Advanced Assessments of Environmental Resources

Sediment Depths, Bathymetry, and Volume Assessment of Lake Lemon, Unionville, Indiana

Report prepared for the
Lake Lemon Conservancy District

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INTRODUCTION

Water volume and sediment information on large lake systems is often incomplete or dated. Much of the government work to develop accurate bathymetry in lake systems around the U.S. was performed in the 1970's or earlier. Lakes are dynamic systems and can change dramatically over time. Since the lake is the lowest point on the watershed, eroded soils are transported and deposited in lakes over time. Excessive amounts of aquatic vegetation can also contribute to the buildup of organic sediments on the lake bottom. Lake management assumptions made using outdated water volume or sediment information can significantly affect the results obtained.

In 2001, the Lake Lemon Conservancy District identified a need to update the water volume and sediment information for Lake Lemon. This need is in response to lake management efforts the Conservancy District wishes to undertake in future years. To better understand the bathymetry and sediment characteristics of the lake, ReMetrix was retained to develop a current understanding of the water and sediment volumes present in the system. Current lake morphology and sediment data are extremely valuable to establish reliable baseline databases for long-term lake management initiatives. In particular, sediment depth data within the littoral zone are important for planning sediment removal activities.

All of the tables and maps included in this report can be found in the Appendix.

Approach

Project activities involved two components: data acquisition and data assembly/interpretation. Three types of data were collected during data acquisition: bathymetric (water depth) data, sediment type, and sediment depth in waters shallower than 8 feet. The contract required a maximum of 150-meters between hydroacoustic transects, and collection of a minimum of 350 sediment depth. No minimum sample numbers were stipulated for sediment type points.

Data were collected on the water body using the technologies described below. Archived aerial imagery was acquired to cover the project area, both for planning and map display purposes. All data collection and analyses were performed by ReMetrix LLC (Carmel, IN). For the purpose of this report, the terms "lake" and "water body" refer to Lake Lemon, unless otherwise noted.

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METHODOLOGY

Data Acquisition – General Information

The primary data collection tools used for this mission were a digital scientific echosounder linked to a Differential Global Positioning System (DGPS) receiver, and a graduated sediment probe for collecting sediment depth data. The Global Positioning System is a technological tool for accurately locating and recording coordinates on the Earth's surface.

Fieldwork was conducted from August 11-16, 2003. Equipment was mounted on an 18-foot watercraft. Lake conditions were calm during the six days of fieldwork.

Field maps were used to increase efficiency and accuracy of the data collection. Field maps were prepared prior to data acquisition and underwent review and approval by representatives of the Lake Lemon Conservancy District. Transect locations and spacing were carefully considered, as were GPS point sampling locations and spacing.

Transect spacing and point sampling densities were maximized within the context of the overall goals of the project, as well as the budget and timeline of the project. The transect map and GPS point sampling map used for this project are shown in the Appendix.

Hydroacoustic Data Acquisition

The digital scientific echosounder was used to collect the data for water depth and lake morphology. The acoustic signal from the echosounder is reflected back to the boat when the signal encounters a material density change in the water column. As an example, the lake bottom is a substantial density change as compared to the water column, and thus the acoustic signal bounces strongly off the lake bottom.

Aquatic vegetation also represents a density change within the water column. Dense, submersed plant beds can return a strong echo, mimicking the bottom (a "false bottom" echo). A digital scientific echosounder enables proper adjustment of acoustic signals and receiver sensitivity to minimize plant detection, which results in an accurate depiction of the actual lake bottom. Considering the presence of aquatic vegetation in Lake Lemon—especially in the lake's east end—the ability to eliminate the possibility of false bottom interpretation is important for the overall accuracy of the final maps and calculations.

The acoustic signal response is digitally recorded along with a corresponding coordinate from the DGPS beacon. The echosounder was set to ping eight times per second, often resulting in thousands of data points along each transect. For this survey, pre-planned transects were spaced at an average of 100 meters apart.

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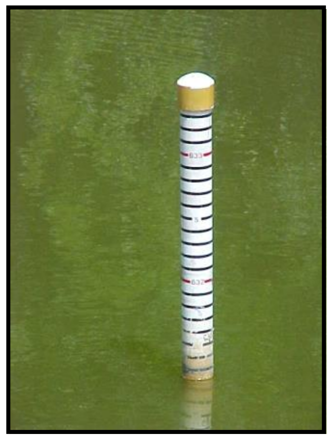
A total of 84 transects of hydroacoustic data were collected throughout the water body (see transect layout map in the Appendix).

The lake water level was monitored during the field data collection. Water level was monitored using the gauge located in the small bay adjacent to the east of the Lake Lemon Conservancy District office in Riddle Point Park (see gauge photo below, taken during fieldwork). The water level did not change during the fieldwork.



Depth gauge showing 629.7 feet of elevation.

GPS Sediment Depth Data Acquisition

Sediment depth survey information was acquired using a sediment probe, a GPS unit, and data collection sheets. The use of GPS facilitates replicate sampling in future studies. Sediment depth survey points were selected to maximize data near docks. A total of 369 sediment depth points were surveyed throughout the lake. Most of the points were distributed within 50-feet of the shoreline because a key goal of this study was to determine shallow-water sediment thickness.

At each sediment probe sampling point the following information was recorded: water depth, sediment type, and sediment depth. The sediment probe used is pictured below. The probe was lowered in the water column until it struck the top of the sediment surface, determining the water depth. The probe was then pushed into the soft sediment layer until it met resistance. Resistance is defined as the sediment not yielding to moderate pressure applied by arm strength. No mechanical means were used to push the sediment probe into the sediment.

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Sediment depth sampling probe (orange markings are 1-foot increments). Sediment from a sample point is visibly clinging to the probe in the photo at right.

GPS Sediment Type Acquisition

General sediment type was acquired at 369 points using a Ponar sediment sampling device (sediment type points correspond to the sediment depth points). The Ponar sediment sampling device is pictured below. It is a scooping device that collects sediment samples from the top few inches of sediment.

Ponar sediment type sampling device and mucky sediment example.

DISCUSSION OF ANALYSES

Bathymetric Analysis

It was necessary to complete the bathymetric analysis prior to the sediment volume analysis. The reason is that the bathymetric contours define the top of the sediment surface, and the top surface should be defined before one begins to contour the depth values below the sediment surface. Without the top of the sediment surface defined, the sediment depth values have little real-world context.

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The digital echosounder data points were processed using software designed for hydroacoustic equipment. The software algorithm is able to identify the bottom depth for each point collected along a transect. The software analysis was supervised by an analyst to ensure that the analysis proceeded correctly. Also, depth readings from the echosounder were double-checked against water depth readings gathered during the sediment depth probing.

The bathymetric data was plotted using Geographic Information Systems (GIS) software. From the data a bathymetric TIN (an acronym for "triangulated irregular network") model was created using geostatistical software designed for surface modeling. Inverse distance weighting (IDW) was the statistical technique used to create the TIN model. The contour intervals used in this study were established in the project proposal. Again, as in all stages described in this report, the software analysis was supervised by an analyst to ensure that the analysis proceeded properly. Contours above 10-feet in depth were smoothed from the contours derived from the TIN. Contours 10-feet and below were created by hand using the TIN as a reference. The resulting bathymetric contours were smoothed and checked for positive correlation to the field data. The completed bathymetric map is shown in the Appendix.

Creation of the bathymetric contours in a true geographic framework is necessary for calculating water volumes on an entire lake basis and on an individual contour interval basis. Using a true geographic framework is also necessary in order to integrate the data with other lake and regional data sets. Results of the bathymetric calculations indicate that 4,698,804,865 gallons (14,420 acre-feet) of water are in the lake (at a lake water-level of 629.7 feet).

Within the context of this project, the bathymetric data will be useful in interpreting which areas near shore currently have the least water depth. The data collected are not exhaustive, but should aid greatly in such determinations.

It should be noted that thermoclines can become established in Lake Lemon during summer months, and the exact depth of the thermocline can vary seasonally and from year to year. Thus, the water volume table can also be used to calculate the water volume above a thermocline as needed.

Comparison To Historical Water Volume Data

ReMetrix checked the 2003 results against lake water-volume estimates from previous years. The original 1953 water volume for the lake was calculated by the USGS to be 14,400 acre-feet, at a lake water-level of 630.0 feet above sea level. In 1973, water volume was re-calculated by the USGS to be 13,920 acre-feet, also at a lake water-level of 630.0 feet. ReMetrix has calculated a 2003 water volume of 14,420 acre-feet at a lake water-level of 629.7—a difference of

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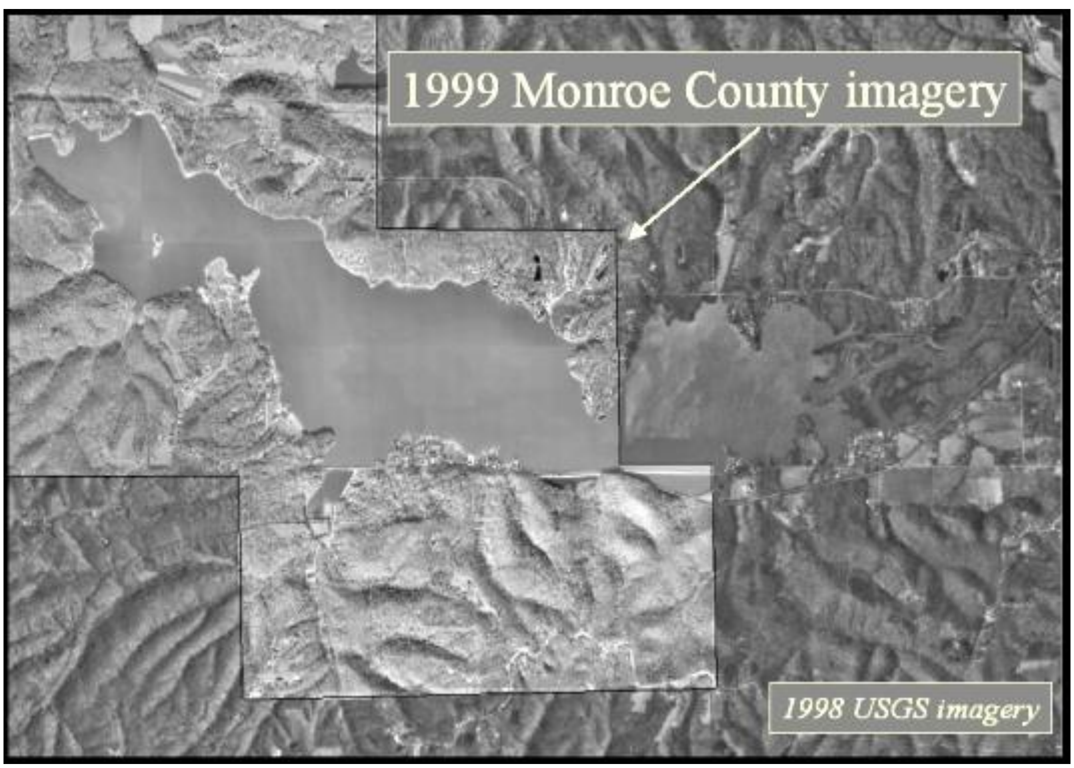
500 acre-feet (3.6%) *greater* in 2003, despite a gauge reading of 0.3-feet *lower* in 2003.

At least six possibilities could contribute to the 3.6% variation in water volume calculations. One reason for the variation could be a difference in the mathematical formulas and computational techniques used to calculate the volumes. Water depth contour calculations were modeled using geostatistical techniques, and such models rely on certain parameters and statistical assumptions to carry out their calculations (the basic parameters used in this study are identified in the digital metadata layers provided with this report). Similarly, mathematical nuances in different geographic coordinate systems used to reference the data could introduce variation in volume calculations (e.g., GPS was not available in 1973).

A third reason might be variability in determination of the lake shoreline, which affects surface acreage calculations. Shorelines can and do change due to natural processes and human modifications, and methods to calculate shorelines have varied in the past 30 years. At the request of the Conservancy District, ReMetrix used a combination of aerial photographs from 1998 (USGS 1-meter resolution orthoquads, Monroe and Brown Counties) and 1999 (6-inch resolution, Monroe County) to determine the shoreline (see figure below). Six-inch resolution imagery for Brown County was not available for this project.



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A likely possibility for the comparative volume variations are the level of sampling programs undertaken. For example, the USGS collected data points along 12 bathymetric transects, plus 13 additional sample points. ReMetrix collected data along 84 bathymetric transects, plus 369 sample points. The reason for the differences in sampling programs are primarily due to significant advancements in technology between the two studies, and also partly due to slightly different approaches for the studies.

Discrepancies between actual lake water surface elevation measurements can also be a possible reason for the 3.6% difference. ReMetrix based its measurement on the gauge in the cove adjacent to the east of the Lake Lemon Conservancy District building (in Riddle Point Park). Gauges used by the other researchers may have been different, and there may be no accurate way to cross-correlate gauge readings between studies. Decades of topographic settling or shifting may have also altered the accuracy of gauges or dam height measurements.

An overall change in lake morphology (e.g., scouring) is very unlikely as an explanation for the volume variation. Sedimentation is accumulating in Lake Lemon, so scouring processes would only redistribute sediment, not remove it. However, internal redistribution of the sediment could potentially affect volumetric calculations if, for example, the sediment redeposited in "pockets" of the lake and the sampling program did not detect this phenomenon. Of the six possibilities suggested for the volume variation, this latter possibility is considered the least likely scenario.

Considering the above factors, a difference of +3.6% between 2003 and 1973 (and +0.1% between 2003 and 1953) is well within reasonable expectations. Considering the far more rigorous sampling program of 2003 and the associated technological advancements, the 2003 calculations can be interpreted to represent an accurate depiction of current lake conditions.

Sediment Depth Analysis

The geostatistical software modeled the sediment depth values by creating a raster grid from the field data. Two methods were attempted to model the data: inverse distance weighting (IDW) and kriging. Both have strengths and weaknesses in how they model data, and so it was worthwhile to consider both options since the sediment depth data are clustered around the shoreline of the lake. After considering the parameters used in the models and the results obtained from them, the IDW model was chosen to be the more reliable of the two. Final maps were produced from the IDW model results. However both models are included in the final digital data layers provided to the Conservancy District, as a means of comparison.

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The final map of sediment depth contours from the IDW model is shown in the Appendix. The relevant field data points are overlain as a reference layer on the map.

A volume of the soft sediment layer was calculated from the top of the sediment surface (the sediment-water interface) to the "hard pan" layer at the base of the soft sediment layer. Using the IDW sediment-depth TIN model, this volume was calculated within a minimum of 8-foot water depth and shallower, but in some places the calculations extended deeper than 8-feet if the data permitted. The total sediment volume within the modeled region is 1,398,768 yards^3 (867 acre-feet). For comparison, the same calculation using the kriging TIN model is 1,180,000 yards^3 (731 acre-feet). As noted above, the IDW result (867 acre-feet) was chosen to be the most reliable calculation.

Using the grid layer created from the sediment data, the distribution and volume of lake sediment can be calculated within different water-depth intervals or within specific sub-basins (such as coves).

Within the context of this project, the sediment depth data will be useful in interpreting the areas near shore that currently have the greatest depth of sediment. *The data collected are not exhaustive*, but should aid greatly in such determinations throughout the lake.

Comparison To Historical Sediment Volume Data

ReMetrix checked the 2003 results against lake sediment volume estimates from the 1973 USGS analysis. In 1973, sediment volume *for the entire lake* was calculated by the USGS to be 500 acre-feet. The 2003 calculation indicates a sediment volume of 867 acre-feet *in the modeled region.* (Sediment sample points in waters more than 300-feet from shoreline were generally not collected in this study due to the focus on shallow-water sediment depths.)

While the 2003 calculation is not an entire-lake calculation—and thus prevents a direct comparison between the 1973 and 2003 data—the 2003 calculation makes sense within the context of the 1973 USGS calculation. In the 20 years between 1953 (the year the lake was created) and 1973, 500 acre-feet of sediment were deposited in the lake. This averages to a rate of 25 acre-feet (40,333 yards^3) per year. In the 30 years since 1973, another 367 acre-feet of sediment were deposited in the regions of the lake shown on the Soft-Sediment Thickness map in the Appendix.

Based on the sedimentation rate from 1953-1973, one would expect a total of 1,250 acre-feet of sediment *in the entire lake* in 2003. The calculation of 867 acre-feet in the modeled region does not contradict this projection, and is consistent in proportion to the projected total. Since sediment movement and

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deposition is influenced by gravity, it is reasonable to suggest that approximately 383 acre-feet of sediment are deposited in the deeper, non-modeled regions of the lake. For example, a former stream channel cuts through the center of the lake, representing a significant topographic low where proportionally greater sediment deposits could accumulate.

The average yearly sedimentation rate may have changed since 1973, but the current data do not suggest any apparently dramatic increase or decrease in sedimentation rate.

Variations in sediment volume calculations can occur for some of the same reasons as variations in water volume calculations (discussed above in the Historical Water Volume Comparison section). It must be stressed once again that the sediment depth calculations are modeled using geostatistical techniques, and such models rely on certain parameters and statistical assumptions in their calculations (the basics of which are indicated in the digital metadata layers provided with this report). In addition, variation is also possible due to differences in sediment sampling methodologies between the two studies.

Sediment Type Analysis

The Ponar sediment data and hydroacoustic data were also analyzed to create a point map of major sediment types, which can be found in the Appendix.

The Ponar sediment data was used to identify major sediment types at specific points, and to provide reference points for the acoustic signal analysis. Sediments were categorized in general terms: clay, sand, cobbles, and combinations thereof. No sediment core samples were taken as part of this project, and no grain-size, geochemical, or geotechnical analyses were conducted; such data were outside the scope of the project.

Data Delivery - Metadata

All final GIS data layers for this project have been provided on CD-ROM to the Lake Lemon Conservancy District for use in their local GIS system. The data were provided as ESRI ArcGIS shapefiles and grids in the following geographic coordinate system:

Projection: State Plane Indiana West
Datum: NAD83
Spheroid: GRS1980
Units: feet

Metadata in ArcCatalog format is included with each of the digital GIS layers provided on CD-ROM.

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Other project-relevant metadata

- All project field data were collected August 11-16, 2003.
- The hydroacoustic data were collected using a digital system integrating a BioSonics DT 420 kHz transducer and a JRC DGPS beacon. DGPS locations were collected in decimal degrees and were subsequently converted into the above coordinate system.
- The project point locations were planned in advance, and then navigated to using a Garmin GPS 12XL and visual cues (docks, etc.). Point data values were recorded on a spreadsheet, so no coordinate-system conversion was necessary for the point data.
- Water depth contours for the GIS layers were created by interpolating the values between the field data points into an inverse distance weighting (IDW) TIN using ESRI Geostatistical Analyst. Water depth contours above 10-feet in depth were generated directly from the TIN and smoothed by visual editing, while contours 10-feet and below were drawn by hand using the TIN as a guide. During visual editing, contours were also re-checked to make sure that they adhered to the field data values.
- Sediment depth contours are an ESRI grid raster file. The grid displayed on the Soft-Sediment Thickness map in the Appendix was created using inverse distance weighting (IDW) of the field data points. Another grid was created using the kriging method and is included in the digital files provided to the Conservancy District with this report. No vector contours were derived from the grid because the raster grid values indicate the sediment depth, and can be queried using ArcGIS. The color-coded depths on the map depict where the vector contours would be located using the IDW model.
- Volume calculations were derived by using ESRI 3D Analyst to create a TIN surface of the contours described above, and then using the software to query the statistics for each specified interval within the TIN.
- ReMetrix obtained the aerial imagery used in the project from a free web-site operated by Indiana University. However, ReMetrix does not own the imagery and is thus unable to redistribute it. For this reason, the background imagery was not delivered with the final GIS data on CD-ROM.

The data and calculations delivered for this project are presented to the best of ReMetrix's knowledge. Interpolated and/or statistically modeled data are inherently estimates, by definition, so no warranty or guarantee is made concerning such information presented herein. ReMetrix makes every reasonable effort to provide the most accurate data within the scope of the project and the limitations of the technology and associated equipment used to conduct the project. In effect, these data create a snapshot of project-area characteristics and conditions, but should at no time be interpreted as unequivocally accurate in every instance (particularly in regard to interpolated data).

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Appendix

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