Cedar Lake Bathymetric Study Report
Cedar Lake
Denville Township, Morris County, NJ

Prepared for:

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Introduction –
The following report details the recently conducted bathymetric study and assessment of Cedar Lake. This project was conducted in keeping with the scope of services outlined in Princeton Hydro's April 2011 proposal to the Cedar Lake Property Owners Association (CLPO). As was detailed, Princeton Hydro was to conduct a bathymetric study of Cedar Lake that encompassed both the main lake and the lagoon. The objective of the bathymetric study was to investigate and quantify the lake's morphometry (size, shape and contours) and obtain in-field data documenting the existing water depths, the distribution of accumulated sediment, and fishery habitat qualities of the main lake and the lagoon. These data would provide the Association with up-to-date, site-specific information regarding the average depth, maximum depth, water volume, sediment thickness, sediment volume, and general contours of both waterbodies.

Overview of Bathymetric Assessment –
Basin morphometry or bathymetry is an important factor that can influence a number of biological, chemical and physical lake interactions. It is thus an important element that defines the cumulative ecological properties of a lake. Among some of the key factors directly affected by a lake's bathymetry are thermal properties, mixing dynamics and internal phosphorus recycling. Bathymetry also largely defines the type and amount of habitats available for fish to support feeding, nursery and spawning activities. Thus the bathymetry of a lake can affect the success, structure, and species composition of a lake's fishery. Bathymetric information also enables lake managers to forecast lake problems and design management plans. For example, shallow lake systems will also tend to be more prone to weed and algae problems, higher summer time water temperatures and potentially lower dissolved oxygen concentrations. These conditions in turn play a role in the management of a lake's fishery and are the primary factors why warm water fish assemblages do well in shallow lakes.

When lakes become impacted by extensive deposits of fine grain sediments, problems indirectly linked to water quality and fish become manifested. Such sediments often have large amounts of easily assimilated nutrients, that help foster the development of filamentous algae and provides fertile grounds for the establishment of invasive and nuisance aquatic macrophytes (weeds). Sediment accumulations can also alter circulation patterns that in turn promote stagnation that as well as promoting further sediment deposition, triggers water quality impacts including dissolved oxygen depletion. Sediment deposits can smother fish eggs or create conditions that are not conducive for successful spawning. Additionally, as sediments accumulate and water depths decrease the recreational use and aesthetic appeal of a waterbody declines.

Thus there are a number of reasons why it is important to have a firm understanding of the bathymetric properties of a lake. The bathymetric study of Cedar Lake is designed to obtain information that can be used as a foundation for future management and restoration decisions; from fishery management to weed control and dredging.

Field Methodology and Data Collection –
In advance of conducting any field work, a recent (2009) aerial photo of the lake and adjacent watershed were downloaded from the NJDEP GIS (Geographic Information Services) digital data library. The aerial photo was used to create a base map of the lake. Transects lines, spaced at 200 foot intervals were then placed on the aerial photo running longitudinally from shoreline

to shoreline. This was done for both the lake and the lagoon. An additional transect was run through the lake's north-south axis. The transect lines formed a predefined grid, with set longitude and latitudinal coordinates. The transect lines and grid were subsequently used in the field to guide the bathymetric data collection.

Bathymetric data were collected using a combination of standard field survey equipment and a continuing recording fathometer, both of which incorporate an integrated GPS (Global Positioning System) to ensure accurate map development. All areas of the lake deeper than approximately 12 inches in total water depth were surveyed using Princeton Hydro's calibrated Knudsen 320BP dual frequency fathometer. The fathometer emits both high and low frequency sound waves enabling the accurate measurement of water depth and the detection of the top and bottom of the accumulated sediment layer; referred to herein as "sediment thickness". The fathometer's transponder was lowered from the side of our boat to a depth approximately 6" below the water surface. As the boat traversed each transect, the transponder continuously recorded water depth and sediment thickness measurements. The raw accuracy of the fathometer recorded water and sediment depth soundings is approximately 0.10 inches. As noted above, the sounder is tied to a horizontal datum via an integrated Trimble Pro-XRS Global Positioning System (GPS) antenna and receiver. The GPS continuously monitors the boat's location along each transect and provides an instantaneous readout in latitude and longitude coordinates. These reading can then be accurately positioned on the digital aerial photo of the lake and interpreted by the computer to illustrate in-lake contours or isopleths.

Traditional survey equipment and methodology was used in those portions of the lake and lagoon shallower than 12" in total water depth. In shallow or "weedy" areas the fathometer transponder generates too much scatter and false echoes that compromise the accuracy and precision of fathometer recorded data. The traditional survey methodology, involving the use of a calibrated survey rod, is not affected by shadow water depths or dense weed growth, thus ensuring the nearshore bathymetric data is accurate. As with the fathometer surveyed areas of the lake, the data collected using traditional survey equipment was also integrated using the Trimble Pro-XRS Global Positioning System (GPS) antenna and receiver. This ensured the accurate location of each spot measurement.

The raw digital fathometer and survey rod data were post-processed using GIS based software. The corrected digital water depth and sediment depth data were then used to create maps showing changes in water depth in 1 foot increment isobaths (contour lines) for the lagoon area and in 2 foot increments (contour lines) for the main lake. The resulting two figures contained in Appendix A of this report provide the following information:

1. A plan view (aerial projection) bathymetric map of Cedar Lake documenting the existing water depths of the lagoon and the main lake.
2. A plan view map depicting the distribution of thickness of sediment in the main lake and lagoon.
3. Computed summary statistics of the lake's area, volume of water, average water depth, maximum water depth, average sediment thickness, maximum sediment thickness and total sediment volumes.

The findings and significance of the bathymetric study results are discussed in the following section of this report.

Results of Bathymetric Study of Cedar Lake –
Table 1 provides a summary of the bathymetric statistics for both the lake and the lagoon. As illustrated, the main lake has a surface are of approximately 94 acres with a mean depth of slightly more than 7 feet. The much smaller lagoon (2.84 acres) is also much shallower, having a mean depth of slightly less than 2 feet.

Figures 1 (Water Depth Contours) and 2 (Sediment Thickness Contours) respectively present the existing water depths of the lake and the lagoon, and show the distribution and accumulation of sediment present in both waterbodies. As previously noted water depths in the lagoon are presented in 1 foot increments, while the same data is shown in the main lake in 2 foot increments. With regard the sediment contours, deposition is illustrated at 1 foot contours for both the lake and the lagoon.

Table 1 - Summary of Lake Bathymetric Statistics	
Main Lake	**Lagoon**
Surface Area - 94 Acres	Size of Survey Area - 2.84 Acres
Maximum Depth - 15.5 feet	Maximum Depth - 1.98 feet
Mean Depth - 7.18 feet	Mean Depth - 1.38 feet
Water Volume - 1,085,110 yds^3 = 219 million gallons	Water Volume - 6,347 yds^3 = 1.28 million gallons
Total Sediment Volume - 117,260 yds^3	Volume of Sediment - 10,608 yds^3

For the main lake, in general the bathymetric map (Figure 1) shows water depth to increase substantially (to depths of approximately 5-6 feet) within 50 to 100 feet of the shoreline. In general the overall bottom of the main lake can be characterized as relatively uniform and “flat”. Closer examination of Figure 1 shows that the main lake can be divided up into three general areas; a south end, a central area, and a north end.

The northern end of the lake is the shallowest area. It is characterized by a broad flat plateau with minimal topographic relief or changes. The south end of the lake also has gentle slopes, and a fairly uniform, somewhat flat bottom. Within the south end there is a small depression that attains a depth of approximately 5 feet and a slightly larger depression that reaches about 9 feet in depth. In general, of the three areas of the main lake, one would expect the north and south ends of the lake to be most susceptible to colonization by invasive aquatic weeds and filamentous algae blooms given the relatively shallow depths and uniform contours that characterize both areas.

The central portion of the lake has somewhat steeper contours that are reflective of a geologically created depression or excavation. This central area is essentially the original lake with the north and south ends being areas that became flooded with the construction of the dam. Proceeding out from the shore, the contours in the central basin area are much steeper and the lake is much deeper (maximum depth of 15 feet) than observed in either the north or south ends. This deep "hole" in the central basin is somewhat segregated for the remainder of the lake. Typically, such isolated deeper areas tend to become thermally stratified. This means that over the course of the summer distinct thermal bands will develop in the water column as one proceeds from the surface to the bottom. With this thermal stratification comes differences in water density, with the warmer water being lighter than the cooler water. These density differences can become great enough to inhibit the free vertical mixing of the water column, a condition referred to as thermal stratification. Once the lake is stratified and water column mixing is impeded, the bottom waters quickly become devoid of dissolved oxygen due to the continued bacterial decomposition (and related consumption of oxygen) of organic sediments and debris. This then leads to anoxic (without oxygen) conditions in the deeper cooler areas of the lake. Anoxia alters the chemistry of the lake at the sediment/water interface triggering the liberation of phosphorus, minerals and metals from the sediments into the water column. Given that phosphorus is the nutrient most needed by algae, the liberation of phosphorus into the water column from the sediments sets the stage for algae blooms. Because of these possible physio-chemical ramifications, it would be prudent to carefully monitor over the course of the summer the thermal properties and water chemistry of the lake in the central basin, especially within this deep center hole.

Examining Figure 1 in its entirety shows that with the exception of the 15 foot deep "hole" in the center of the lake, there is relatively little in the way of any distinct physical features. As such, the lake does not have a large amount of topographic relief that can naturally provide important habitat or fish holding areas. However, this lack of relief can be compensated for through the introduction of artificial habitat. This will be discussed in greater detail at the close of this report. Additionally, the three distinct areas of the lake can be capitalized upon with respect to habitat augmentation and enhancement. Again, this will be discussed in greater detail in the last section of this report.

With respect to the lagoon, this section of the lake is very shallow with very uniform bottom contours. Its overall shallow nature makes it more susceptible to colonization by invasive aquatic weeds and filamentous algae blooms.

Figure 2 shows the distribution of accumulated sediment. Accumulated sediments by definition are soft sedimentary deposits, comprised mostly of silts and clays and partially decomposed organic material. They are typically reflective of material that has settled in the lake over time. Sources of these sediments include shoreline erosion, stream scour, stormwater loading and the deposition of dead algae and aquatic plants along with leaf litter and other organic material.

The contour intervals on Figure 2, as previously noted, are presented in 1 foot increments, and the darker brown areas of the figure are representative of areas characterized by extensive sediment deposits. As such, referring to Figure 1 the greatest amount of sediment accumulation exists to the west of the island in the lake's northern end. In that area, sediment deposits total well in excess of 7-9 feet thick. It is unclear why so much sediment is present in this area. Besides this one area, sediment deposition throughout the reminder of the lake, even in the far south end, is minimal, typically 1 foot or less.

The lagoon is characterized by an evenly distributed, fairly thick sediment layer. Sediment accumulations are as much as 6 feet thick, and on average range from 3-5 feet. The abundance of sediment in this portion of the lake would appear to mostly a function of its historical origin.

On a per unit basis (that is volume of sediment per area of lake), it is clear that the greatest sediment related impacts are observed in the lagoon. In that section of the lake the unit sediment relationship is about 3,700 yds^3/acre. For the main lake this relationship is only 1,200 yds^3/acre. To put this in perspective, as much as 250 truck loads of sediment per acre could be removed from the lagoon. Additional examination of Figures 1 and 2 show that in terms of existing and potential water depths, the lagoon area would benefit the most from a dredging operation. That is, assuming that the sources of sedimentation to the lagoon are under control, the dredging of the lagoon would yield the greatest positive return and overall water depth, water quality and ecological improvements. The same could be said for the targeted dredging of the area behind the island located at the north end of the main lake. Again, comparing the couture data presented in Figures 1 and 2, a significant increase in water depth could be realized if this area of the main lake was dredged.

However both projects would be expensive to implement. Assuming the local disposal of the dredged sediments and the presence of no contaminants in the sediments, the cost to dredge the lagoon area would be at least $340,000, while the cost to dredge around the island would be at least $250,000. Please note that these are very preliminary estimates that are subject to additional refinement, and are being provided in this report for discussion purposes only. However, these general cost estimates highlight that the amounts of sediment present in these two areas of Cedar Lake are significant and that the removal of this material would be costly.

Fish Habitat Enhancement –
As noted for the most part the lake's bottom is relatively flat. The lack of any significant physical relief can be mitigated through the addition of artificial habitat elements, including porcupine cribs and tree piles. Such fish habitat enhancement devices/techniques were identified and discussed in the *Cedar Lake Fish Restoration Plan* and in subsequent reviews of the material by conducted by Princeton Hydro. Given the relatively uniform nature of the lake's bottom in the north and south ends of the main lake, the introduction and placement of fish habitat structures need not follow any specific pattern. For the most part in the south and north ends it would be best to cluster habitat as opposed to placing artificial structures in a defined uniform arrangement. Additionally, as in keeping with our earlier report, the introduction of structures could be conducted lake wide (even along the edges of the deeper central area) and involve the placement of structure in a variety of locations and at different depths. In the May memo we limited our discussion to the placement of structure in the north end and near the island, and the

introduction of twelve artificial structures was recommended as a "starting point". The bathymetric study shows that the lake could greatly benefit from even more introduced structure and artificial habitat. Interestingly, the bathymetric profile and contours in the center of the lake show this area to have the least amount of littoral habitat. Note that the lake gains depth rather quickly in this area as compared to either the north or south ends. Referring to Figure 1, note how water depths drop off quickly from the shoreline. This lack of a well defined "littoral zone" could limit desired interactions between the large game fish that use the deep hole and their forage fish which would prefer the safety of the shallows. This condition could be easily rectified by placing artificial structure in set areas and different water depths extending from the shallows into the deeper water.

Before introducing any structure into the lake, existing recreational uses and use patterns, as well as the intensity of shoreline development, need to be taken into account. We suggest that structure be clustered in areas that are easily accessible to anglers, including those fishing from shoreline locations. Clustering structure and artificial habitat typically enhances or intensifies fish attraction and fish "holding capacity". As noted above, while some artificial structure should be placed around or within the deep center hole of the lake, the placement of structure should focus on the lake's shallow south and north ends. Given that most warm water fish (including the larger predatory game species) tend to spend most of their time in shallower water, improving the fish holding capacity of the lake's shallow areas is more in keeping with the natural habits of bass, pickerel and the forage fish species that these fish feed upon. However, as noted above more should be done in the central area of the lake to create a littoral transition from the shore into the deeper center hole.

Summary –

A bathymetric study was conducted of Cedar Lake and the lagoon. The study generated data specific to the morphometric characteristics of both waterbodies. The water depth and general contours of the main lake can be summarized as follows; a deep central pool with large shallow north and south coves. The lake in general has fairly gentle sloping contours, and each of the three distinct areas of the main lake have fairly uniform bottom contours that can be characterized as fairly flat and lacking any erratic depressions. Sediment deposition in the main lake is minimal and largely limited to a fairly segregated area located to the west and northwest of the island located in the lake's north end. In total it is estimated that there is a total of 117,000 yds^3 of accumulated sediment in the main lake with between 10-15% of this deposition occurring adjacent to the island.

In contrast to the main lake, the lagoon is very shallow, having a mean depth of only about 2 feet. There is a large amount of sediment accumulation in this small subarea of the main lake; 10,608 yds^3. The distribution of this sediment is relatively uniform across the entire bottom of the lagoon.

If the CLPO wishes to pursue the dredging of either of the noted locations, the next step would be to conduct physical and chemical testing of the sediments. The presence of contaminants in the sediments can dramatically escalate the cost of dredging. As such, before work is done on permits or plans, the quality and composition of the sediments should be quantified and the data used to refine the preliminary dredging cost estimates provided in this report.

The lake's fishery could greatly benefit from the introduction of more artificial structure and habitat. The report details how this artificial structure and habitat could be distributed throughout the main lake. Given the existing shallow nature of the lagoon there is no need to add any structure to this area.

During the summer, *in-situ* thermal and dissolved oxygen data should be collected in the lake's deep central basin, and deep water samples collected for the analysis of phosphorus. The isolated nature of this deep hole and its relative position to the lake's main inlet and the lake's outlet may lead to thermal stratification that can in turn lead to depressed dissolved oxygen levels and internal phosphorus release and recirculation.

Appendix A

Bathymetric Study Figures