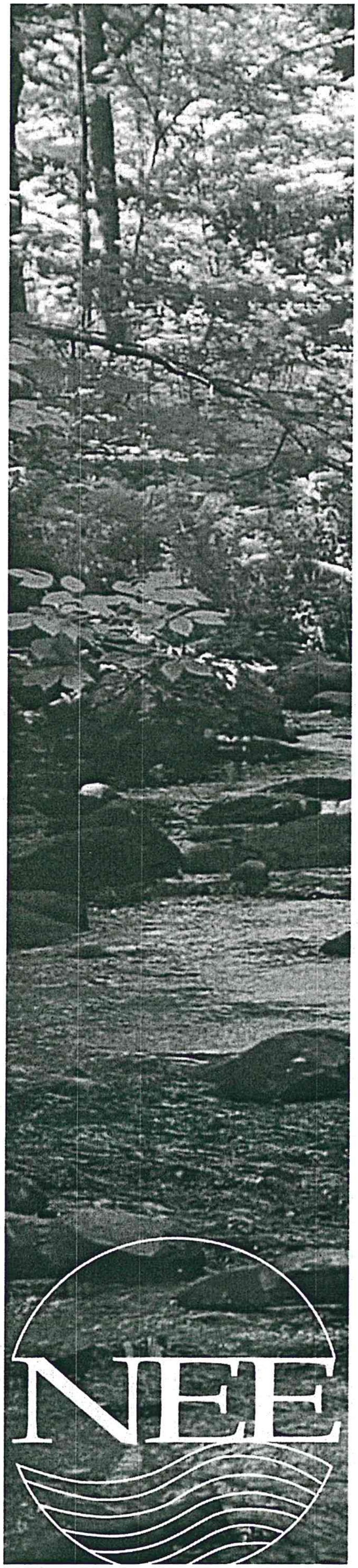

NEE environmental consulting

Candlewood Lake – 30 Year Water Quality and Drawdown Efficacy Analyses

Submitted: May 27th, 2014
(RFQ #12-13-5-31)

Prepared for:
The Chief Elected Officials of Brookfield, Danbury, New Fairfield, New Milford, and Sherman, Connecticut

NEE Project No. 13-4364

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RE: 30 Year Water Quality and Drawdown Efficacy Analyses
Candlewood Lake
Brookfield, Danbury, New Fairfield, New Milford, Sherman, CT

Dear Chief Elected Officials,

New England Environmental, Inc. appreciates the opportunity to provide you with this comprehensive report, which analyzes 30 years of water quality data from Candlewood Lake. The approaches used in this report addressed the questions presented in the RFQ, and are intended to provide clarification of the ecological issues driving the water quality conditions in Candlewood Lake.

We would be pleased to address any questions you may have after reviewing this report. If you have any questions feel free to contact us.

Sincerely,
New England Environmental, Inc.

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TABLES

FIGURES

FIGURES (cont.)

1.0 EXECUTIVE SUMMARY

New England Environmental Inc. (NEE) was engaged by the Chief Elected Officials of the Towns of Brookfield, Danbury, New Fairfield, New Milford, and Sherman, Connecticut to determine the causes of diminishing water quality in Candlewood Lake, and to develop recommendations to improve the water quality within the lake. NEE reviewed the methodology and findings of the Northeast Aquatic Research, LLC (NEAR) report entitled, "Evaluation of the Effects of Winter Water Level Drawdown on the Ecology of Candlewood Lake, CT" (Knoeklein, 2012). NEE performed statistical analysis of all available data to evaluate data trends related to the diminishment of water quality in Candlewood Lake. The water quality monitoring protocols currently being employed at the Lake were also evaluated by NEE. The trends in Eurasian Milfoil establishment, including a comparative analysis of plant control techniques including recommendations for future studies, were also analyzed.

Based on our review of existing data, NEE has made the following conclusions regarding the requests of the Candlewood Lake RFQ:

Statistical Findings:

The principal finding from this study is that water quality trends are a result of in-lake phosphorus being released from sediments and, that this source of phosphorus is not likely a result of the drawdown protocol. Our results suggest that phosphorus, which leads to late season algal blooms, is a result of diminishing oxygen concentrations in the hypolimnion (deep cool waters) throughout the season. This leads to a build-up of phosphorus in the hypolimnion during the summer season, which diffuses to the epilimnion (surface waters) as the season progresses and is released in mass when the lake mixes (i.e. September/October). Notably, the lowest water clarity occurs when the lake mixes and the deep-water phosphorus is released to the whole water body.

The conductivity of Candlewood Lake waters has increased significantly since 1985. This concerning trend appears to be a result of a growing population and increased impervious surface area in the watershed since 1985. Conductivity can increase due to nutrient, salt, or other pollutants entering the lake from the watershed; therefore, more investigation is necessary to identify the sources controlling this trend.

Deoxygenated water volume varies from year to year and is not related to the current drawdown regime. This follows a seasonal trend, which suggests that the volume of deoxygenated water is a result of the ambient air temperature (i.e. solar radiation) and the lack of mixing between top and bottom waters (i.e. thermal stratification) during the summer. The volume of deoxygenated water reaches its peak in July/August and then diminishes when the lake mixes (i.e. September/October), which coincides with distinct peak in algal productivity.

Finally, there was no statistical difference in the coverage of milfoil following deep or shallow drawdowns. However, the absolute difference in milfoil acreage was large. There were 445 and 307 acres of milfoil following shallow and deep drawdowns, respectively.

Data Base and Current Monitoring Protocol:

The current water quality monitoring protocol's design is sufficient to analyze the water quality trends of Candlewood Lake. However, there are several modifications needed to maximize the value of those collected data.

Consistency is the most important feature of the data set that requires improvement. To analyze a complex system like Candlewood Lake, all variables must be collected during every sampling initiative. Due to inconsistencies in these data set, a 36% reduction in data volume was necessary to undertake a comprehensive analysis.

Some variables need to be included in the monitoring protocol. Nitrogen was inconsistently monitored during the analyzed timeframe. It should be measured in the epilimnion, metalimnion, and hypolimnion (i.e. surface, thermocline, and bottom waters). Furthermore, it should be measured as Ammonia, Nitrite, Nitrate, and TKN. Finally, alkalinity should be measured in the same water volumes (i.e. epilimnion, metalimnion, and hypolimnion).

Phosphorus and nitrogen should be measured in micrograms per liter, not milligrams per liter, because natural waters are low in these nutrients. Therefore, measuring them in milligrams per liter results in a loss of resolution during statistical analyses.

Comments on "**Evaluation of the Effects of Winter Water Level Drawdown on the Ecology of Candlewood Lake, CT" – *May 2012***

The report prepared by Northeast Aquatic Research LLC in May of 2012 was conducted using a data set that contains sufficient information for an analysis of Candlewood Lake's water quality. In regards to other data sets used during that initiative, NEE did not analyze them because those assessments were beyond the scope of this study.

This report characterized the physical features of the lake and the amount of shoreline exposed during drawdown in depth. The report found that drawdown depth was correlated with diminished water quality; NEE's results do not agree with this finding.

The NEE study agrees with the following NEAR findings: 1) water clarity is significantly less when data from 1974 and 2013 (or 1985) are compared, 2) that there is no relationship between water clarity and drawdown, 3) anoxic water volume is variable from year to year and there is no relationship between anoxic water volume and drawdown, 4) total phosphorus in the epilimnion is significantly greater when data from 1974 and 2013 (or 1985) are compared, and 5) that drawdown duration is variable from 1985 to 2013.

2.0 INTRODUCTION

Basic Lake Characteristics and Water Volume:

Candlewood Lake is a ~5,064 acre, man-made water body located in Western Connecticut. It is owned by the First Light Power Resources (First Light), a subsidiary of GDF Suez Energy North America. The lake spans five municipalities: Brookfield, Danbury, New Fairfield, New Milford, and Sherman. The lake includes at least 35 islands and has a shoreline length of 65 miles (Knoecklin, 2012). The normal water level of the Lake is 428 feet; it is maintained through watershed flows and by water being pumped up 250 feet from the Housatonic River. The water level is manipulated by the power company to generate electricity during times of need; it is released back to the Housatonic River.

The Candlewood Lake basin extends approximately 10 miles along a north-south axis and spans less than two-miles at its widest point. The northern extent of the lake is comprised of two arms: The New Milford and the Sherman Arms, each approximately five-miles in length. The southern extent of the lake is comprised of one 2.5-mile long bay, commonly referred to as Danbury Bay. The bay and each of the aforementioned arms are narrow, being no wider than 0.6 miles at their widest points. The lake has a mean depth of 9.72 meters (m) and a maximum depth 25.91m. At normal water elevations, the total water volume is approximately 55 billion gallons (Knoecklin, 2012).

Water Chemistry:

Between 1985 and 2013, water quality in Candlewood Lake has been a topic of significant debate with the underlying principles driving water quality falling under scrutiny. The factors influencing lake water quality will be discussed later in this report; however, averages of water quality parameters will be presented here.

Total phosphorus, chlorophyll-a, and Secchi depth averages between 1985 and 2013 were 22.33µg/L, 6.83µg/L, and 2.56m, respectively. Finally, the lake's specific conductance and pH were 181.45µs/cm^2 and 7.84, respectively. These water quality parameters indicate that it should be classified as meso-eutrophic by most standards (Carlson 1977, Wetzel 2001).

Aquatic Plants:

Since the early 1980's, Candlewood Lake has been residence to Eurasian Milfoil (*Myriophyllum spicatum*), an invasive aquatic plant species. Two other non-native species, curly leaf pondweed (*Potamogeton crispus*) and minor naiad (*Najas minor*), have also been documented within the lake. Throughout the years, as these species have become more widespread (particularly *M. spicatum*), the number of native species has declined (CAES Database, 2014). The reason for this decline is likely due to the proliferation of the non-native species *M. spicatum* and the displacement of native species in the littoral zone.

To control the spread of *M. spicatum*, the Candlewood Lake Authority and First Light designed a winter drawdown regime, which is now regulated under First Light's FERC license (Article 403). The decision to employ a winter drawdown to control *M. spicatum* is based on a study conducted by Siver et al. (1986), which surmised that drawdowns would effectively thwart the spread of *M. spicatum* in areas exposed during drawdown, would have no adverse effects on water quality, and that Eurasian milfoil would further spread if the drawdown ceased. However, that study failed to analyze long-term water quality trends and did not evaluate the long-term impacts of drawdown on the native plant community. This lack of investigation regarding the impact of drawdowns on the native plant community in lakes has led many to believe that drawdown is an ecologically responsible way to control nuisance plant species.

The plant management protocol designed by First Light and the Candlewood Lake Authority includes water level manipulation (i.e. drawdown) that varies on a two-year cycle. Since 1985, the drawdown regime has included 14 shallow (420-423 ft.) and 14 deep (<420 ft.) drawdowns. During the 1985-2013 period, the water level targeted during drawdowns was fairly consistent for each class of drawdown (i.e. shallow – 420-423ft and deep – 418-420ft). However, the number of days the drawdown level was maintained varied widely. This does not necessarily suggest that there is an issue with this protocol because ambient temperature and precipitation are important things to consider when evaluating drawdown efficacy. Current research suggests that a minimum temperature between -5 and 2°C must be maintained for at least 24 hours for exposed roots (Lonergan and Wagener, in press) to be impacted. However, for these results to translate to soil-bound plants, longer periods of freezing/desiccation are likely required. Finally, winters with significant snow accumulation may result in less than anticipated control due to incomplete freezing of the substrate.

Purpose:

The purpose of this study is to evaluate the water quality and aquatic plant community trends as they relate to the current drawdown regime. Furthermore, this study will include the following:

1) A statistical analysis of water quality trends including the relative importance of all relevant factors.

2) A statistical analysis of Eurasian milfoil population trends as they relate to the drawdown regime to determine drawdown efficacy.

3) An assessment of existing data, identification of data shortages, and recommendations for future studies.

4) A water quality monitoring protocol designed to evaluate phosphorus sources and fates.

5) A comparative assessment of aquatic plant control methods; including costs and potential for success.

6) A review of the report entitled *"Evaluation of the Effects of Winter Water Level Drawdown on the Ecology of Candlewood Lake, CT"* by George Knoecklin – May 2012.

3.0 A REVIEW OF AVAILABLE DATA SETS

Disclaimer and Notes:

Those data provided for this initiative are assumed to have been responsibly collected and organized. Furthermore, NEE assumes that the sampling and analyses have been conducted in accordance with standardized practices and in no way have influenced the validity of the data; and, that no data have been falsified or manipulated prior to delivery to NEE. New England Environmental Inc. accepts no liability as it applies to data reliability. All analyses were undertaken with and require the aforementioned assumptions. Datasets were quality controlled by NEE using a variety of statistical techniques which may have resulted in reductions of sample size. Below is a summary of the data sets used for this evaluation.

First Light Power Resources – Water Level Data Set:

Data were provided to NEE by First Light for the period spanning 1984-2012. A copy dataset was provided by George Knoecklin, Ph.D. of Northeast Aquatic Research LLC for the period of 1984-2011. These data sets provided information on the daily water level in Candlewood Lake for each calendar year and were used to calculate yearly drawdown depth and duration. Since both data sets were identical, NEE assumed that these data were high quality.

Candlewood Lake Authority – Water Quality Data Set:

These data were provided to NEE by the Candlewood Lake Authority. Data were provided in a Microsoft Excel spreadsheet as well as with the original documentation. These data included a data set for dissolved oxygen/temperature by depth and a data set for water quality parameters. Both data sets included monthly data collected at four sampling sites from 1985-2013. The water quality data set included epilimnetic phosphorus, metalimnetic phosphorus, hypolimnetic phosphorus, Secchi depth, surface conductivity, surface chlorophyll-a, surface pH, surface oxygen concentration, surface nitrogen, surface temperature, bottom oxygen concentration, and bottom temperature organized by site, month, and year.

Since the application of multivariate analytical techniques requires that data sets are uniform and complete (i.e. do not contain data gaps), the data set was evaluated for consistency prior to statistical analysis. Many data gaps were present for the nitrogen variable and, were so removed from analysis by NEE prior to any statistical analysis. Chlorophyll-a data was not available for the years 2007, 2008, 2009, and 2010; therefore, these years were removed from the overall analysis. Additionally, there were randomly distributed data gaps in the set that needed to be removed for the execution of multivariate analyses. Those data from the months of April and November were removed because samples were not taken regularly during those months and they represented a very small portion of the overall data set. In the end, the data set used for analysis consisted of 457 sample entities, which was reduced from 720 for the aforementioned reasons (a 36% reduction).

New England Environmental, Inc. Data Set:

New England Environmental Inc. developed a data set derived from aerial imagery of watershed features that included site latitude/longitude, agricultural land, developed land, forested land, wetland, lawn, and impervious cover. These data were included because they have been associated with changes in water quality. Furthermore, they were derived from aerial imagery of the study area for the years 1985, 1990, 1995, 2002, 2006, and 2010. Though those data were punctuated, they were extended to span the years of the entire study to allow for evaluation of watershed influences. The populations of all the towns in the watershed were obtained for every year available, summed, and included in this data set. Those data were obtained from Connecticut's Department of Economic and Community Development (DECD).

Connecticut Agricultural Experiment Station Data Set:

The Connecticut Agricultural Experiment Station supplied the acreage of Eurasian milfoil collected annually from 2007 to 2013. Those data were supplied in their raw form and were converted to yearly-sum values by NEE's statistician.

4.0 DATA SETS USED IN ANALYSES

#1 - Watershed vs. Water Quality Data Set

Canonical Correspondence Analysis was selected to evaluate the relative influence of watershed on water quality. This technique requires two specific data sets which share their sample entity (i.e. they must be exactly the same number of data points). The first set is called the constraining variables (i.e. the set of variables thought to be controlling the other). Variables included in this data set were Site Latitude, Site Longitude, Watershed Population, Agricultural Land (acres), Developed Land (acres), Forested Land (acres), Wetlands (acres), Lawn (acres), and Impervious Land (acres). The second set is called the target variables (i.e. the set of variables responding to the constraining variables). Variables included in this data set were Secchi Depth (m), Epilimnetic Phosphorus (µg/L), Metalimnetic Phosphorus (µg/L), Hypolimnetic Phosphorus (µg/L), Chlorophyll-a (µg/L), Conductivity (µs/cm), and pH. Both of these data sets were mirrors in regards to the sample identity and contained 457 data points.

#2 – Temporal/In-lake Characteristics vs. Water Quality Data Set

Canonical Correspondence Analysis was selected to evaluate the relative influences of temporal and in-lake factors. This technique requires two specific data sets which share their sample entity (i.e. they must be exactly the same number of data points). The constraining data set included Year, Month, Drawdown Depth (elevation in feet above mean sea level), Drawdown Duration (days), Bottom Oxygen Concentration (mg/L), and Bottom Temperature (degrees C). The target variable data set included Secchi Depth (m), Epilimnetic Phosphorus (µg/L), Metalimnetic Phosphorus (µg/L), Hypolimnetic Phosphorus (µg/L), Chlorophyll-a (µg/L), Conductivity (µs/cm), and pH. Both of these data sets were mirrors in regards to sample identity and contained 457 data points.

#3 – Drawdown/Temporal Variables vs. Deoxygenated Zone/Trophic Variables

Canonical Correspondence Analysis was selected to evaluate the relative influences of time and drawdown on the trophic characteristics of the lake. Prior to creating these data sets the following data development protocols took place: 1) Depth/Temperature/Oxygen measurements from the deepest site were isolated (New Milford Site), 2) Years with measurements deeper than 20 meters were also isolated (i.e. 1993-2013), 3) Total depth of deoxygenated water was calculated for each month (i.e. May-October), and 4) Drawdown Depth, Drawdown Duration, Secchi Depth, Epilimnetic Phosphorus, and Hypolimnetic Phosphorus were overlaid with the calculated variables. That data set was then broken into the constraining set (i.e. Year, Month, Drawdown Depth (elevation), and Drawdown Duration (days)) and the target set (i.e. Total deoxygenated water (m), Secchi Depth (m), Epilimnetic Phosphorus (µg/L), and Hypolimnetic Phosphorus (µg/L)). Each data set was 93 samples long.

#4 – Drawdown vs. Milfoil Acreage

A Students' T-Test was selected for this analysis and requires a single data set organized by a class and response variable. For purposes of this analysis, Drawdown Type and Acres of Milfoil were selected as the class and response variable, respectively.

#5 – General Trends: Resolving Univariate Trends

Multivariate Analysis of Variance (MANOVA) and Analysis of Variance (ANOVA) were used to evaluate specific trends in these data sets. To conduct these analyses, the constraining and target sets from data set #1 (i.e. dissolved oxygen/temperature and the water quality parameters Secchi Depth (m), Epilimnetic Phosphorus (µg/L), Metalimnetic Phosphorus (µg/L), Hypolimnetic Phosphorus (µg/L), Chlorophyll-a (µg/L), Conductivity (µs/cm), and pH) were united into a single data set of 457 sample entities organized by year and month.

5.0 ANALYSES AND RESULTS

Watershed Influences on Water Quality:

Methods:

Canonical Correspondence Analysis was conducted with the use of the constraining and target variables from **data set #1**. The full model was constructed using a Monte-Carlo Permutation Test and the relative influence of each variable was assessed in a multivariate framework (i.e. conditional effects). Analysis of variance was used to evaluate the independence and strength of each canonical axis. The total variance explained by the final multivariate model was calculated by taking the sum of all constrained eigenvalues and dividing it by the total inertia. Biplots were constructed using canonical-scores for each variable and Hill Scaling.

Results:

The full model was found to contain a significant relationship between the two data sets ($F=5.75$ $p=0.005$) and the constraining set explained 10% of the total variance in the target data set. The first two canonical axes were found to be independent and contain the strongest relationships (Table 1, F= 37.18 and 10.61, respectively). The first two axes accounted for 90% of the data variance explained by the full model.

The first variable to load in the multivariate model was Watershed Population (Wpop – $F=26.42$, $p=0.01$). The second variable to enter the model was Impervious Cover (Imp.Land – $F=5.99$, $p=0.01$). Following, Forested Land (For.Land), Site Latitude (Site.Lat), and Wetlands (Wet.Land) loaded sequentially in the multivariate model with $F<4.00$ (Table 1).

Watershed Population and Impervious Cover exhibited significant positive relationships with the conductivity of Candlewood Lake (Fig. 1). Forested land did not exhibit any direct relationships with the target variables but the Biplot suggests that the amount of forested land is positively correlated with the trophic variables (i.e. Epilimnetic Phosphorus (TP.EPI), Metalimnetic Phosphorus (TP.META), Hypolimnetic Phosphorus (TP.HYP), Chlorophyll-a (Chloro), and Secchi (Fig. 1)). Site Latitude exhibited positive correlations with Epilimnetic and Metalimnetic Phosphorus. Furthermore, that variable had negative relationships with Hypolimnetic

Phosphorus and Chlorophyll-a. Wetlands showed positive associations with Secchi, Epilimnetic Phosphorus, and Metalimnetic Phosphorus.

Discussion:

Despite the level of significant found when these variables were analyzed in a multivariate setting, we must exercise caution when drawing broad conclusions. First, the total amount of variance explained in the target variables by the constraining variables was low compared to similar ecological studies. Secondly, only two variables loaded strongly during the construction of the multivariate model (Watershed Population/Impervious Cover). Therefore, the relationships associated with those variables can be considered as valid but the tertiary/quaternary associations must be weighted against the evaluation of "Temporal/In-lake Influences" portion of this study (i.e. next section).

Temporal and In-lake Influences on Water Quality:

Methods:

Canonical Correspondence Analysis was conducted with the use of the constraining and target variables from **data set #2**. The full model was constructed using a Monte-Carlo Permutation Test and the relative influence of each variable was assessed in a multivariate framework (i.e. conditional effects). Analysis of variance was used to evaluate the independence and strength of each canonical axis. The total variance explained by the final multivariate model was calculated by taking the sum of all constrained eigenvalues and dividing it by the total inertia. Biplots were constructed using canonical-scores for each variable and Hill Scaling.

Results:

The full model found a significant relationship between the constraining and target data set (F=20.57, p=0.005) and the constraining data set explained 21% of the total data variance in the target data set. The first three canonical axes were found to be independent and contain the strongest relationships (F=76.88, 30.96, and 15.01, respectively). The first three axes accounted for 99% of the data variance explained by the full model (Table 2).

The first variable to enter the model was Bottom Oxygen (F=39.19, p=0.01). The second variable to be included in the model was Month (F=38.09, p=0.01) and Year was the tertiary factor to enter (F=36.32, p=0.01). The fourth, and final significant variable, to be included was Bottom Temperature (F=4.43, p=0.03). Drawdown Depth and Drawdown Duration entered the model fifth and sixth but were not significant contributors to the overall fit of the model (F=2.94 and 2.47, respectively – Table 2).

Bottom oxygen (O2.Bot) exhibited significant negative relationships with Hypolimnetic Phosphorus (TP.HYP) and Chlorophyll-a (Chloro). Month (MonthNum) showed strong positive correlations with Hypolimnetic Phosphorus and Chlorophyll-a. Furthermore, negative relationships between Month and Secchi Depth (Secchi)/Epilimnetic Phosphorus (TP.EPI)/Metalimnetic Phosphorus (TP.META) were detected (Fig. 2). Year exhibited a significant positive relationship with Conductivity (Cond). Drawdown Depth and Duration did not exhibit any significant relationships.

Discussion:

Weighing this analysis vs. the previous watershed analysis suggests that the factors evaluated here are the primary set of variables affecting the water quality of Candlewood Lake. This interpretation is due to the following: 1) A greater amount of explained data variance by this model, 2) a larger multivariate F-value, and 3) multiple variables with large conditional F-ratios (Tables 1 & 2). These statistical features suggests that watershed factors are secondary effectors of water quality, but they should not to be ignored. Overall, the results from this portion of the study suggest that deep water oxygen and Month are the strongest factors effecting of water quality (Fig. 2). And, that there is a strong relationship between Year and lake conductivity, which (based on our watershed analysis) could be a result of a growing population and increasing impervious cover within the watershed (Table 1, Fig. 1). Finally, the current drawdown regime does not appear to be negatively affecting water quality in any significant way; at minimum it is should not be the primary focus of an effort to improve the water quality in Candlewood Lake (Table 2, Fig. 2).

Note;

The relationships that were identified as questionable in the watershed analysis remain weakly accounted for following this portion of the study. To further resolve the patterns associated with Epilimnetic (TP.EPI) and Metalimnetic Phosphorus (TP.META) additional studies will be required. The increasing conductivity of Candlewood Lake over the years is a significant concern because it may be indicative of nitrogen and salt enrichment or other pollutants entering the lake, which may cause significant water quality problems in the future.

<u>Deoxygenated Lake Waters, Phosphorus, Drawdown:</u>

Methods:

Canonical Correspondence Analysis was conducted with the use of the constraining and target variables from **data set #3**. The full model was constructed using a Monte-Carlo Permutation Test and the relative influence of each variable was assessed in a multivariate framework (conditional effects). Analysis of variance was used to evaluate the independence and strength of each canonical axis. The total variance explained by the final multivariate model was calculated by taking the sum of all constrained eigenvalues and dividing it by the total inertia. Biplots were constructed using canonical-scores for each variable and Hill Scaling.

Results:

The full model detected a significant relationship between the constraining and target data sets (F=8.09, p=0.005). A total of 27% of the target data set's variance was accounted for by the constraining variables. The first two canonical variables were found to be independent and contain the strongest relationships (F=26.45 and 6.20, respectively). The first two canonical axes also accounted for 100% of the data variance explained by the full model (Table 3).

The first variable to enter the model was Month (F=24.45, p=0.01). The second variable to enter the model was Year (YR, F=4.17, p=0.04). Drawdown Depth and Drawdown Duration entered as tertiary and quaternary factors but did not improve the fit of the multivariate model (F=2.90 and 0.84, respectively (Table 3).

Month exhibited a significant positive relationship with Hypolimnetic Phosphorus (TP.HYP) and a significant negative relationship with Secchi Depth (Fig. 3). Furthermore, Month showed a significant unimodal relationship with the Amount of Deoxygenated Water (deoxy – Fig. 4). Year exhibited a significant negative relationship with the Amount of Deoxygenated water (Fig. 3) but no discernable trend was obvious when this univariate trend was evaluated. Finally, Drawdown Depth and Duration did not show any strong relationships with the measured target variables (Table 3, Fig. 3).

Discussion:

The results of this portion of the study suggest that the monthly dynamics of oxygen and hypolimnetic phosphorus are most important. These findings show that phosphorus and deoxygenated water volume are controlled primarily by monthly dynamics. In fact when univariate curves are pulled out, strong unimodal curves are found for both of those variables where they increase throughout the summer season and taper off through September and October (figs. 4 & 5). This supports the idea that phosphorus builds up in the deep deoxygenated waters, which increases in volume throughout the season, and is released in mass when thermal stratification breaks down, and causes increased algal productivity. This analysis further supports the findings from the previous portions of this study and acts as a second analysis that indicates a lack of drawdown influence on the water quality of Candlewood Lake.

Drawdown and Milfoil Control:

Methods:

A Students' T-test was used to analyze whether deep or shallow drawdowns provided a significantly greater level of Eurasian milfoil (*Myriophyllum spicatum*) control. To conduct this analysis **data set #4** was used. The T-statistic was used to calculate the p-value.

Results:

This test suggests that there was no significant difference in the acres of *M. spicatum* present following deep or shallow drawdowns ($T=-2.54$, $p=0.07$). The average acres of Eurasian milfoil following deep and shallow drawdowns were 307.81 and 445.84, respectively (Table 4).

Discussion:

These results suggest that the impact of larger drawdowns on the population of *Myriophyllum spicatum* is not significantly different. However, the average amount of Eurasian milfoil following deep drawdowns was 138 acres less compared to the years following shallow drawdowns (Table 4). This difference is large; and, the standard deviations (or standard errors) do not overlap, which in most cases would indicate a significant difference. Essentially, this suggests one of the following: 1) There truly is no difference or 2) That the critical sample size necessary to detect a difference has not been reach (n's for deep and shallow drawdowns were 4 and 3, respectively). Future analyses will determine the true effect of the current drawdown regime.

General Trends – Year and Water Quality:

Methods:

Multivariate Analysis of Variance (MANOVA) was used to compare water quality variables among all years (i.e. 1985-2013). To conduct this analysis, **data set #5** was used. Pillai's Trace was used to calculate the multivariate F-statistic and p-value, respectively. Due to the fact that those data used in this analysis exhibited significant derivations from normality, a permutation test (PERMANOVA) was used to confirm the result. Individual variable ANOVAs were extracted from the final model to evaluate univariate data trends.

Results:

MANOVA detected significant differences among years in the multivariate data set ($F=113.63$, $p<0.001$). Furthermore, PERMANOVA confirmed this finding ($F=105.14$, $p=0.002$). The hierarchy of variables that contributed to this overall effect was: 1) Conductivity ($F=665.88$), 2) Metalimnetic Phosphorus ($F=38.54$), 3) Secchi Depth ($F=6.00$), 4) pH ($F=5.42$), 5) Hypolimnetic Phosphorus ($F=4.98$), 6) Epilimnetic Phosphorus ($F=4.93$), and 7) Chlorophyll-a ($F=1.69$ – Tables 5 & 6).

Conductivity exhibited a strong positive trend over the years included in this portion of the study. Between 1985 and 2013 lake conductivity increased in a highly significant fashion (Fig. 6).

Metalimnetic Phosphorus exhibited a highly variable state from 1985-2013; however, the overall trend is slightly negative until 2001 when the trend in subsequent years becomes more positive. (Fig. 7)

Secchi Depth has been highly variable since 1985 but appears to be negative in nature since 2007 (Fig. 8).

The pH of lake water has been stochastic between 1985 and 2013, with no discernable trend (Fig. 9).

Hypolimnetic Phosphorus has been variable from year to year and the trend appears to be negative in nature since 1997 (Fig. 10).

Epilimnetic Phosphorus exhibited a negative trend from 1985 to 2001 but appears to be moving toward a positive trend in recent years (Fig. 11).

Chlorophyll-a exhibited a stochastic nature throughout most of the timeframe but may be moving toward a positive trend in the recent years (Fig. 12).

Discussion:

As would be expected for this type of analysis, water quality variables were significantly different among years with most variables exhibiting oscillating trends. These types of analyses must be considered carefully because they simply compare means among years, which can vary enough to cause a significant result (i.e. includes all seasonal variation). The important part of these analyses is to evaluate the individual trends in each water quality variable. As previously mentioned most variables did not exhibit interpretable trends; however, lake conductivity did show a strong positive trend over the years. This is an important result that should be addressed because conductivity is a rough indicator of trophic state and may indicate salt or other types of pollutants entering the lake.

General Trends – Month and Water Quality:

Methods:

Multivariate Analysis of Variance (MANOVA) was used to compare water quality variables among all months (i.e. May-October). To conduct this analysis **data set #5** was used. Pillai's Trace was used to calculate the multivariate F-statistic and p-value, respectively. Due to the fact that those data used in this analysis exhibited significant derivations from normality, a permutation test (PERMANOVA) was used to confirm the results. Individual variable ANOVAs were extracted from the final model to evaluate univariate data trends.

Results:

MANOVA detected significant differences among months in the multivariate data set ($F=19.29$, $p<0.001$). This result was confirmed by PERMANOVA ($F=17.23$, $p=0.002$). The hierarchy of variables that contributed to the overall effect was: 1) Bottom Oxygen Concentration ($F=96.69$), 2) Chlorophyll-a ($F=42.07$), 3) pH ($F=37.80$), 4) Hypolimnetic Phosphorus ($F=25.85$), 5) Secchi Depth ($F=25.57$), 6) Conductivity ($F=7.96$), 7) Metalimnetic Phosphorus ($F=3.57$), 8) Epilimnetic Phosphorus ($F=1.38$ – Tables 6 & 8).

Bottom oxygen exhibited the normal U-shaped curve throughout the summer season. The concentration of oxygen in the deep water diminishes as the summer progresses and thermal stratification is established. It then recovers as the stratified conditions break down and the lake mixes (i.e. September – October, Fig. 13).

Chlorophyll-a consistently increases throughout the summer months and reaches its maximum when the lake mixes; this suggests that the release of phosphorus rich water from the hypolimnion may be fueling increased productivity of the algal community later in the season (Fig. 14).

Lake water pH increases slightly from May to July but then decreases sharply from July to October (Fig. 15). This trend may be the result of a number of factors, potentially including 1) early season watershed influxes increasing the amount of basic compounds in the lake followed by 2) the use of those chemicals (i.e. bicarbonate) by aquatic vegetation such as Eurasian milfoil later in the season, which is thought to use bicarbonate as a carbon source (Hutchinson, 1970).

Hypolimnetic Phosphorus increases throughout the growing season followed by a sharp decrease from September to October (Fig. 16). This pattern is likely a result of deep/cool waters being separated from surface waters during times of thermal stratification. Furthermore, the diminishment of oxygen in this water volume promotes the release of phosphorus from the sediment, which drives the concentration of phosphorus up during the summer season. The reason for the sharp decrease in October is the breakdown of thermal stratification resulting in full lake mixing and a drop in hypolimnetic phosphorus.

Secchi Depth is variable early in the season and then diminishes in a linear fashion from August to October. The reason for the early season variability is unclear because phosphorus trends do not support an algal based interpretation; however, it may be due to significant watershed flushing resulting in an early season turbid state. Later in the season the Secchi averages follow a more "normal" trend where the average Secchi measurement decreases with increasing deep water phosphorus and it reaches its peak when that phosphorus rich water volume is mixed throughout the entire water body (Fig. 17).

Conductivity exhibited a platykurtic unimodal (broadly-peaked) curve. Variation among months was not large and was difficult to interpret in a seasonal sense (Fig. 18). Therefore, this variable is probably controlled by larger scale factors such as watershed features over longer time-scales (i.e. Years).

Metalimnetic Phosphorus concentration did not exhibit large differences among months. However, there is a significant drop in the concentration of this water volume when the lake mixes later in the season (Fig. 19). This suggests that the concentration is maintained through slow diffusion from the hypolimnion from June to August and then is reduced when the entire water body mixes and the concentration of phosphorus in the hypolimnion is distributed throughout the entire water volume.

Epilimnetic phosphorus did not exhibit a significant monthly trend; it remained stable throughout most of the summer season except for a slight decrease from May to October (Fig. 20).

Discussion:

These types of analysis are generally more valuable than the analysis of yearly trends because most of the water chemistry dynamics that are of value to the management of lakes in temperate regions occur in the summer season (i.e. May-October). These results suggest that seasonal dynamics are dictating the water quality properties of Candlewood Lake. Deep water oxygen has been associated with a variety of other patterns in this lake, namely: 1) Chlorophyll-a 2) Hypolimnetic Phosphorus, and 3) Secchi Depth. These findings indicate that water clarity and algae are being driven by the properties of the hypolimnion (i.e. isolation and slow diffusion during thermal stratification/ high concentration water being released during lake mixing). The results obtained from this analysis suggest that the major factors driving water quality is that of dissolved oxygen controlling the amount of phosphorus in the water body (i.e. low oxygen in the bottom leads to high phosphorus in the hypolimnion and that phosphorus is released during lake mixing).

6.0 IDENTIFICATION OF DATA SHORTAGES AND RECOMMENDATIONS FOR FUTURE STUDIES

<u>Data Shortages:</u>

Ecological Data:

Candlewood Lake is a large and complex system that is influenced by a number of interacting factors. Trends in the system's ecology are truly a multivariate problem that needs to be evaluated with this level of complexity in mind. Therefore, measuring a variety of important variables in a consistent manner is of the utmost importance. The inconsistency of measured variables from 1985-2013 was the most significant data shortage encountered during this study. Due to data gaps and measurement errors, 36% of the total data set needed to be removed in order to undertake a statistically sound, multivariate analysis of this system.

In general, the number of sites used and the variables measured during the growing season were suitable (i.e. Conductivity, Nitrogen, Phosphorus, Chlorophyll-a, etc.) for the analysis of water quality trends. However, some variables were measured at resolutions that could be improved. In particular, phosphorus was measured at the mg/L resolution and then converted to ug/L; it should always be measured at the ug/L level because natural waters are low in phosphorus, which means that significant variation is being missed by measuring this variable in mg/L. Nitrogen variables should also be measured in ug/L and evaluated in the epilimnion, metalimnion, and hypolimnion. Additionally, nitrogen should be measured as ammonia, nitrite, nitrate, and TKN. Alkalinity data was not available for analysis. Traditionally alkalinity is a parameter that is part of a generally accepted battery in lake management. It is unlikely that alkalinity data would have affected the outcome of these analyses, but it should be measured during every sampling event in the epilimnion, metalimnion, and hypolimnion.

In conclusion, the most important feature of the data set that must be addressed is that of consistency. This can be accomplished through the development of a QAPP and pursuit of additional funding to ensure that the sampling entity is properly prepared, outfitted, and staffed to obtain the necessary data. The optimal result would be a database of consistently sampled variables spanning the summer months (May-October or longer). Also, all data should be converted to digital format so it is easily accessible for statistical analysis.

Recommendations for Future Studies:

Phosphorus/Nutrient Sources:

This study identified two levels of interacting factors that are controlling the water quality trends in Candlewood Lake. They were, in order of importance: 1) Temporal/In-lake and 2) Watershed factors. Furthermore, monthly oxygen/phosphorus dynamics were the most important set of variables from the temporal/in-lake analysis and watershed population/impervious cover were the most important variables in the watershed analysis. These findings support the need for the following studies:

1) In-lake phosphorus dynamics study

This study would document the various forms and abundance of phosphorus in the water body throughout the summer season along a depth gradient (i.e. each meter). It would require a single season study of the system where phosphorus and related variables (oxygen, iron, manganese, etc.) are evaluated over short time-frames (i.e. daily). It would not be necessary to do this at all of the current sample points; the deepest two points would suffice for this analysis.

2) In-lake sediment mass/nutrient study

This study would document the chemical and physical composition of in-lake sediment throughout the lake. It would result in an understanding of total nutrient load available in the sediment and lead to the development of in-lake phosphorus control protocols. (Note: It is necessary to undertake a watershed study before developing in-lake phosphorus management protocols).

3) Watershed study

This study would document the specific watershed inputs of nutrients and pollutants into the lake; it would also document seasonal dynamics of watershed inputs. The watershed study would lead to the development of a watershed management plan that would outline strategies for mitigating the identified nutrient and pollutant sources.

7.0 COMMENTS ON 'EVALUATION OF THE EFFECTS OF WINTER WATER LEVEL DRAWDOWN ON THE ECOLOGY OF CANDLEWOOD LAKE, CT'

Introduction:

The report entitled *"Evaluation of the Effects of Winter Water Level Drawdown on the Ecology of Candlewood Lake, CT"*, dated May 2012 by Northeast Aquatic Research LLC. (NEAR). summarized a variety of ecological data collected from the lake by a variety of entities. The report attempted to summarize and resolve interactions among a variety of organisms including aquatic plants, fish, and aquatic insects. Data sources used for this evaluation include those obtained from CL&P, Connecticut Department of Energy and Environmental Protection (DEEP), the Connecticut Agricultural Experiment Station (CAES), and the Candlewood Lake Authority. The report evaluated changes in the relative compositions of those species as they relate to winter water level drawdown. Most importantly, this study evaluated the water quality trends of Candlewood Lake and related changes in those water quality variables to the current drawdown protocol.

NEAR Report Findings:

1) Water clarity has decreased significantly since 1974 and winter water level drawdown does not influence water clarity.

2) The water volume that is anoxic in the lake varies widely from year-to-year and, that the anoxic zone develops early in the season, increasing in size during the summer months. An improving or worsening anoxia trend was not found but the report suggests that intermittent loading of organic matter may be driving the year to year variability in anoxic water volume.

3) Phosphorus concentrations are higher now than in 1974 and are highest following deep drawdowns.

4) Thermal stratification begins to develop early in the season and water clarity decreases when stratification meets the anoxic zone.

5) Native aquatic plant species have declined since 1974 and are currently rare in Candlewood Lake.

6) Twenty-nine species of fish were identified in the lake. The number of small fish found during surveys was weakly and negatively correlated with drawdown depth indicating that the deep drawdown may have reduced the amount of small fish.

7) Evaluation of the aquatic insect and vertebrate communities was not possible due to a limited data set.

8) Drawdown depth and duration have been erratic and that weather may be playing a role in plant control efficacy.

Study Strengths:

1) The study clearly outlines the physical parameters of Candlewood Lake.

2) The study clearly outlines the water volumes released and the amount of shoreline exposed during winter drawdowns.

3) The study clearly outlines additional studies required to understand the effects of winter drawdown on Eurasian milfoil and the physical parameters of the lake.

4) The study clearly outlines data shortages in regards to organism assemblages such as aquatic insects and vertebrates.

5) The study shows a distinct change in water clarity and surface water phosphorus concentration from 1974 to present.

Study Deficiencies:

1) The study did not use computational strategies to draw conclusions, which may have indicated that some trends were significant while other were not.

2) There was no indication that any data QA/QC protocols were employed, which are standard protocols in statistical analyses.

3) Only drawdown was assessed; other factors affecting water quality were not considered, which may have caused some influential factors to be missed

4) Strength of trends were not evaluated, which leads to an inability to determine a hierarchy of variables affecting water quality.

Comparison of NEAR and NEE Study Findings:

The results of the NEE study were compared to those derived from the NEAR LLC. study. Our comparison resulted in the following:

1) *NEAR – Clarity has diminished since 1974 and that there is no relationship with drawdown.*

NEE's study agreed with this finding in absolute terms; meaning that if 1974 and 2013 (or 1985) are compared, the two years are significantly different. However, from 1985 to 2013 there was no interpretable trend in the yearly averages of water clarity; it fluctuates from year to year. An interesting question still persists following both studies: What phenomena drove the significant change in water clarity from 1974 to 1985? Additionally, NEE Inc.'s study indicates that summer oxygen/hypolimnetic phosphorus dynamics are the strongest factors affecting water clarity though not the only possible reasons. Finally, NEE Inc.'s study did not find any relationship between drawdown and water clarity, which confirms NEAR LLC's finding.

2) *NEAR – The volume of anoxic water in Candlewood Lake varies significantly.*

NEE's study found that the volume of anoxic water in Candlewood Lake varies widely from year to year. Furthermore, that there does not appear to be any indication that there is an improving or worsening trend in those data.

3) *NEAR – Surface phosphorus has increased from 1974 and that phosphorus concentrations were highest following deep drawdowns.*

NEE's study agrees with one facet of this finding in absolute terms; meaning, that if surface phosphorus from 1974 and 2013 (or 1985) are compared directly that they do differ significantly. However, when this variable was evaluated from 1985 to 2013 there was no interpretable trend. An interesting question still persists following both studies: What phenomena drove the significant change in surface phosphorus concentration from 1974 to 1985. Finally, NEE's study suggests that there is no relationship between epilimnetic phosphorus and drawdown.

4) *NEAR – Thermal stratification develops early in the season and water clarity decreases when the metalimnion meets the anoxic zone.*

NEE's study agrees, in part, with this finding. Our results suggest that watershed sources are driving early season water clarity (i.e. turbidity) because the concentration of chlorophyll-a remains low (i.e. suggestive of low algal productivity) in the water column until July. In addition, our results suggest that water clarity is controlled in July and August by phosphorus diffusing from the anoxic zone. Finally, NEE's study suggests that the late season increase in the algal community (i.e. chlorophyll-a) is driven by the release of phosphorus from the anoxic zone during lake mixing.

5) *NEAR – Native aquatic vegetation has diminished in Candlewood Lake.*

NEE did not investigate the state of the plant community beyond the efficacy of drawdown on non-native species.

6) *NEAR – Twenty-nine species of fish were found and that after deep drawdowns the number of small fish was reduced.*

NEE did not investigate the state of the fish community.

7) *NEAR – There was not enough data to evaluate the aquatic insect community.*

NEE did not investigate the state of the aquatic insect community.

8) *NEAR – Drawdown depth/duration was variable and weather may be playing a role in its plant control efficacy.*

NEE's study agreed with this finding. Furthermore, there was a large but statistically insignificant difference in milfoil acreage when deep and shallow drawdowns were compared.

NEE did not investigate weather effects on drawdown efficacy in plant control; therefore, no presumptions about influencing factors were made.

8.0 WATER QUALITY MONITORING PROTOCOL

Current Water Quality Monitoring Protocol:

Variables assessed:

1) Conductivity (us/cm^2)
2) Epilimnetic phosphorus (mg/L)
3) Metalimnetic phosphorus (mg/L)
4) Hypolimnetic phosphorus (mg/L)
5) Chlorophyll-a (mg/L) – not in 2007, 2008, 2009, 2010
6) Dissolved Oxygen (mg/L)
7) Secchi Depth (m)
8) Temperature (°C)
9) Nitrogen (mg/L) – sporadic

Sites:

1) New Milford
2) New Fairfield
3) Sherman
4) Danbury

Design:

1) At each site the temperature, dissolved oxygen, and conductivity of the water is measured at every meter to the bottom.

2) At each site the remaining variables are measured.

3) Each site is measured monthly during the summer (i.e. May to October sometimes April and November are included).

Comments on design:

The current water quality monitoring program is designed suitably for the long-term analysis of Candlewood Lake. However, the consistency in timing and the measured variables needs to be improved. The phosphorus/nitrogen variables need to be measured at the µg/L resolution and alkalinity/nitrogen need to be measured in the epilimnion, metalimnion, and hypolimnion. Nitrogen should also be measured as ammonia, nitrite, nitrate, and TKN in µg/L. The time-frame for which water quality is analyzed should be standardized; NEE Inc. recommends using the time-frame of May through October (though increasing it would improve the data set but will require additional funding).

In summary, increasing the consistency with which the variables are measured, the variable resolution (i.e. µg/L), and sample timing will enhance the nature of the data set and make it more informative in future analyses. To achieve this a QAPP should be developed.

9.0 PLANT CONTROL OPTIONS AND COSTS

Mechanical:

Method	*Cost*	*Benefits*	*Risks*	*Effectiveness*
Diver Assisted Suction Harvesting	$12,000 – 18,000/acre (when used alone)	No chemical application or significant permitting Plant material removed from system	High cost for minimal long-term control Plant fragmentation	Low when used alone
Drawdown	$0.00 to municipalities Potential loss of revenue to CL&P	No chemical application or significant permitting	May impact fish, invertebrate, and native plant populations	High when regime is standardized
Mechanical Harvester	$220,000 – 250,000 per machine	No chemical application or significant permitting Plant Material removed from system	Plant fragmentation	Low for Eurasian milfoil

Biological:

Method	Cost	Benefit	Risks	Effectiveness
Grass Carp	$120,000 or more in first year. And, subsequent surveying and stocking costs.	No chemical application.	Negative impact to native vegetation. Significant permitting and infrastructure. Fish escape/population collapse.	Variable/medium.
Milfoil Weevils	Unknown due to unknown effective stocking rates.	No chemical application.	Collapse of weevil population. May impact the rare Northern Milfoil.	Unknown/variable.

Chemical:

Method	Cost	Benefits	Risks	Effectiveness
2-4D	$1,640.00/acre	Practical for use in hard water systems. Effective in late season treatments. Short soil activity/residual. Systemic herbicide.	Moderately toxic to fish and other aquatic organisms. Requires ground water testing and significant permitting.	High with proper application.
Diquat	$1,560.00/acre	Good for use in early season treatments before native vegetation arises. Broad scope.	Highly toxic to juvenile fish. Moderate toxicity to adult fish. Strongly adheres to sediment – increasing soil pollution with subsequent applications. Non-systemic.	High with proper application.

Flumioxazin	$3,760.00/acre	Broad scope, works well on a variety of non-native species. Short soil activity/residual. Effective for early season treatments. Can be mixed with other systemic chemicals.	Contact herbicide. Moderate toxicity to fish and other aquatic organisms.	High with proper application.
Fluridone	$4,340.00/acre	Broad scope. Effective in early season treatments. Essentially non-toxic.	Expensive. Requires long exposure times and "bump" applications to maintain concentration.	High with proper application.
Triclopyr	$2,550.00/acre	Very selective. Relatively low toxicity. Can be mixed with other systemic chemicals.	Requires mixing with other chemicals to maximize results.	Moderate when used alone. High when used in cooperation with 2-4d.
2-4D/Triclopyr	$2,760.00/acre	Synergistic effects of two chemicals. Selective. Early or late season application.	See 2-4D and Triclopyr cons.	High with proper application.

Summaries:

1) Diver Assisted Suction Harvesting:

Diver Assisted Suction Harvesting (DASH) is a mechanical harvesting technique that involves the use of a barge supported pump and a diver on the lake bottom who hand picks plant stems and feeds them into the inlet hose of the pump system. The harvested material is sucked from the lake bottom, up to the barge where it is collected and bagged and later disposed of.

On a per acre basis, this method is slow and expensive. It is generally not a practical approach to manage large-scale infestations of aquatic plants such as those in Candlewood Lake. However, it is well suited as a follow up technique to herbicides because the reduced plant density resulting from chemical application reduces the amount of plants which require picking by the diver, thus reducing costs. For Candlewood Lake, DASH is best used as an auxiliary technique to herbicides or as a management method in small areas with less dense stands of invasive aquatic plants.

2) Drawdown:

Drawdown is the physical manipulation of the lake's water level to expose portions of the littoral zone to freezing temperatures and drying. The result is plant death through the drying of soil and freezing of root material. Drawdown success is heavily impacted by weather in that if temperatures do not permit freezing within the rooted zone or snow cover insulated the sediment surface, plant mortality is not achieved. Since weather conditions cannot be controlled, the effectiveness of drawdowns is regionally and annually subjective.

On a per acre basis, this method is relatively inexpensive to implement. However in the case of Candlewood Lake, the revenues of First Light may be affected by using this technique because the lake is a hydroelectric storage facility.

3) Mechanical Harvesting:

Harvesters are essentially large boat driven mowers. These large machines scrape the top of the lake-bottom sediment and cut the target plants from the base. The plant material is then fed "top-side" on a conveyor and disposed of.

The costs associated with purchasing a mechanical harvester are high, usually in the range of $200,000 – 300,000. It is likely that more than one machine would be necessary for management within a lake the size of Candlewood; it is likely that 5-10 of these machines would be required to have an impact on the population of target plants. Additionally, harvesters cause significant fragmentation of plant material, which is not ideal when managing Eurasian milfoil because the fragments can establish new plant stands. For Candlewood Lake, plant harvesters are not likely the best method for use in plant control.

4) Grass Carp:

Grass carp (*Ctenopharyngodon idella*) are large herbivorous fish that can be bred as sterile and thus not spread through reproduction. Since the carp are non-native, sterility is essential to ensure they don't outcompete and displace native fishes. Using grass carp for plant management requires that the lake is properly stocked, generally a 30% surface area ratio is used to determine the number of fish to be introduced. Candlewood Lake would require 23,000 fish to satisfy the 30% surface area recommendation. Maintaining the effectiveness of this plant control measure requires that fish populations are surveyed yearly and that more fish are stocked as necessary.

On a cost per acre basis, the price of this technique is relatively low (~$75/acre, at ~$5 per fish) but requires significant manipulation of the physical environment to ensure fish do not leave the system. Every inlet and outlet of the lake, whether natural or anthropogenic, needs to be blocked using gating with gaps less than two-inches. Furthermore, any natural inlet and outlet will require that fencing is installed that is two-feet above the high-water-level and has gaps less than two-inches. For Candlewood Lake, these fish are a viable option but will require significant financial input by all vested agencies costing $120,000 or more in the first year (note: only price of fish). Surveying and restocking costs including maintenance of the fish retention structures will also be required in subsequent years.

5) Milfoil Weevils:

Milfoil weevils (*Euhrychiopsis lecontei*) are a small beetle that spends its lifecycle on the stems of milfoil species. Their native host is Northern milfoil (*Myriophyllum sibiricum*) but will exploit Eurasian milfoil stems when the population is dense. The use of this species to control problem stands of Eurasian milfoil has been the focus of much research over the years. Unfortunately, the results are highly variable and reliable stocking rates have not been established.

The cost to control milfoil using Milfoil weevils is difficult to determine because their efficacy is still in question and stocking rates have not been established. Furthermore, there a many unanswered question regarding this species' ecology, which has led to the an incomplete understanding of the factors dictating their success as a control measure. This is probably not a viable strategy to control the milfoil population of Candlewood Lake.

6) 2-4 Dichlorophenoxyacetate

2,4-dichlorophenoxyacetate (2-4D) is a plant hormone analog that causes uncontrolled cell division and elongation. This chemical causes plants to exhaust root carbohydrate stores thus acting as a systemic herbicide. 2-4D is produced under a number of label names and is most commonly applied in a granular form in aquatic systems. The use of this chemical allows for application late in the season, which can be exploited to conserve native vegetation while managing the target plant. There are numerous restrictions on the use of 2,4D; and currently the use of 2-4D requires review by the Department of Public Health and monitoring of groundwater during application. The cost is about $1,640.00 per acre.

7) Diquat Dibromide:

Diquat dibromide is a contact herbicide that interferes with the energy production cycle in plants and results in the breakdown of intercellular membranes. Diquat dibromide is produced under a number of labels and is commonly applied to lake systems in its liquid form. Because this chemical can be applied to cold water (i.e. early in the season), when non-native species have begun growing, native vegetation can be insulated from the negative effects of this chemical. However, diquat dibromide binds strongly to sediment and, when it does, it becomes effectively inactivated and builds up in the sediment with subsequent applications. Finally, recent research has shown that this chemical is highly toxic to juvenile fish and is currently under scrutiny by numerous state agencies due to these findings. The cost is about $1,560.00 per acre.

8) Flumioxazin

2-[7-fluoro-3,4-dihydro-3-oxo-4-(2-propynyl)-2H-1,4-benzoxazin-6-yl]-4,5,6,7-tetrahydro-1H-isoindole-1,3(2H)-dione (Flumioxazin) is a protoporphyrinogen oxidase inhibitor that results in the reduced production of chlorophyll. Plants exposed to this chemical are limited in their ability to harvest the sun's energy. The result is cell death and a reduction in standing biomass. Flumioxazin is produced under a number of labels and is commonly applied to lake systems with the use of a boat and trailing hoses, in its liquid form. It should be noted, however, that this chemical is sensitive to water pH; therefore, it is best applied in the morning before plant stands cause swings in water acidity. Furthermore, this herbicide is a Group 14 herbicide and repeated use may result in resistant populations of the target plant. Therefore, this herbicide should probably be alternated with other herbicides during long term herbicide initiatives. Finally, the toxicity of this chemical is low and off target effects are thought to be minimal. The cost is about $3,760.00 per acre.

9) Fluridone

Fluridone (1-Methyl-3-phenyl-5-(3-(Trifluoro-methyl)phenyl)-4(1H)-Pyridinone) influences pigment production (i.e. a phytoene desaturase inhibitor) that diminishes carotenoid development in growing plants. Plants lacking this pigment can not effectively photosynthesize and die. Fluridone is produced under a variety of labels and can be applied to lakes in liquid or granular forms. Because this herbicide is systemic, aqueous concentrations must remain consistent for up to 90 days, which generally requires supplemental applications. Due to this requirement, it is not an optimal choice for systems with short water residence times. A final constraint associated with fluridone is the price, it is generally very expensive to use this chemicals in large lakes, as the entire water body is treated. The cost is about $4,340.00 per acre.

10) Triclopyr:

Triclopyr ((3,5,6-trichloro-2-pyridinyl)oxy]acetic acid) is a plant hormone analog that causes uncontrolled cell elongation and division. It causes the plant to exhaust its carbohydrate root stores and results in the plant mortality. Triclopyr is produced under a number of labels and has only recently become widely used in aquatic systems. The use of this chemical alone in aquatic plant control has been met with limited success; however, significantly greater levels of control have been encountered when coupled with other systemic herbicides. The cost is about $2,550.00 per acre.

Recommendations:

Candlewood Lake is a large system with a significant population of Eurasian milfoil. Due to the breadth of the problem a simple unidirectional approach to plant control will not likely suffice. Therefore, NEE recommends an integrated management approach that incorporates the current drawdown regime, with an improvement in the consistency of depth and duration, and includes the use of herbicides and DASH.

Preferred Approach:

2-4D/Triclopyr and DASH:

This protocol should begin in the northern most portion of the lake. All acres infested with Eurasian milfoil should be treated over a three year period; where, 33% of the area is treated with a 2-4D/Triclopyr cocktail in the first year, 33% in the following year, and 33% in the final year. The chemical treatments should take place either in mid-June or immediately following Labor Day (no later than September 30th) to ensure the target plants are present and growing.

In the first year of chemical treatment, no DASH is recommended. However in the following years, DASH should be initiated in areas where chemical treatment had occurred in the previous year. This will significantly reduce the cost of DASH and will increase the efficacy of the plant control initiative in areas treated the year before.

If this management method is coupled with a consistent drawdown regime, the Eurasian milfoil population should be well managed. The following is a theoretical timeline:

- Fall 2015: Treatment of northern 33% of Eurasian milfoil using 2-4D/Triclopyr.
- Summer 2016: DASH in northern treatment area.
- Fall 2016: Treatment of middle 33% of Eurasian milfoil using 2-4D/Triclopyr.
- Summer 2017: DASH in middle treatment area.
- Fall 2017: Treatment of southern 33% of Eurasian milfoil using 2-4D/Triclopyr.
- Summer 2018: DASH in southern treatment area.
- Subsequent Years: Maintenance treatments with DASH or 2-4D/Triclopyr.
- Considerations:
    - Natural Diversity Database (NDDB) review.
    - CTDEEP Aquatic Herbicide Permit.
    - CTDPH Review.
    - Monitoring of 3-5 test wells in treatment areas (2-4D/Triclopyr).

Exploratory Approach:

Given the fact that a drawdown regime is already in place, it may be advantageous to explore the following approach to milfoil management. This will require that funds be dedicated to conducting 1-2 years of research to discover appropriate rates and chemicals.

Drawdown Timed Herbicide Application:

This strategy for plant control couples a drawdown with an herbicide application. However, it will require a change to the drawdown regime for a single year. That change is an earlier target date for the deep drawdown. By drawing the lake down earlier and spraying the exposed milfoil, a high level of plant control should be achieved with a single treatment. That does not mean that some follow up maintenance will not be required. It is likely, that maintenance treatments will be required in subsequent years. These maintenance treatments can occur without the coordinated drawdown.

The initial treatment should take place after drawing the lake down to a minimum of 10ft but preferably to 12 or 15ft. A systemic herbicide should be used to kill the exposed milfoil. This will require the services of a firm that has the equipment (i.e. Marsh Master) to approach a project of this complexity. The following is a theoretical timeline for this type of application:

- Between September 15th and October 1: Drawdown lake.
- Between September 15th and October 1: Apply herbicide to exposed weeds.
- Early – Mid January: Refill lake.
- Subsequent Years: Maintenance following option #1 (minus DASH).
- Considerations:
  - Natural Diversity Database (NDDB) review.
  - CTDEEP Herbicide Permit.
  - Other permits and considerations for maintenance treatments

10.0 CITATIONS

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