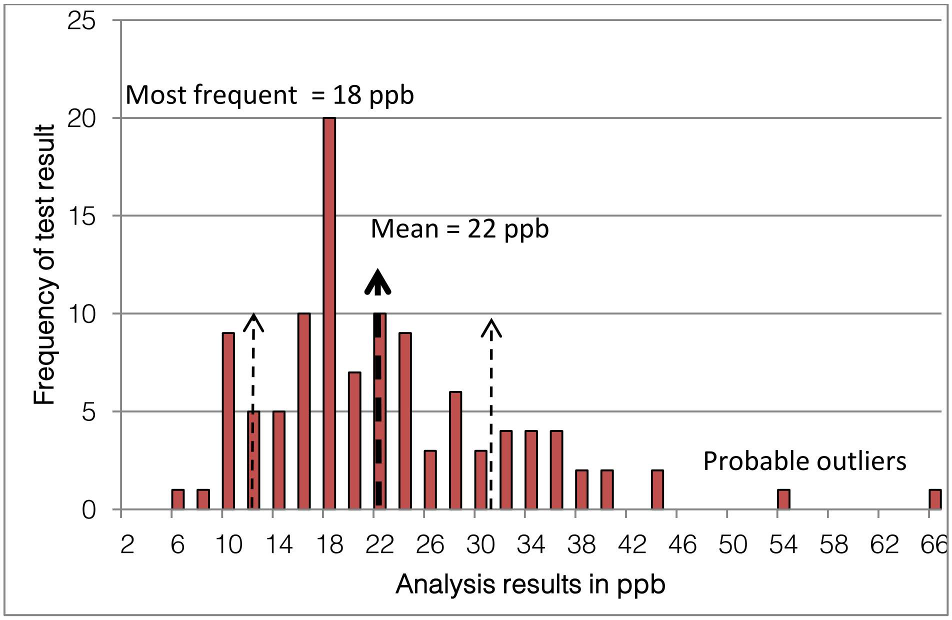
Total phosphorus collected from the epilimnion or surface waters of Candlewood Lake at the New Fairfield station between 1990 and 2010 show concentrations have ranged from a low of 5 ppb to a high of 65 ppb, with a mean of 21 ppb (**Figure 23**). Also shown in **Figure 23** are results from phosphorus testing conducted by CAES in 1973 and 1974 (Frink and Norvell 1984) when surface phosphorus concentrations ranged from 10 ppb to 16 ppb.

Figure 23 – Total phosphorus concentration (as ppb) in surface water of Candlewood Lake collected at the New Fairfield station



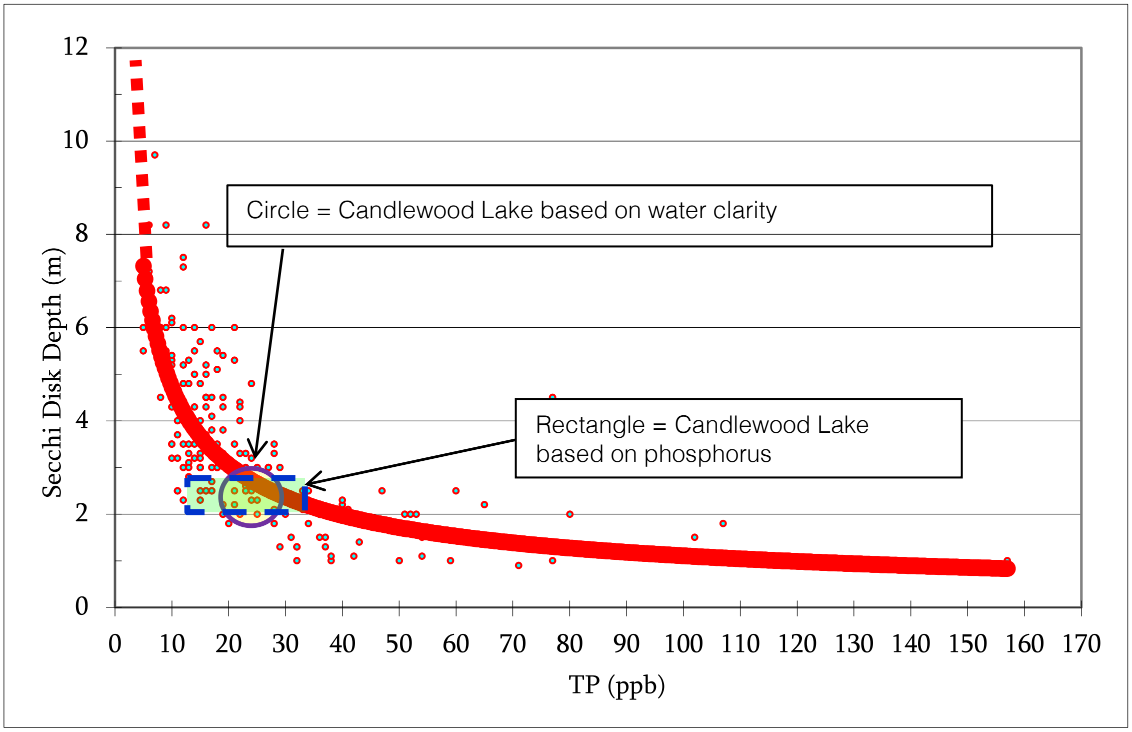
Phosphorus concentration results from 1990–2010 testing, as shown in **Figure 23,** appear scattered, with no pattern. Data are shown sorted by frequency of test result in **Figure 24**. The mean of the data is 22 ppb (heavy dashed arrow), although the most frequent value is 18 ppb, suggesting that the concentrations are skewed to the right or toward higher levels. Two-thirds of the results fall within the range of 12 ppb to 31 ppb (light dashed arrows). This range means that about one-third of the time phosphorus concentration results show the lake to have between 22 and 31 ppb, or high enough to support blue-green algae blooms. The very high values of 53 and 65 ppb appear as outliers, or values that don't fit with the rest of the data.

Figure 24 – Epilimnetic phosphorus test results between 1990 and 2010



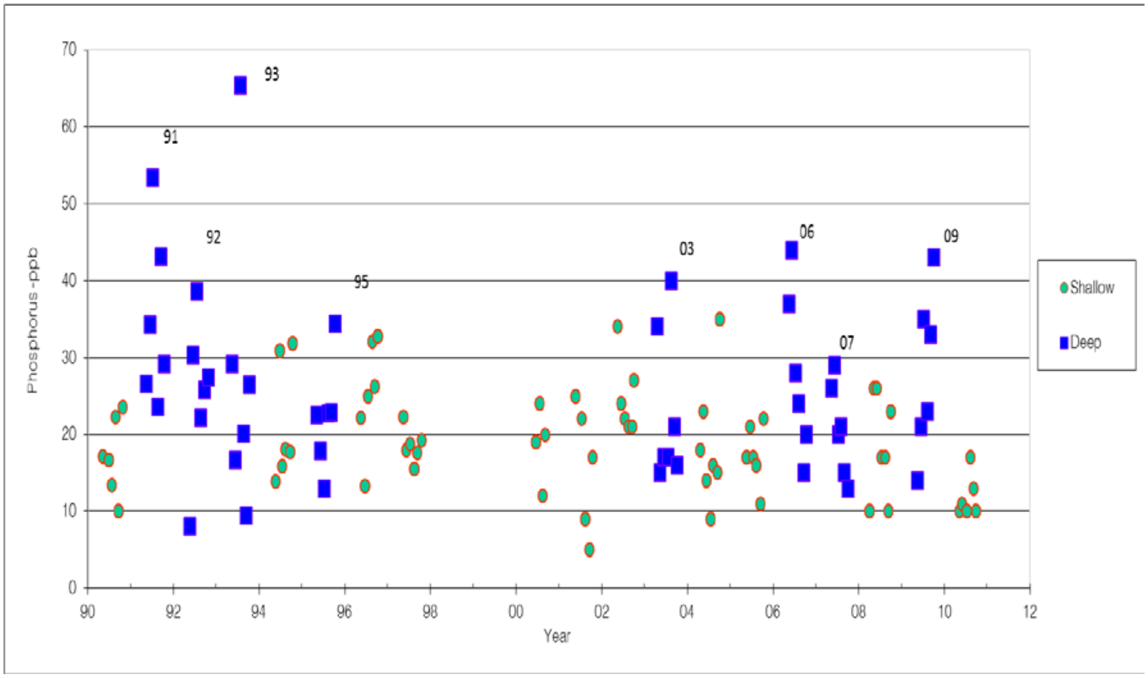
Candlewood Lake epilimnetic (surface water) phosphorus and water clarity data are shown superimposed over general relationship between these parameters in CT lakes see Figure 25 (Frink and Norvell 1986). Candlewood Lake data for phosphorus and water clarity plot together, indicating that phosphorus is principal driver of algae and water clarity. Phosphorus frequency data in Figure 24 shows that the upper end of the 68% phosphorus confidence limit (light dashed arrow) is 31 ppb, indicating that it is likely that the lake will have concentrations over 30 ppb. This is very probable now that the lake condition is tracking down and to the right in Figure 25 -- that is, toward more frequent periods of water clarities of less than 2 meters caused by blue-green algae blooms during summer months. The trend in water clarity during 2010 (see Figure 15, page 42) suggests that this may be happening now. Two periods of very poor clarity, 1.5 meters, occurred during that summer. Serious blue-green blooms that lower clarity to below 2 meters tend to become dominant due to changes caused in the water column under low light conditions of a dense bloom. Lack of light increases anoxia, which leads to accelerated internal loading and recycling rates. The high growth rates of blue-green algae during a bloom greatly add to the number of cells dying and sinking into deep waters. The sinking cells decompose, furthering the loss of dissolved oxygen and adding to the increase in anoxia, which in turn augments recycling and release of phosphorus. With the increase in the phosphorus concentration, the feedback loop is completed as the renewed flux of nutrient causes more algae growth.

Figure 25 – Candlewood Lake and phosphorus and water clarity



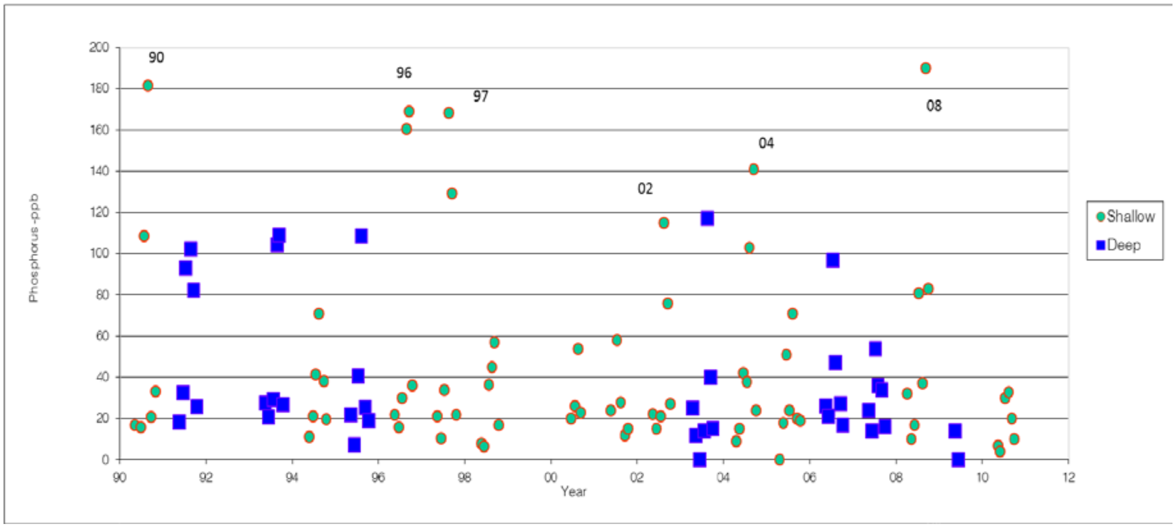
Phosphorus concentration appears to be higher after deep drawdowns. Phosphorus concentrations in surface waters the following summer are shown differentiated by either deep or shallow drawdown (Figure 26). The chart shows that after deep drawdown (years 91, 92, 93, 95, 03, 06, 07, and 09) phosphorus is high for at least part of the year. In fact, concentration values in the 30-40 ppb range are common after a deep drawdown but rare after shallow drawdowns, while values that exceed 40 ppb occur only after deep drawdowns, indicating that deep drawdown might be responsible for increased phosphorus in the lake. The mean TP after a deep drawdown is 26 ppb, while after a shallow drawdown it's only 19 ppb, but these averages may not be significantly different, so more analysis is needed to determine this.

Figure 26 – Phosphorus concentration (ppb) in surface water after deep drawdowns (squares), and shallow drawdowns (circles) with deep drawdown years also shown



Phosphorus recycling and internal loading of phosphorus from anoxic sediment causes the concentration of phosphorus in bottom water to be higher than epilimnetic water. Phosphorus concentrations in bottom waters at the New Fairfield station are shown in Figure 27. Phosphorus typically exceeds 100 ppb each year. However, data suggest that highest bottom water concentrations occurred after shallow drawdowns.

Figure 27 - Phosphorus concentration (ppb) in bottom water after deep drawdowns (squares) and shallow drawdowns (circles) with shallow drawdown years also shown.



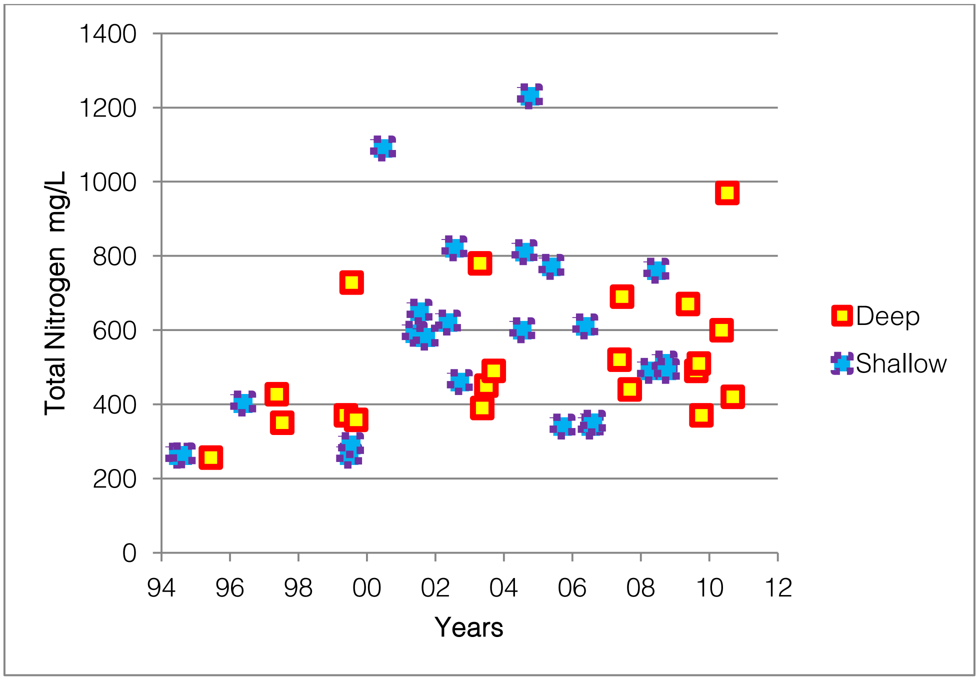
High phosphorus values in the epiliminon after deep drawdown could be due to phosphorus release from dead vegetation and re-suspension of winter depositions of silt. During a deep drawdown, the influx of ground water may be higher, bringing in more nutrients, causing increases in surface water the following year. Phosphorus in bottom water appears to reach higher values after shallow drawdowns. This may be due to more efficient transport from shallow areas to deepest water during the deeper water depths along the shorelines.

No significant difference was found between phosphorus concentration results from New Milfoil station, where Housatonic River water enters the lake, and results from the New Fairfield station. This suggests that Housatonic River water is not causing increased phosphorus in Candlewood Lake.

Nitrogen

Nitrogen is the plant nutrient with second highest supply-to-demand ratio after phosphorus. Nitrogen tends to be limiting in lake sediments because it's typically transformed into nitrogen gas, which escapes to the atmosphere. High nitrogen in lake water implicates high sediment nitrogen levels. Nitrogen loading to shallow lake sediments within the littoral zone from the drainage basin will fuel aquatic plant growth. Total nitrogen in lake water has increased since monitoring began (**Figure 28**). In 1994, nitrogen levels were around 250 mg/L. Now nitrogen ranges between 400 and 1,000 mg/L. No differences are apparent between nitrogen concentrations after a shallow vs. deep drawdown.

Figure 28 – Total nitrogen concentrations in Candlewood Lake between 1994 and 2010



Fisheries

Fisheries data for Candlewood Lake comes from CT DEEP Inland Fisheries Division records. Two types of collections have been conducted by CT DEEP, gill-net hauls and electroshocking surveys. Gill-nets, employed in open-water, target pelagic fish, while electro-fishing favors littoral zone fish, indicating that the two types of data may not be directly comparable.

Gill-nets were set in 1976, 1977, and 1978 to assess possible changes in the trout fisheries due to introduction of landlocked alewives (Orciari 1977, 1979). The new forage fish was expected to cause changes in fishery. There were 19 species of fish caught using gill-nets at uniform abundances in each set (**Table 9).** The table arranges species into three categories: abundant, common, and scarce.

Table 9 – Fish species caught in gill-nets set between 1976 and 1978

Abundant	Common	Scarce
Alewife	Largemouth Bass	Smallmouth Bass †
Yellow Perch	Brown Trout *	Black Crappie
White Catfish*	Rainbow Trout *	Black Bullhead
Rock Bass	Brown Bullhead *	Golden shiner †
Chain Pickerel*	Yellow Bullhead	White Sucker
Bluegill Sunfish	Banded Killifish	Common Sunfish
White Perch	Spottail Shiner *	

* indicates species was rare in electro-fishing
† = indicates species was abundant in electro-fishing

One species, chain pickerel, has not been caught during any subsequent electroshocking survey. Chain pickerel had been found at slightly above state average with 15 inch (38 cm) specimens caught in gill-nets. All other species collected in gill-nets have been recorded from electroshocking surveys, suggesting that chain pickerel population has been impacted, causing the fish to become very scarce.

One species, smallmouth bass, found at very low numbers during gill nets, is now found in high numbers.

Electro-fishing surveys have been performed during 9 different years between 1988 and 2010, spanning a number of different drawdown conditions. This suggests that electroshocking data may reflect impacts to fisheries in Candlewood Lake. The surveys were conducted during the spring months of May–June during the following years: 1988, 1992, 1998, 1999, 2002, 2003, 2005, 2009, and 2010.

During each electroshocking survey, lengths and numbers for 30 fish species were recorded (**Table 10**). The table gives species presence during the surveys in order of abundance.

Table 10 – Fish species caught during electro-fishing surveys on Candlewood Lake

	1988	1992	1998	1999	2002	2003	2005	2009	2010
Bluegill sunfish	x	x	x	x	x	x	x	x	x
Alewife	x	x	x	x	x	x	x	x	x
Redbreast sunfish	x	x	x	x	x	x	x	x	x
Pumpkinseed sunfish	x	x	x	x	x	x	x	x	x
Yellow bullhead	x	x	x	x	x	x	x	x	x
Yellow perch	x	x	x	x	x	x	x	x	x
Largemouth bass	x	x	x	x	x	x	x	x	x
Smallmouth bass	x	x	x	x	x	x	x	x	x
Rock bass	x	x	x	x	x	x	x	x	x
Golden shiner	x	x	x	x	x	x	x	x	x
Common carp	x	x	x	x	x	x	x	x	x
Bluntnose minnow			x	x	x	x	x	x	x
White perch	x	x	x	x	x	x	x		
Spottail shiner			x	x					
Banded Killifish		x	x	x	x	x	x	x	x
Brown trout	x	x			x	x	x	x	
Black crappie	x	x		x		x			x
Bluegill x Pump Hybrid				x	x	x	x	x	x
Pumpk X Red hybrid			x		x	x		x	
Red x Bluegill Hybrid					x	x	x		
Rainbow trout	x	x	x	x	x	x	x		x
Brown bullhead	x	x					x	x	
White sucker		x				x		x	x
White catfish	x	x					x		
Hybrid sunfish			x						
Brook trout						x			
Tesselated darter							x		
Cutlips minnow							x		
Black bullhead				x					

The first 11 species were found during each survey, so presumably they have not been seriously impacted by drawdowns because they continue to persist at high enough numbers to be caught during each survey. The next 13 species were caught during 2 to 8 of the surveys, but without any apparent trends showing increasing or decreasing frequency of occurrence. The last 5 species have only been caught once and are presumed to be rare in Candlewood Lake, generally.

The numbers of fish of each l-cm length increment that were caught after each type of drawdown were compared. Comparisons often yielded little or no differences between numbers of fish of different lengths caught after a deep vs. shallow drawdown. The graph in **Figure 29** shows that largemouth bass numbers for each centimeter length after deep and shallow drawdowns were essentially the same. Some fish showed seemingly significant differences between numbers after deep vs. shallow drawdown, shown 10-15 cm yellow bullhead in **Figure 30**. Charts of all species are included in the appendix.

Figure 29 – Number of Largemouth Bass caught by length (cm) after either shallow or deep drawdowns

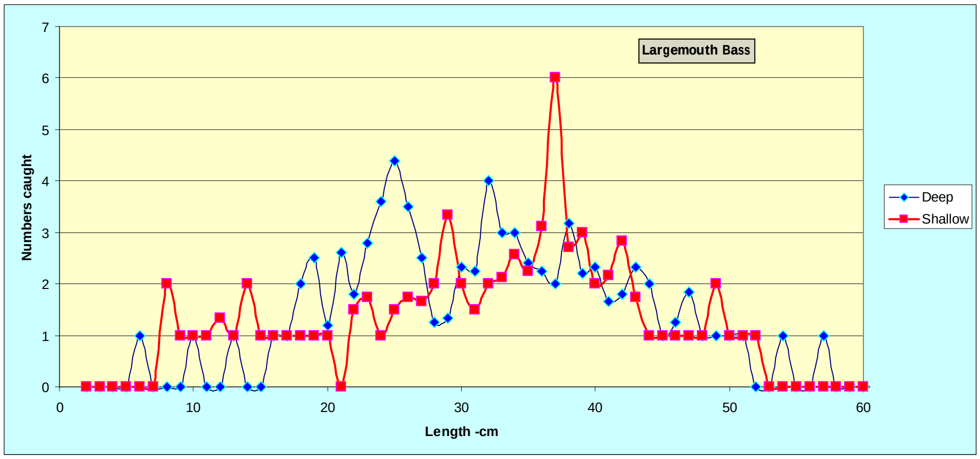
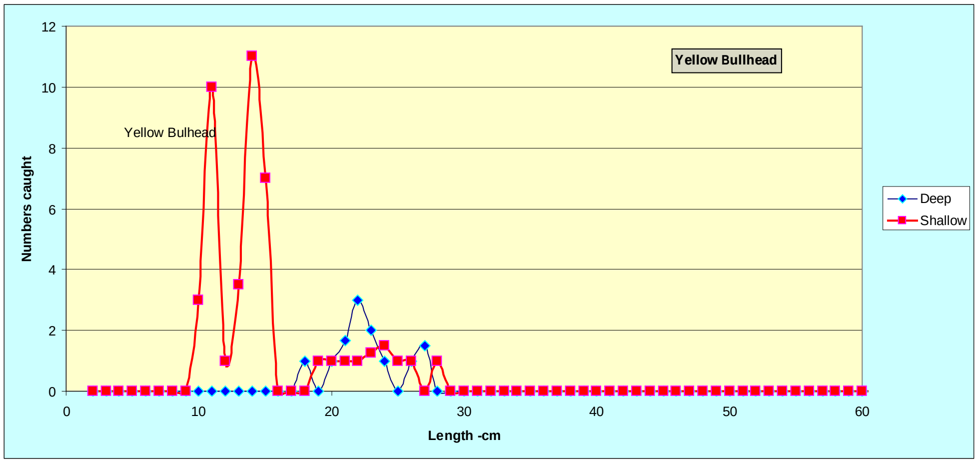


Figure 30 - Number of yellow bullhead caught by length (cm) after either shallow or deep drawdowns



A summary of differences, however slight, in the numbers of fish by size is given in Table 11. Several species show some difference, even if it is within small ranges of size. It is unclear if these differences are meaningful with regard to impacts from drawdown.

Table 11 – Notes on possible species differences after either shallow or deep drawdowns from CT DEEP electroshocking surveys

Species	Notes on abundance after either Shallow Drawdown (SD) or Deep Drawdown (DD)
Bluegill sunfish	More 13 – 17 cm fish after SD
Alewife	Maybe more 10 cm fish after SD
Pumpkinseed sunfish	About the same in each maybe slightly more fish 16 -17 cm after DD
Yellow perch	Maybe more 11 -12 cm fish after DD- other sizes seem the same
Redbreast sunfish	More 7 – 16 cm fish after SD
Spottail Shiner	Very scarce generally - maybe more fish after DD
Bluntnose minnow	Maybe more small 4 & 5 cm fish after SD
White perch	Maybe more <20 cm after SD, almost no fish <20 cm after DD
Yellow bullhead	Definitely more abundant <15 cm fish after SD
Largemouth bass	Not much difference
Smallmouth bass	Not much difference
Rock bass	No difference
Brown trout	Maybe slightly more large fish after SD
Black crappie	Scarce fish not much difference
Golden shiner	More abundant fish >30 cm after SD
Common carp	No difference
Banded Killifish	Scarce fish maybe slightly more larger fish after SD

Rainbow trout	Scarce fish not much difference
Brown bullhead	Scarce fish, maybe a few more small fish after SD
White catfish	No difference
Pump X Redbreast hybrid	Very scarce fish
Hybrid sunfish	Very scarce fish
Redbreast x Bluegill Hybrid	Very scarce fish
Bluegill x Pump Hybrid	Very scarce fish
Walleye	Very scarce fish
Tessellated darter	Found once after SD
Cutlips minnow	Found once after SD
White Sucker	Very scarce fish
Black bullhead	Found once after DD
Brook trout	Found once after DD

Electroshocking records were also looked at for possible changes in species abundance over time. Abundance was assumed to be catch-per-unit effort in hours. It is possible that over the long term, some species will show trends of either declining or increasing numbers, or will show changes in abundance after shallow vs. deep drawdowns. Graphs of catch per unit effort in hours (cpu) for each species over time were constructed and proved to offer little conclusive evidence that drawdown has caused changes in abundance (Figure 31 shows cpu over time for smallmouth bass).

For example, the abundance of smallmouth bass appears to have been stable between 1988 and 1999, increased during 2002-2005, but declined again to previous levels during 2009 and 2010. Deep and shallow drawdowns occurred during each period of similar numbers. For example during the surveys of 2009 and 2010 abundance was about 80 cpu, but 2009 was after a deep drawdown and 2010 was after a shallow drawdown.

Largemouth bass may be the only species to show a possible trend in declining numbers over the time period of the shocking surveys (Figure 32). Early surveys caught between 50 and 70 fish per hour, while latter surveys (2009 and 2010) have caught only 13 fish per hour.

Figure 31 – Abundance of smallmouth bass in Candlewood Lake

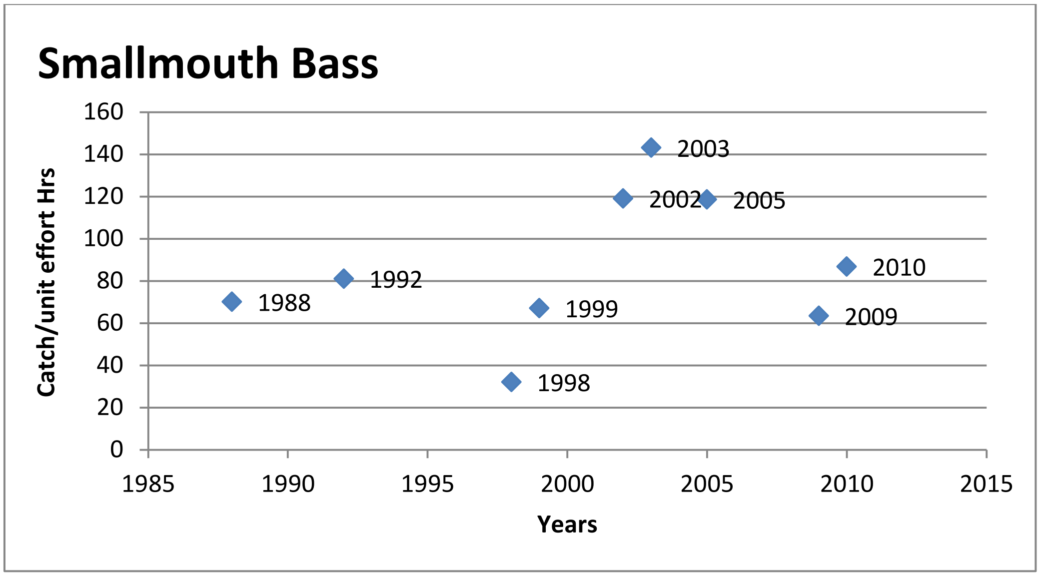
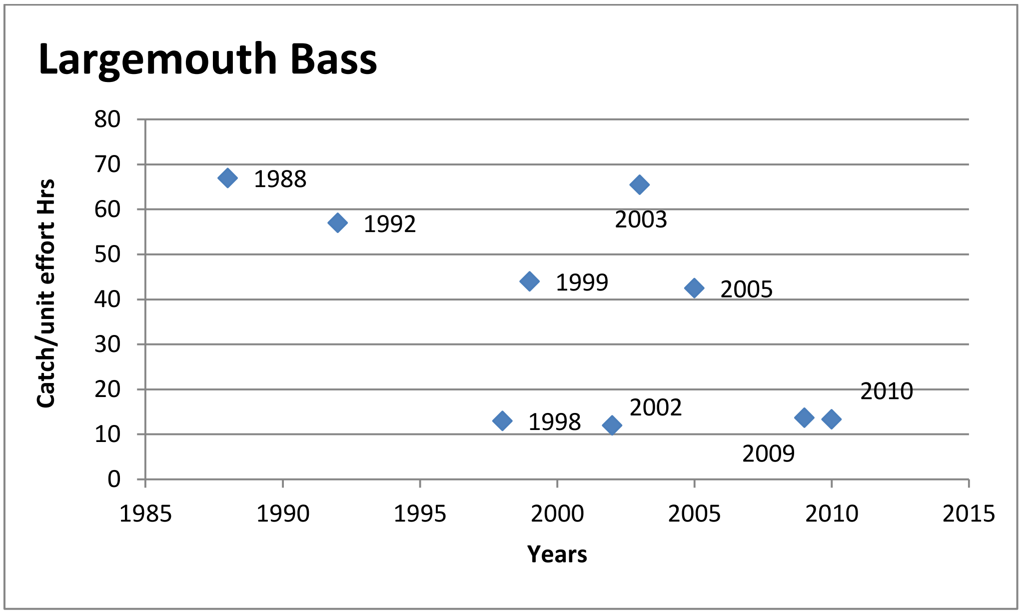


Figure 32 - Abundance of largemouth bass in Candlewood Lake



Available information about spawning requirements and preferred habitats (Table 12) for the different fish species in Candlewood Lake indicates that most species use aquatic vegetation or shallow waters. Removing a majority of the vegetation from the littoral area may put sustained stress on species and populations that require either vegetation structure or forage base associated with healthy habitats of standing vegetation.

Table 12 – Spawning requirements and preferred habitats of fish species in Candlewood Lake

Species	Spawning Requirements	Preferred Habitat
Largemouth Bass	Mid May – June, in shallow water 2 – 8 feet	Water Inshore near vegetation
Smallmouth Bass	Mid May – June, in shallow water 2 – 8 feet	Inshore near rocky structures
Brown Trout	Fall, head water streams	Offshore open water
Rainbow Trout	Spring, head water streams	Near shore open water
Rock Bass	Mid May – July, Shallow water ?	clear lakes rocky w/vegetation
Black Crappie	April, very shallow water 1 - 2 feet	Outside vegetation edge, dead trees
Yellow Perch	Late March – Early April, vegetation in shallow water	Inshore cool weather, offshore hot weather
Brown Bullhead	Spring – early summer, shallow water	Inshore over muddy bottom
Sunfish	Mid May – July, Shallow water	Inshore near vegetation
Golden Shiner	Early spring to late summer, vegetation	Vegetated areas
Spottail Shiner	Feeder streams during spring	Vegetated areas
Alewife	Late May - early June, lake bottom	Open water
White Sucker	Feeder streams during spring,	Bottom with aquatic invertebrates
Bluntnose Minnow	July lake bottom	Silt bottoms in vegetation
White Perch	early spring 2- 20 feet aquatic veg	semi –pelagic
Yellow Bullhead	nest builder in spring to early summer	Benthic
Banded Killifish	Spring vegetation	*
White Catfish	nest builder in spring to early summer	lakes with moderate veg
Black Bullhead	nest builder in spring to early summer	*
Cutlips Minnow	Spring	Large rocks and logs
Tessellated Darter	Spring	*
Walleye	Sandy gravel rubble bottoms	*
Common Carp	late spring early summer broadcast over veg	*

* Information not found on these species

Invertebrates

Lakes have two principal habitats: littoral and pelagic[2]. The littoral habitat is all the shallow water areas of the lake where sunlight reaches the bottom. Water that is deeper than this is considered open water or pelagic. Life in the pelagic habitat is limited to planktonic plants (algae), planktonic animals (zooplankton), and fish. All other life in a lake exists in the littoral zone[3]. Because sunlight reaches the bottom sediments of the littoral zone, this is the part of the lake that supports rooted plant growth. Generally all surfaces of the littoral zone -- plants, rocks, and sediments -- are coated with a covering of attached algae or periphyton. The periphyton is grazed by a number of tiny animals, including insects, snails, small crustaceans, and fish[4]. These tiny grazers attract larger insects, and other organisms that feed on them, and so on, up the food chain.

The littoral zone provides two basic types of sub-habitat, aquatic plant structure and bottom surfaces such as rocks and sediment. Each gives different advantages for growth and development of littoral organisms. Along with serving to transfer energy up the food chain, many insects of the littoral zone also perform important processing and material cycling functions (Table 13). Without representatives of these groups present in the littoral zone, the operations are not accomplished.

Table 13 – Insect functional groups

Shredders $>10^3$	Chewers and miners	Herbivores - living vascular hydrophyte tissue (Diptera-Chironomidae)
	Chewers and wood borers	Detritivores - Decomposing vascular plant tissue (Diptera-Tipulidae)
Collectors = fine POM $<10^3$	Filterers or suspension feeders	Herbivore - Detritivores Living algal cells, decomposing POM (Diptera-Simuliidae)
	Gatherers or deposit feeders	Detritivores - Fine particle detritivores Decomposing POM (Hemiptera-Gerridae)
Scrapers $<10^3$	Mineral Scrapers	Herbivores - Periphyton and other microflora attached to living and non-living substrates
	Organic Scrapers	Herbivores – Algae and associated microflora
Predators	Swallowers (Engulfers)	Carnivores – whole prey
	Piercers	Carnivores – cell and tissue fluids

[2] Lakes also have a benthic or bottom habitat but in Candlewood Lake that zone is probably of minor habitat value because of routine anoxia.
[3] Actually some organisms – insect larva and worms -- can exist in bottom mud during anoxia.
[4] It should also be noted that other animals such as waterfowl and mammals utilize the productivity of the littoral zone.

Parasites		Internal and external parasites

Available data on the invertebrate populations in Candlewood Lake was limited to one set of collections made in June 2010 at three shallow water sites around the lake (Table 14). Whole orders of organisms were represented by a few or in some cases by only a single genus. These few data suggest the macro-invertebrate population exists at very low diversity, composed of a few drawdown tolerant species.

Table 14 – Invertebrate results from 2010 surveys by North East Naturalists Services

Site	Order	Family	Genus
Sherman			
	Insecta	Diptera	Chironomidae
			Ceratopogonidae
		Hemiptera	Gerridae
			Lestidae
	Gastropoda	Physidae	Physella
		Planorboidea	Planorbula
Deer Island			
	Amphipoda		Gammarus
	Insecta	Tricoptera	Leptoceridae
		Ephemeroptera	Heptageniidae
			Ephemerillidae
		Diptera	Chironomidae
New Milford			
	Amphipoda		Gammarus
	Insecta	Ephemeroptera	Heptageniidae
		Odonata	Coenagrionidae
		Diptera	Chironomidae
	Gastropoda	Physidae	Physella

As noted earlier, the littoral zone of Candlewood Lake (the band of lake shore from shoreline to 15 feet of water depth) is approximately 753 acres in size. When the lake is drawdown to 10 feet below normal summer level, approximately 539 acres or about 71% of the littoral zone is exposed to desiccation and low winter temperatures. During a shallow drawdown of 6 feet below normal summer level, 290 acres is exposed or about 38% of the littoral zone. Each year, between a third and two thirds of the littoral zone habitat is impacted by freezing and drying of the bottom surfaces and removal of plant structure. It is unknown at this time how much damage this has caused or will continue to cause to the food web and organic matter processing in the lake. Based on limited invertebrate data so far collected, the existing population is extremely reduced in numbers and species diversity. Results from winter water level drawdown of Lake Bomoseen, Vermont (VANR 1990) showed adverse impacts on all littoral macroinvertebrate communities; mussels and snails were almost eliminated and most insect species were lost. Many species took over 6 months to recover.

Fish feeding preferences are given in **Table 15**. It should be noted that fish, as a group, are opportunity feeders for the most part in that they eat whatever is available. However, most species of fish in Candlewood Lake feed on the invertebrates, or other littoral zone organisms during one or more of their life stages.

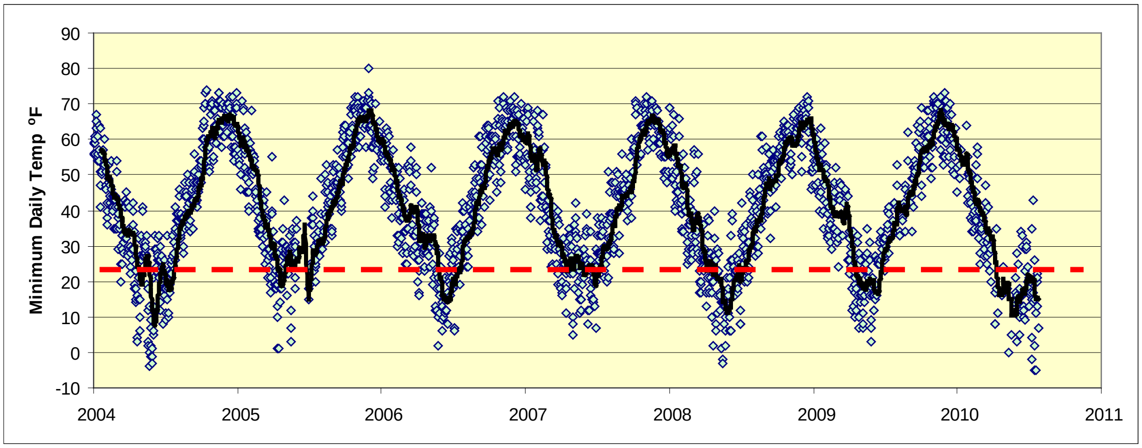
Table 15 – Preferable foods of Candlewood Lake fish species

Fish Species	Preferable Food
Bluegill sunfish	insects midges, sm crustaceans,-lg crustaceans, crustaceans on aquatic plants
Alewife	Zooplankton
Pumpkinseed sunfish	Insect=midges, sm crustaceans,-lg crustaceans
Yellow perch	Zooplankton, crustaceans, fish
Redbreast sunfish	Insect= midges, sm crustaceans,-lg crustaceans
Spottail shiner	sm. Insects, zoops, mollusks
Bluntnose minnow	sm. Insects, sm crustaceans
White perch	sm. and lg. crustaceans
Yellow bullhead	insects, crayfish, snails, fish
Largemouth bass	Lr. = micro-crustaceans Ju.=sm. and lg. crustaceans Ad. = insects & sm. fish
Smallmouth bass	Lr. = micro-crustaceans micro-fauna Ju.=sm. and lg. crustaceans Ad. = crayfish lg. insects & sm. fish
Rock bass	sm. and lg. crustaceans
Brown trout	Insects, fish
Black crappie	insects, crayfish, snails, fish
Golden shiner	sm. Insects, zoops, mollusks
Common carp	organic detritus
Banded Killifish	sm. Insects, sm. crustaceans
Rainbow trout	Insects, fish
Brown bullhead	insects, crayfish, snails, fish
White catfish	insects, crayfish, snails
Hybrid sunfish	sm. Insects, sm. crustaceans
Walleye	Ju..=sm. and lg. crustaceans Ad. = fish
Tessellated darter	insects, crayfish, snails, fish
Cutlips minnow	sm. Insects, sm. crustaceans
White sucker	insects, crayfish, snails, fish
Black bullhead	insects, crayfish, snails, fish
Brook trout	Insects, fish

Drawdown Control Effectiveness

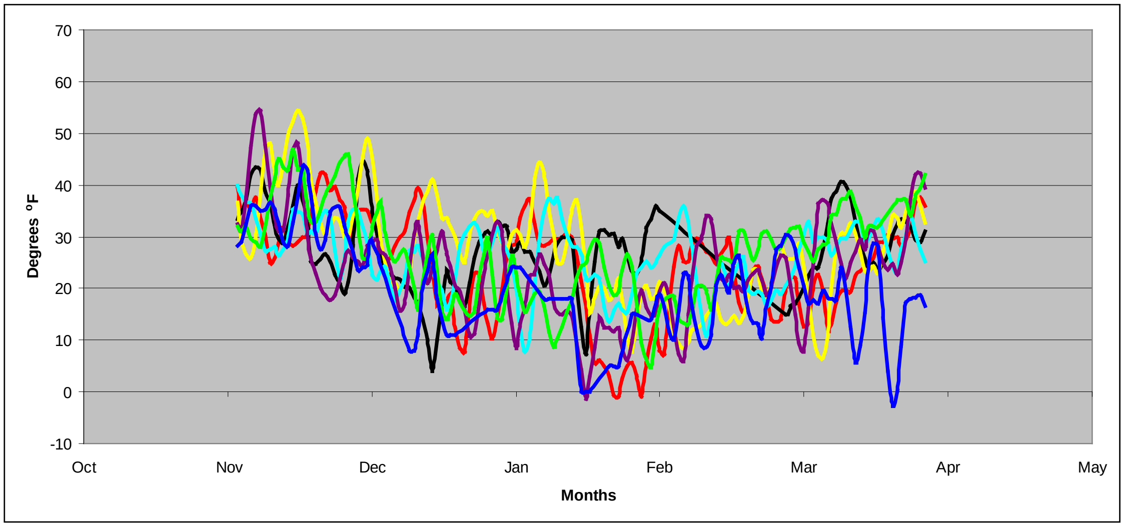
Drawdown has been used annually since the winter of 1983–1984 to control Eurasian milfoil in Candlewood Lake. The success of drawdown to do so may depend on roots reaching a critical temperature 23ºF (-5ºC) for at least 2 consecutive days (Lonergan and Wagener, in press). The minimum daily temperatures for the last 7 years at Danbury Airport are shown in **Figure 33**. The red dashed line shows air temperature regularly declines to or below 23ºF threshold during the winter.

Figure 33 – Minimum daily air temperature as recorded at Danbury Airport



Data shown in **Figure 33** does not indicate if low temperatures were sustained for at least two days in a row. The three-day moving average for minimum temperatures during each of the last 7 winters is shown in **Figure 34**. The lines in the graph show trends for 3-day averages. The lines move down and to the right during November and December, indicating that the average air temperature is getting colder. Consistent temperatures below 30ºF start during the second week of December and persist until March. January appears to be the coldest month; however this has not held for all the years shown in **Figure 34,** as some years don't show continued decline in air temperature in January. In fact, during some years, air temperature is erratic with only short duration of colder temperatures. It is also likely that air temperature can rise above freezing during winter months. Generally air temperatures begin steadily increasing during March.

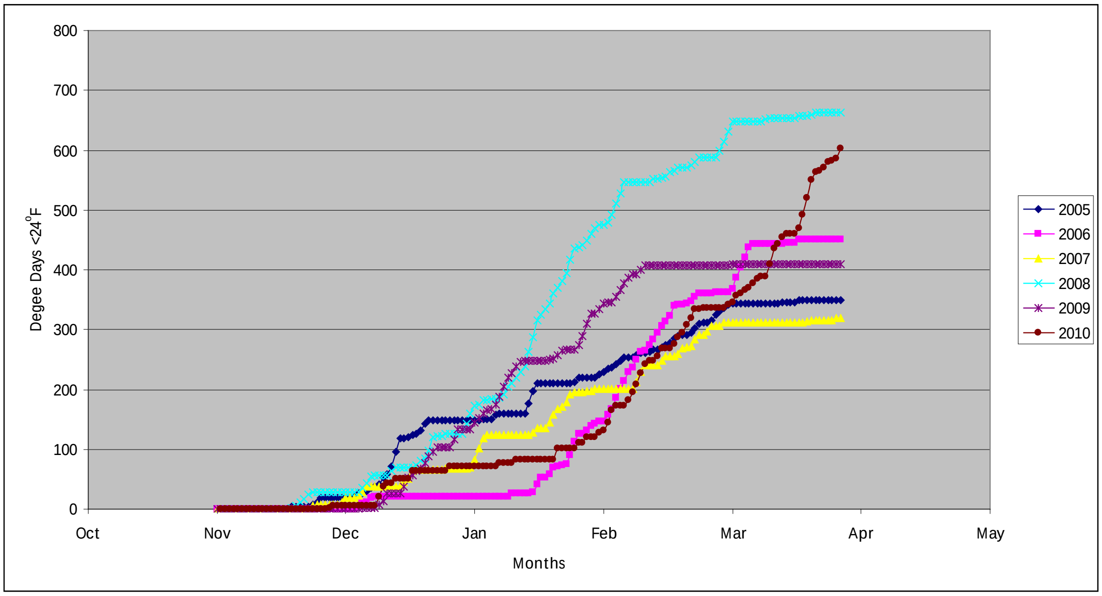
Figure 34 - Three-day moving average of the daily minimum air temperature during winters of 2004-2010



The cumulative number of degree-days when the air temperature is below 24°F is shown in Figure 35. The graph shows lines that increase up and toward the right, as the number of days when temperatures at or below 24°F accumulate. Lines at the bottom of the graph on the left side during November show that no days below 24°F have occurred. Lines begin to move up and toward the right during the second week of December as air temperatures fall and minimum temperature is below 24°F. Some years show steadily increasing number of days below 24°F beginning in early December, such as 2008, which also had the highest number of days below 24°F shown on the graph. Other years show no appreciable accumulation of degrees days until mid- to late January, such as 2006. It is also common for lines to "flat line" for a week or so at a time when air temperatures were above 24°F.

These data indicate that cold temperatures required to cause lethal conditions for exposed plant roots don't always occur during the winter, nor is it possible to predict when the cold temperatures will occur or for how long they will persist. A rule of thumb appears to be that cold temperatures begin during the second week of December and remain until the end of February.

Figure 35 – Degree Days less than 24ºF during 6 winters at Danbury Airport



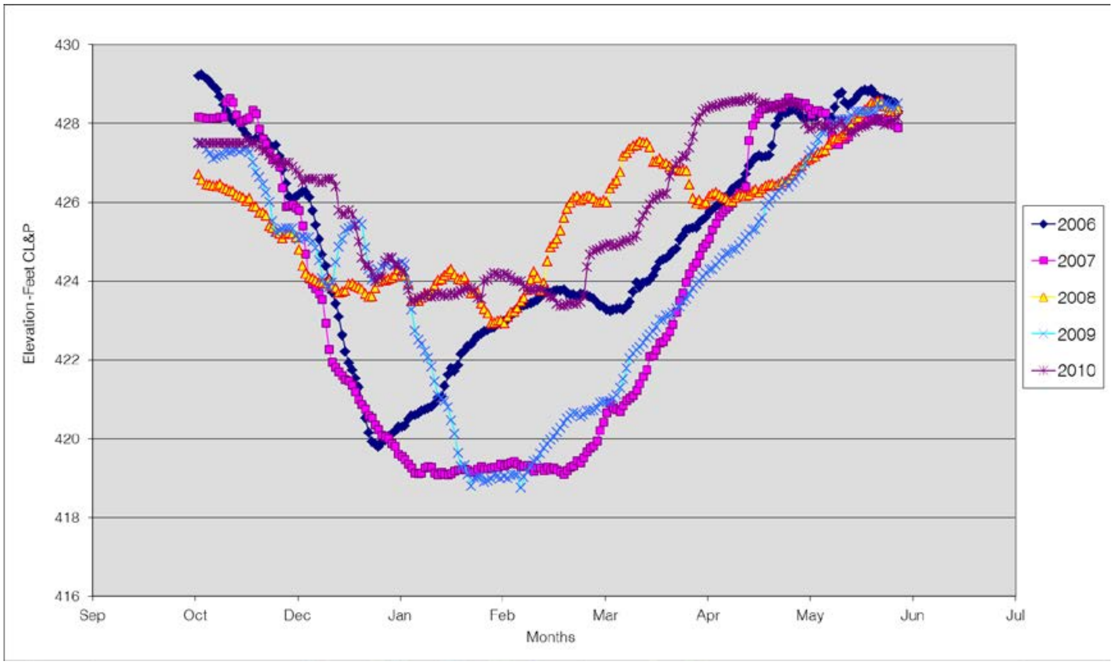
The coverage of milfoil after each of the last five drawdowns is given in **Table 16**. Coverage after the two shallow drawdowns (2008 and 2010) was similar at 451 and 461 aces, respectively, suggesting that shallow drawdowns effectively remove plants from about the same area each year. Coverage after the three deep drawdowns 2006, 2007, and 2009) has varied between a low of 221 acres to a high of 373 acres, a differential of 152 acres. The first two winter drawdowns (2006 and 2007), had similar control with 275, and 221 acres of milfoil, respectively. The 2009 drawdown showed less control with 373 acres remaining, suggesting that something was different during that drawdown than the other two deep drawdowns.

Table 16 – Acres of milfoil coverage mapped during summer surveys by CAES

Year	2006	2007	2008	2009	2010
Shallow			451		461
Deep	275	221		373	

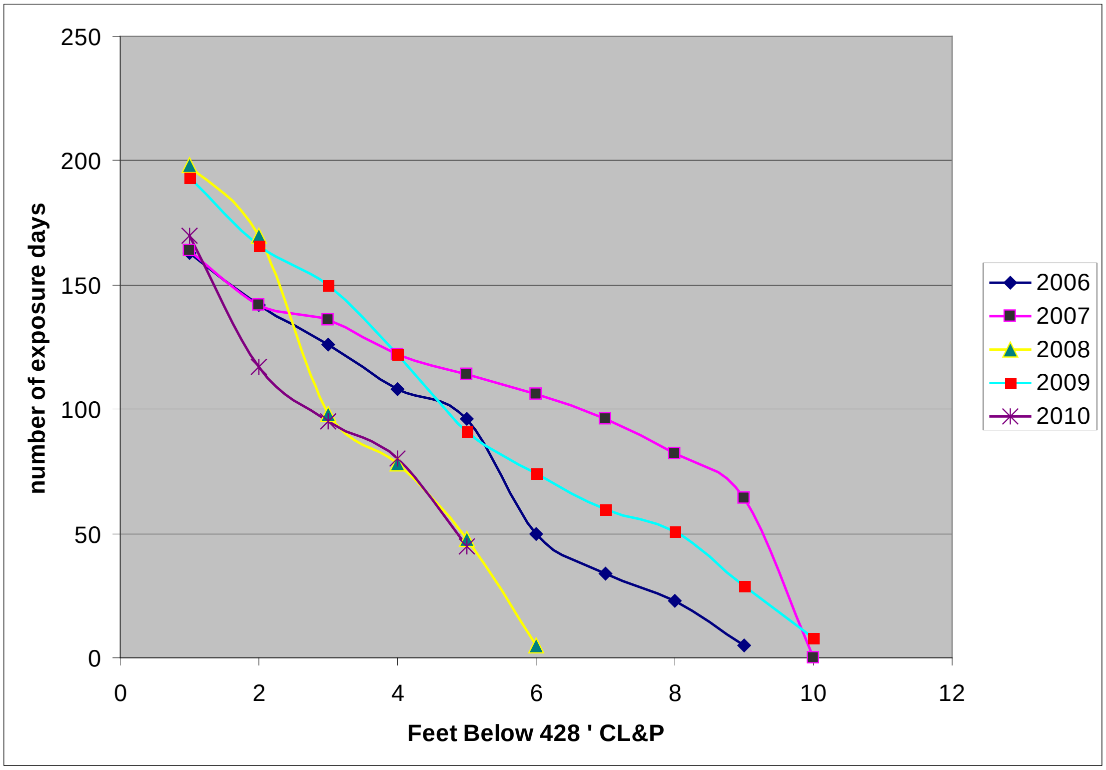
Water level trends for each winter between 2005 and 2010 are shown in **Figure 36**. The water level of the shallow drawdowns of 2008 and 2010 can be seen to approach but not exceed 243 ft. CL&P or 5 feet below normal summer level. The deep drawdowns of 2006, 2007, and 2009 reach at least 420 ft. CL&P. One obvious question is why the drawdown of 2009 was less effective than the other two deep drawdowns. Snow cover during the winter of 2008-2009 is the likely cause for poor control that winter (see below).

Figure 36 – Water levels during the last 5 drawdowns



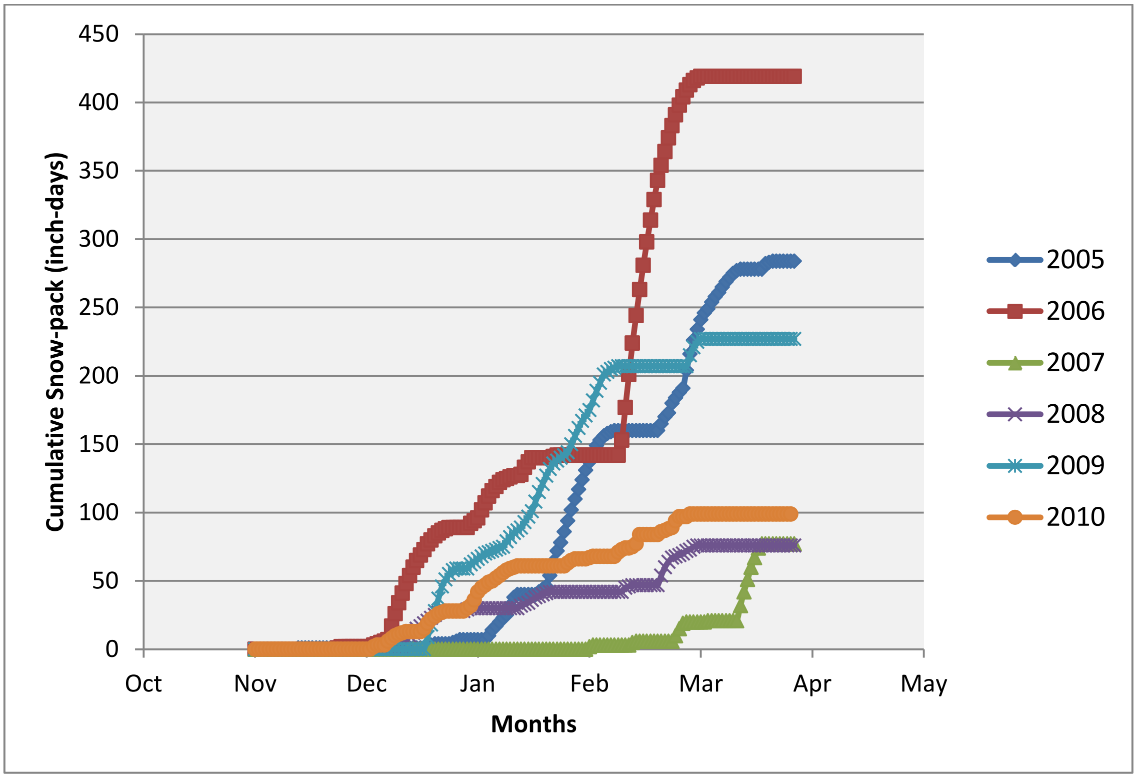
Duration curves for the last 5 drawdowns, winters 2006 through 2010, are shown in Figure 37. The graph shows the exposure duration at each 1-foot depth increment for the deep drawdowns of 2006, 2007, and 2009, and the shallow drawdowns in 2008 and 2010. The chart shows the large difference in duration of deep (>5ft) exposure during the three deep drawdowns. Drawdown of winter 2007 had the longest duration and best control, but drawdown 2006 had shortest duration but with very similar control as 2007. The drawdown of 2009 had exposure duration between these two but had far poorer control, suggesting that duration is not the key factor accounting for effectiveness of drawdown. In fact, the duration of exposure of the shoreline below 5 feet was longer by about a month during 2007 than the other deep drawdowns but did not translate into greater control of milfoil.

Figure 37 - Exposure duration curves for 2006, 2007, 2008, 2009, and 2010



Snow pack during each winter 2006-2010 recorded at Danbury airport are shown in **Figure 38**. The chart shows cumulative snow cover inch-days. An inch-day is defined as the number of cumulative days when snow covered the ground. For example, a snow cover of 1 inch persisting for 7 days would have 7 inch-days of snow pack. Each successive day of 1 inch cover would add an additional inch-day to the total. Lines shown in **Figure 38** rise going from left to right only when snow cover persists. Lines that are flat occur when no snow pack existed. The higher the lines go on the graph, the longer the duration of snow cover. The winter of 2007 stands out as having the least snow pack with no snow cover until the end of February. Winters of 2005, 2006, and 2009 had longest duration of snow cover.

Figure 38 – Cumulative snow cover (inch-days) recorded at Danbury Airport during 6 recent winters



The combination of two factors appears to provide for best control: 1) achieve target depth by mid-December and 2) have low-to-no snow cover. The data so far obtained from studying milfoil coverage are summarized in **Table 17**.

Table 17 – Summary of conditions of 5 drawdowns at Candlewood Lake

Winter	Acres of milfoil	Date reach 8 ft	Duration at 8 ft	Snow cover
2006	275	12/23	23 days	high
2007	221	12/28	81 days	Very low
2008	451	-	-	Moderate
2009	373	1/17	51 days	Very high
2010	461	-	-	Moderate

Discussion/Conclusion

Eurasian milfoil has been in Candlewood Lake since at least 1979 when CT DEP found an unknown species of milfoil (probably Eurasian) mixed with the more abundant northern milfoil. The first record of Eurasian milfoil in southern New England was 1971 in Stockbridge Bowl, Berkshire Co., MA (Les and Mehrhoff 1999). It is likely that milfoil fragments arrived in the lake between 1971 and 1978. The CT DEEP surveys between 1979 and 1981 found an unknown milfoil regularly but as a minor plant to the dominant pondweeds and northern milfoil. By the summer of 1983, Eurasian milfoil had established beds of dense growth that caused serious impairment to recreation and aesthetics (Siver et al. 1986). Experimental drawdowns during the winters of 1984 and 1985 indicted that the practice effectively controlled Eurasian milfoil in Candlewood Lake without causing water quality impacts.

This report shows 26 drawdowns have occurred since the initial experiments. However, only recently has the distribution of Eurasian milfoil in Candlewood Lake been accurately mapped. Connecticut Agricultural Experiment Station mapping shows Eurasian milfoil covers between 221 and 461 acres of the lake, or between 29 and 61% of the littoral zone. There are now dense beds of milfoil along 86%, or 54 miles of the shoreline. Because Candlewood Lake is steep sided throughout, the width of shore from waterline to 15 feet of water depth is narrow at normal summer level. Along most shores, the littoral zone is only 150 feet wide. Beyond 150 feet, the lake becomes deeper and the littoral zone ends.

Based on the drawdown record, there are three different impact zones in the littoral zone of Candlewood Lake.

A shallow-water zone, between the shore and 4 feet of water depth, is impacted by at least 100 days of exposure each winter. The shallow water zone has a surface area of 188 acres.

A mid-depth zone between 5 and 10 feet of water depth is impacted by between 30 and 100 days of exposure during alternate winters. The surface area of the mid-depth zone is 300 acres.

A deep-water zone between 10 and 15 feet of water depth is not impacted by drawdown. The area of the deep-water zone is 264 acres.

Variation in milfoil coverage after drawdown is likely due to declines in milfoil growth within the mid-depth zone. Most milfoil growing in the shallow-water zone is likely controlled during each drawdown, although specific effects are governed by local conditions. Milfoil growing in the deep-water zone will remain unaffected each drawdown. It is expected that milfoil in this depth range will continue expanding until all 264 acres contain beds. Once milfoil has colonized this entire area, the minimum coverage of milfoil after any drawdown will be about 264 acres.

Control of milfoil in the mid-depth zone is dependent on at least these factors: drawdown depth, duration at target depth (maybe), winter air temperature, and depth and duration of snow cover. However, small scale features of the exposed shore probably cause certain sediments to retain moisture, preventing plants from drying and insulating plant systems from lethal temperatures. These areas most likely occur where topography is gentle or where surface water or groundwater flows enter the lake.

Mapping data show milfoil returns to all exposed areas rapidly. Typically, within a year milfoil has recolonized prior cleared areas. Long-term success of controlling milfoil in Candlewood Lake requires better understanding of the method(s) of colonization. Milfoil could be returning to cleared areas in one, or all, of the following ways:

- Regrowth from intact root systems that survived the winter.
- Colonial root runners from established un-impacted plants in deeper water.
- Seedlings of fragments that drift from other areas.
- Germination of viable seeds that had fallen into this area.

Several possible changes in lake ecology appear to have occurred. Water quality has deteriorated between the early 1970's and now. Phosphorus has about doubled during that period causing a 50% decline in water clarity. Increased phosphorus has likely triggered bluegreen algae (cyanobacteria) blooms during summers of most recent years.

Phosphorus concentrations tend to reach higher levels after deep drawdown. Although this implicates deep drawdown as causing increased phosphorus concentrations in the lake, it is not clear what the mechanism for these increases is. Housatonic River water may contain higher phosphorus concentrations than the lake, thereby causing phosphorus in the lake to be higher after deep drawdowns. However, there was no significant difference between phosphorous concentrations at New Milfoil and New Fairfield stations (a full mass balance of phosphorus in the different arms was not performed). If phosphorus concentration of Housatonic River water was higher than the lake, it would cause the New Milfoil arm phosphorus to be higher than the rest of the lake. However no difference in phosphorus concentration was found. Long-term use of winter water-level drawdown may cause continued increases in phosphorus concentration in the lake, with annual deep drawdowns causing even higher levels.

Dissolved oxygen in bottom water shows considerable fluctuation that may be related to drawdown, but with a time delay that makes regression unsuitable as a tool to look for relationship between drawdown depth and oxygen loss. The large fluctuation in anoxic water from year-to-year is probably due to changes in the quantity of decomposable matter exported to the bottom water each year. Higher phosphorus concentration in the lake will accelerate bottom oxygen loss by reducing water clarity and increasing the quantity of algae that rain down to the bottom each summer. It is likely that the long-term use of deep drawdown may cause more anoxic water to develop in the lake each year. Increasing the quantity of anoxic water in the lake will accelerate internal recycling of nutrients from bottom sediments and decrease useable fish habitat.

Native aquatic plant species are rare in Candlewood Lake. Evidence suggests that both floating-leaf and emergent plant beds are near non-existent in the lake now, and that native aquatic plant species in general are found in only a few small sites. Declines in native aquatic plant abundance could be due to both the spreading dominance of milfoil and the impact of the drawdown. Native species may be slower to re-colonize the exposed areas following a drawdown. Repeated drawdowns may have caused native species to become scarce in the lake. CAES survey results show most of the littoral zone is dominated by single species stands of Eurasian milfoil. Loss of native plant species diversity means the biodiversity of organisms using the plant beds will decrease. The combination of loss of native plant species and exposure of a majority of the littoral habitats each winter appears to have resulted in a loss of most invertebrates, at least in the shallow water zone.

Fish populations have shown few obvious changes since surveys began in the late 1970s. Chain pickerel, once common to abundant, as noted by gill-net sets in the late 1970s, have not been caught during any subsequent electro-shocking survey. Electro-shocking has shown that no species has disappeared from the lake since shocking surveys were initiated, although some species remain scarce. Some species show higher numbers of smaller sized fish after shallow drawdowns, suggesting that deep drawdown limits some aspect of survivability. It is difficult to ascertain from the data if this constitutes year classes with poor spawning success. Additionally, no species show any significant trends toward more or fewer fish, either over the period the surveys have been conducted, or due to drawdown depth. Some species show possible trends: smallmouth bass may be more abundant while largemouth bass and rock bass may be less abundant.

Although water quality data show the conditions in the lake have gone from good to poor, differentiation of cause of these changes was beyond the scope of this review. During the interval considered here, 1984 to 2010, the human population in the watershed of Candlewood Lake has certainly increased, leading to a larger area of impervious surface, higher rates of storm-water runoff, and increased degree of shoreline alteration and disturbance. These factors are all capable of causing increased nutrient levels in the lake. Although drawdown has been implicated in causing phosphorus levels to increase, it is unclear how much of that increase is actually due to drawdown and how much is due to other factors.

Drawdown is essentially a simple method that affects (although with unpredictable success) all milfoil in the exposure zone simultaneously during a drawdown. Only one other method would provide effective control over such a large area, a whole-lake herbicide application. This method would be considerably more expensive than drawdown, but would affect milfoil growing in the entire lake, including the deep-water zone where drawdown, under the existing FERC license, cannot reach. All other methods are applicable in only small localized areas. Milfoil weevil stocking theoretically has the capability of affecting large areas of milfoil, but NEAR is unaware of any large area-stocking projects that have been attempted or are being considered.

Continued use of drawdown to control milfoil in Candlewood Lake is the simplest alternative, depending on utility use of pump-up for refill, but it is probably not the best method, as it always leaves milfoil, and has been ineffective for more than 1 season. The current practice removes an unpredictable amount of milfoil from shallow and mid-depth littoral zones, but leaves up to 264 acres of milfoil in the deep-water zone each year. If changes in water-quality are due to drawdown, then it is possible that back-to-back deep drawdowns will greatly magnify these affects because impacts would happen each year as opposed to every other year. However, the rate at which milfoil re-colonizes drawdown-exposed areas greatly decreases the effectiveness of the method, suggesting that no matter the level or frequency of the drawdown, milfoil will always completely return. This re-colonization needs to be investigated to determine how it is accomplished, and in what way it can be minimized.

If drawdown is going to be continued as the milfoil control method, it appears prudent to investigate at least the following, although more questions may arise as closer attention is paid to some of the ideas mentioned here: 1) standardize the timing and duration of drawdown as much as possible, 2) map the distribution of milfoil in the exposed areas early in the season, prior to re-colonization, 3) increase limnological monitoring to include, in the least, more nutrient sampling each year, 4) quantify existing littoral habitat value along the shoreline, exposed, and deep-water non-exposed, areas, 5) refine understanding of conditions lethal to milfoil, 6) thoroughly document the method of milfoil re-colonization and seek ways of minimizing it, 7) assess possible increased oxygen demand in deep water, 8) verify that drawdown has not seriously impacted the few continuous wetlands to the shore of the lake, 9) assess the apparent loss of native aquatic plant species in the lake, verify if drawdown, or milfoil, has caused native species diversity to decrease, 10) continue to refine milfoil mapping, 11) survey populations of young-of-year fisheries, 12) conduct more analysis of existing fisheries records, 13) map existing inlets to the lake and correlate storm-water outfall points with milfoil beds, 14) quantify water quality in storm-water, 15) investigate and map erosion of exposed shores during drawdown, and 16) continue to document milfoil weevil control success.

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