Lake Forest Mapping

ANALYSIS OF SHOALING AND POOL VOLUMES

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Analysis of Shoaling and Pool Volumes

Final Report

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Executive Summary

This report presents the data and results of topographic and bathymetric mapping of Lake Forest in the city of Daphne, Alabama. The work was performed by the University of South Alabama's Center for Applied Coastal Engineering and Science under the direction of Dr. Bret Webb.

Data collection was performed over the period May 24, 2016 – June 21, 2016 and consisted of topographic and bathymetric elevation measurements made with highly accurate Global Positioning System (GPS) and acoustic sonar equipment. Over 12,000 discrete locations were sampled for position and elevation within the study area boundary. That boundary was generally the lake shoreline, truncated by the Bayview Drive bridge to the east on D'Olive Creek, just upstream of the Tiawasee Creek delta to the south, and the dam to the west. Elevation data were screened for instrumentation errors. These data were used to generate two-dimensional Digital Elevation Models (DEMs)of the 2016 lake bed surface. A 1958 topographic survey was georeferenced and its elevations digitized using Geographic Information System software. These elevations were used to generate a DEM of the 1958 lake bed surface for comparison to present day. This DEM served as the "pre-construction" conditions that existed before completion of the Lake Forest dam in 1973.

Comparison of the 1958 and 2016 DEMs reveals that nearly 313,296 yd^3 of sediment has accumulated, or shoaled, over 78% of the study area, most likely since construction of the dam. This accumulation of sediment has reduced the lake's open water surface area from 61.6 acres in 1974 to 43.3 acres in 2016. The corresponding shoaling rates in volume and weight are 7,285 yd^3/yr and 16,272 tons/yr, respectively, over the 43-yr period between 1973 and 2016.

The accumulation of sediment within the impoundment has reduced the flood attenuation capacity of the reservoir. Within the present study area boundary, the available pool volume has decreased from 356 acre-feet in 1958 to less than 197 acre-ft in 2016 (relative to the normal pool elevation). In other words, the lake has lost nearly 45% of its flood volume storage. This value may be as high as 61% considering the original open water extent of the Tiawasee Creek arm of the lake at the time of dam construction.

Prior studies provide some limited confirmation of these findings. While it is difficult to directly compare the various study results, there is an order of magnitude agreement in the shoaling volumes and rates. The existing literature states that shoaling rates were very high in the late 1970s and early 1980s, but have since reduced for various reasons. Therefore, the values presented in this study should be considered averages over the period in question.

Table of Contents

List of Tables

List of Figures

Introduction

This report outlines the facts and findings of a limited field investigation in the Lake Forest lake/reservoir (hereafter referred to simply as Lake Forest) located in Daphne, Alabama. This study was of limited scope, schedule, and budget with a very narrow focus: mapping lake bed elevations and documenting areas and volumes of shoaling. The text that follows in this introduction will summarize the study goals and objectives, describe the study area, and present some limited background information that provides context for this specific study. The other major report sections will describe the data collection and analysis procedures (Methods & Mapping), the study findings (Results), and provide a cursory analysis of the results (Discussion).

This work was performed for the Lake Forest Property Owners Association and the City of Daphne, under contract with the Mobile Bay National Estuary Program, by the University of South Alabama's (USA) Center for Applied Coastal Engineering and Science (ACES) under the direction of Dr. Bret Webb, Ph.D., P.E., D.CE, Associate Professor of Civil, Coastal, and Environmental Engineering, and Director of ACES. Additional field assistance was provided by USA students Patrick Hautau and Brittany McMillan.

Goals & Objectives

The goal of this mapping exercise was to document existing lake bed elevations for the purpose of estimating: 1) the remaining normal pool volume available for flood routing; and 2) the amount of sediment within the lake. The more specific objectives of the mapping study were:

1. To survey existing elevations, above and below water, within the lake study area;
2. To correct and document the survey data, as appropriate, for use by others in future projects and/or decision-making;
3. To prepare and deliver topographic-bathymetric (topo-bathy) cross-sections of the lake;
4. To prepare and deliver two-dimensional maps of the topo-bathy survey data; and
5. To document survey-specific information and metadata in the form of a summary report.

In pursuit of this mapping study, USA-ACES was provided with a digital image file containing a 1958 topographic survey of the Lake Forest area prepared by Irby & Rester Engineering & Surveying Co., Inc. (dated April 14, 1958). The 1958 survey data were used to extend the mapping study beyond the original five objectives. These additional tasks included:

6. To georeferenced and digitize the 1958 topographic survey to establish pre-construction (of the dam) lake bed elevations within the study area;

7. To assess the change in lake bed elevations between 1958 and 2016;
8. To identify the locations, areas, and volumes of shoaling between 1958 and 2016;
9. To determine sediment volume yields as a function of height above the 1958 pre-construction elevations; and
10. To evaluate the change in pool volume between 1958 and 2016.

These additional tasks were not included in the original scope and fee proposal as it was unclear, at the time, whether use of the 1958 survey data would even be possible owing to the lack of a coordinate reference system.

In the performance of this work and discussions with the City of Daphne it became apparent that some information about the basic characteristics of sediment within the shoaling areas would aid in future work. Some limited sampling of surficial sediments will be performed within the study area using shallow, benthic push cores (2 ft in length, 3 in diameter sample). These data will be provided as Appendix B when available.

Study Area

The Lake Forest lake is located within the Lake Forest Subdivision in the city of Daphne, Alabama. A map of the study area is provided in Figure 1. The general location of the lake is in the northwest portion of the subdivision development, which is immediately east and south of US Highway 98 and US Highway 90, respectively. The lake is a man-made feature that resulted from the construction of the existing gravity dam in 1973 (MBNEP, 2010).

The study area for this project was mostly limited to the existing open water sections of Lake Forest due to the nature of our mapping methods (as described in a later section). This open water area is generally restricted to areas below the 20-ft elevation contour on the map shown in Figure 1. The current operating pool level is at approximately +19 ft NAVD88[1]. In 1974 the approximate surface area of open water in Lake Forest was 61.6 acres. The extent of open water surface area in the lake during this 2016 survey was measured at 43.3 acres, or approximately one-third less than the 1974 value immediately after construction of the dam. A series of aerial photographs in Figure 2 shows the progression of changes in the area from 1938 to 2009.

Some effort was made to map elevations above the pool level, specifically at the mouths of D'Olive Creek and Tiawasee Creek. However, extensive data collection in these areas was not possible due to the excessive overhead tree cover and difficulty accessing upstream sections of those streams. In addition to the two major streams listed above, four lesser unnamed tributaries deliver water and sediment to the lake from within the D'Olive watershed (Cook and Moss, 2008; Cook, 2010).

[1] North American Vertical Datum of 1988

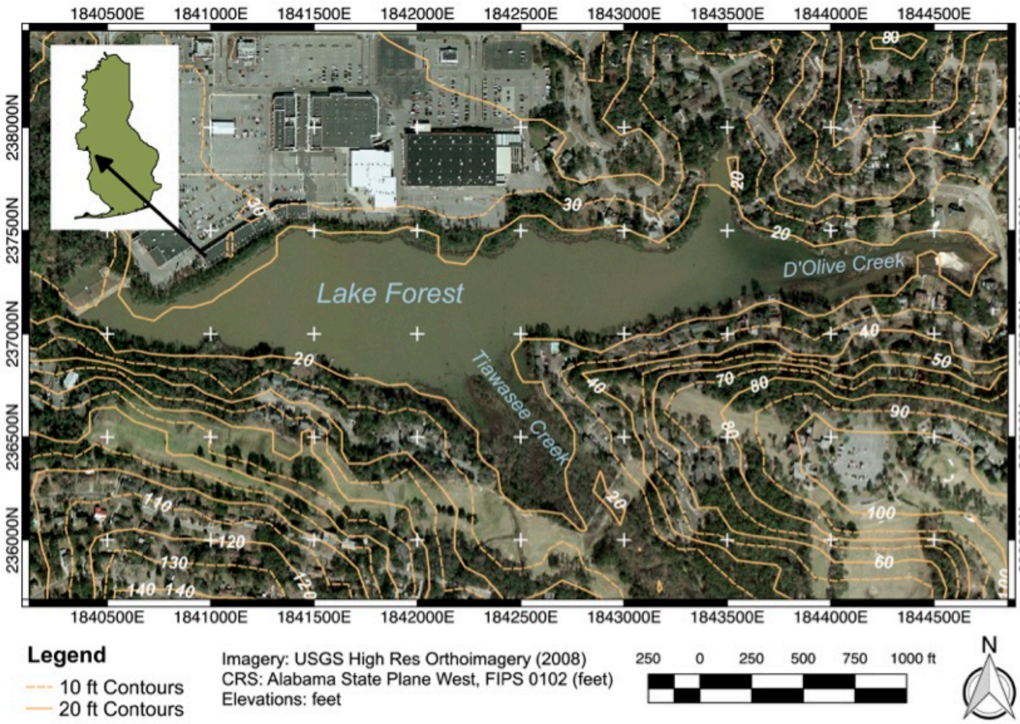

Figure 1. Map of the Lake Forest study area showing aerial imagery and elevation contours. The inset panel shows the location (arrow) relative to Baldwin County.

Background

This study is not the first attempt at mapping lake elevations and evaluating the extent of sediment shoaling. Prior studies have been performed by Isphording (1981), Douglass (1994), Cook and Moss (2008), Cook (2010), and MBNEP (2010). These documents have been briefly reviewed in the performance of this study. The elevation/depth mapping performed by Isphording (1981) and Douglass (1994) were of a limited nature. The information contained in Cook and Moss (2008) and MBNEP (2010) provide specific information and estimates related to potential sediment transport loads and rates, water quality and chemistry, and biological activity in the streams and tributaries within the D'Olive watershed. The brief report by Cook

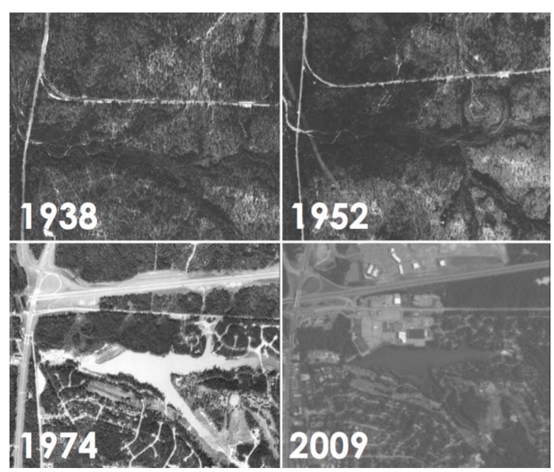

Figure 2. Aerial photography of the study area from 1938 - 2009.

(2010) presents an analysis of trapping efficiency and capacity that was helpful in the preparation of this report.

The author of this report is unaware of any comprehensive survey of lake bed elevations since construction of the dam in 1973 and the pre-construction survey dated 1958. While some discussion of our findings relative to those contained in the reports previously cited will be provided, the intent of this study was not to draw specific comparisons to previous works, figures, and estimates. In fact, doing so would be impractical given the varied nature of these studies.

Methods & Mapping

The mapping for this project was performed over the period May 24, 2016 to June 21, 2016. A combination of land-based and water-based mapping was used within the study area. Each of these is described more fully in the sections that follow. A brief overview of the materials and methods used to generate the final maps is also provided below.

Land-Based Mapping

Topographic and very shallow water (i.e., waist-deep water and shallower) elevations were collected by wading survey (see Figure 3). Elevations were sampled at discrete locations (>1500 points) using two Magellan (Ashtech) ProMark 500 Global Navigation Satellite System (GNSS) receivers and MobileMapper CX field terminals. Each of the GNSS receivers were equipped with cellular connections to the Alabama Department of Transportation (ALDOT) Continuously Operating Reference Station (CORS) network, thereby providing Real Time Kinematic (RTK) corrections to the position data. Typical horizontal and vertical root mean square errors were commonly 0.1 ft or less (i.e., HRMS < 0.1 ft; VRMS < 0.1 ft). Points were sampled and recorded in the Alabama State Plane Coordinate System (in feet) using a vertical datum of NAVD88 (ref. Geoid 12a).

The topographic mapping was conducted over a two-day period in late May 2016. Over 1000 points were surveyed along D'Olive Creek between the Bayview Drive bridge and the terminus of the creek delta in Lake Forest on May 24, 2016. An additional 500+ points were surveyed at the terminus of the Tiawasee Creek delta on May 25, 2016.

Figure 3. Topographic RTK GNSS mapping in D'Olive Creek on May 24, 2016.

Water-Based Mapping

The original methodology proposed for bathymetric mapping of the lake, using the South Alabama Jag Ski system, was attempted on May 25, 2016 but abandoned due to operational safety concerns. The Jag Ski was launched and used on May 25 but sustained substantial damage during the process. The decision was made to retrieve the watercraft and develop an alternative plan. Lack of adequately safe access to the lake, in addition to the abundance of freshwater vegetation, makes use of a personal watercraft impractical.

Based on the shallow nature of the lake system, presence of vegetation, and lack of access options, the decision was made to proceed with a kayak survey. All of the required instrumentation was transferred from the Jag Ski to a 12-foot-long ocean kayak, which was modified to perform this study (see Figure 4).

Figure 4. Modified ocean kayak.

The bathymetric mapping was conducted on June 21, 2016 using the modified ocean kayak system. Depth sampling was performed with a SonTek M9 RiverSurveyor Acoustic Doppler Profiler (ADP) and RTK GNSS position referencing system. An RTK base station was established on top of the dam as shown in Figure 5. Samples were obtained and recorded to instrument memory at a rate of 1 sample per second. The resulting sample spacing was typically less than 4 ft. Over 10,400 samples were obtained over a four-hour period.

The depth samples were recorded in a geographic coordinate reference system (i.e., WGS84) and measured relative, in the vertical dimension, to the lake surface. The lake surface elevation, relative to NAVD88, was obtained before and after the data collection: the water surface elevation remained constant at +18.9 ft NAVD88. Depth samples were later corrected for changes in the speed of sound based on water temperature and conductivity throughout the study area. These corrections were applied in the SonTek RiverSurveyor Live software using conductivity-temperature measurements made with a YSI CastAway profiler (orange device shown in Figure 4). Finally, all depth sample coordinates were transformed to the Alabama State Plane system for consistency with the topographic elevation data.

Figure 5. The RTK base station location used for the bathymetric mapping.

Georeferencing

The original 1958 topographic survey (Figure 6) was georeferenced and its elevations digitized using Geographic Information System (GIS) software. The 1958 survey contained no horizontal coordinate reference system nor any stated vertical datum to which elevations were referenced. There were not enough common, readily identifiable features on the 1958 topographic survey by which to directly georeference the data. However, I was able to scale and fit the 1958 survey image to aerial imagery of Lake Forest and, combined with the understanding that the approximate 20 ft elevation contour represents the current shoreline position, identify 10 common points within Google Earth for the purpose of referencing (see Figure 7). Once completed, over 800 elevations were manually digitized from the 1958 survey (see Figure 8). As the survey was conducted in 1958, it was assumed that the elevations were measured and recorded relative to NGVD29[2].

[2] National Geodetic Vertical Datum of 1929

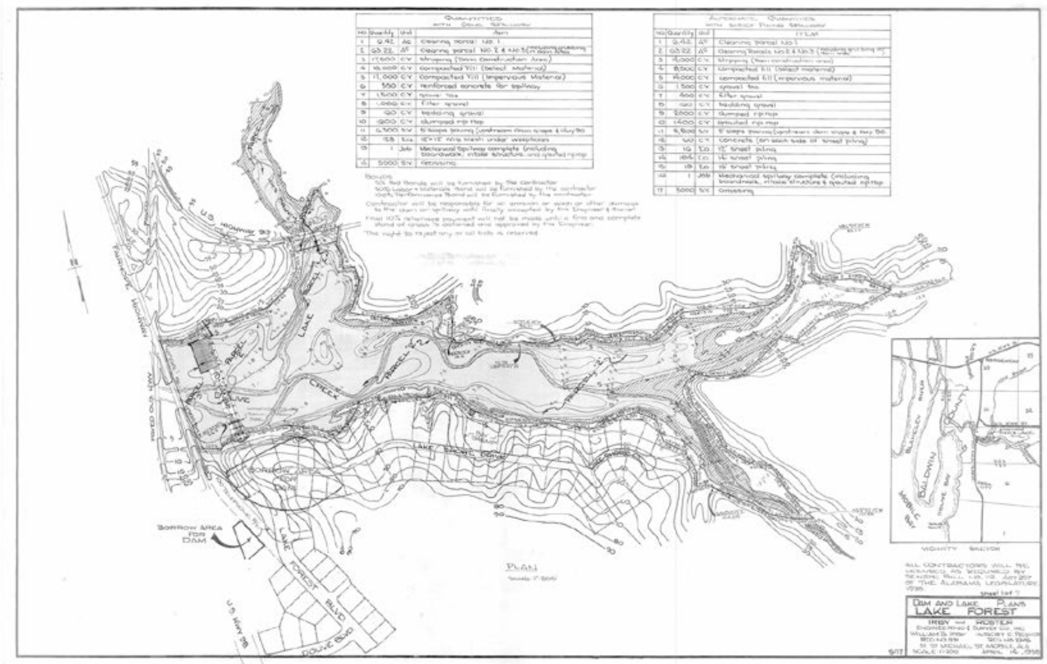

Figure 6. Pre-construction 1958 topographic survey of the Lake Forest area.

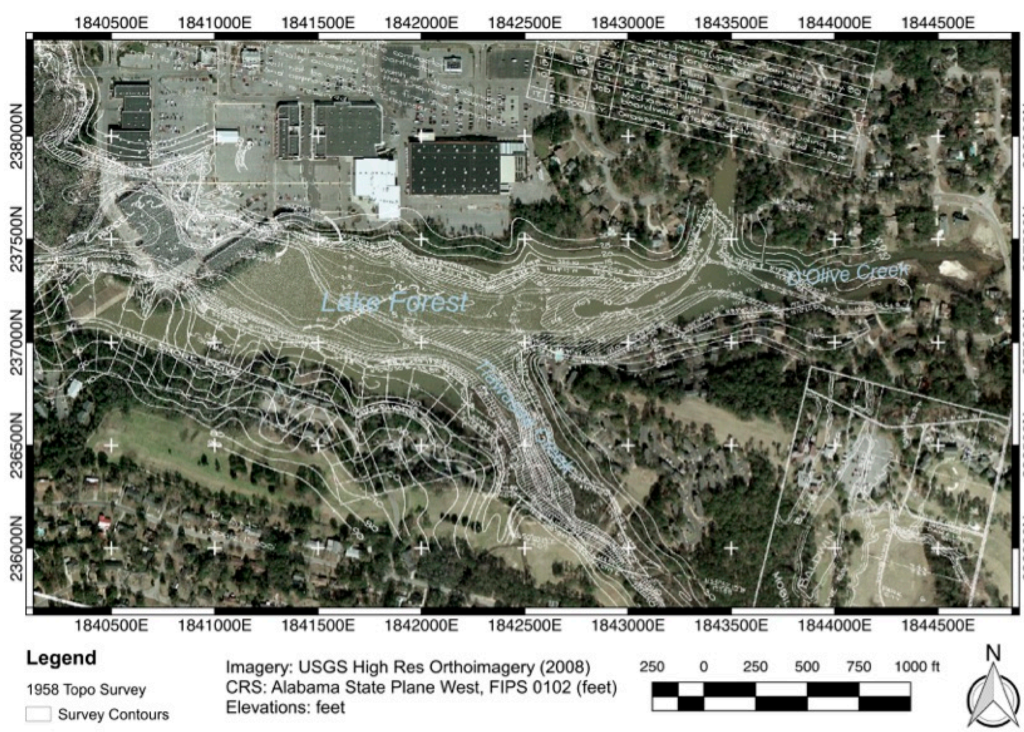

Figure 7. Overview of the georeferenced 1958 survey shown with 2008 aerial imagery.

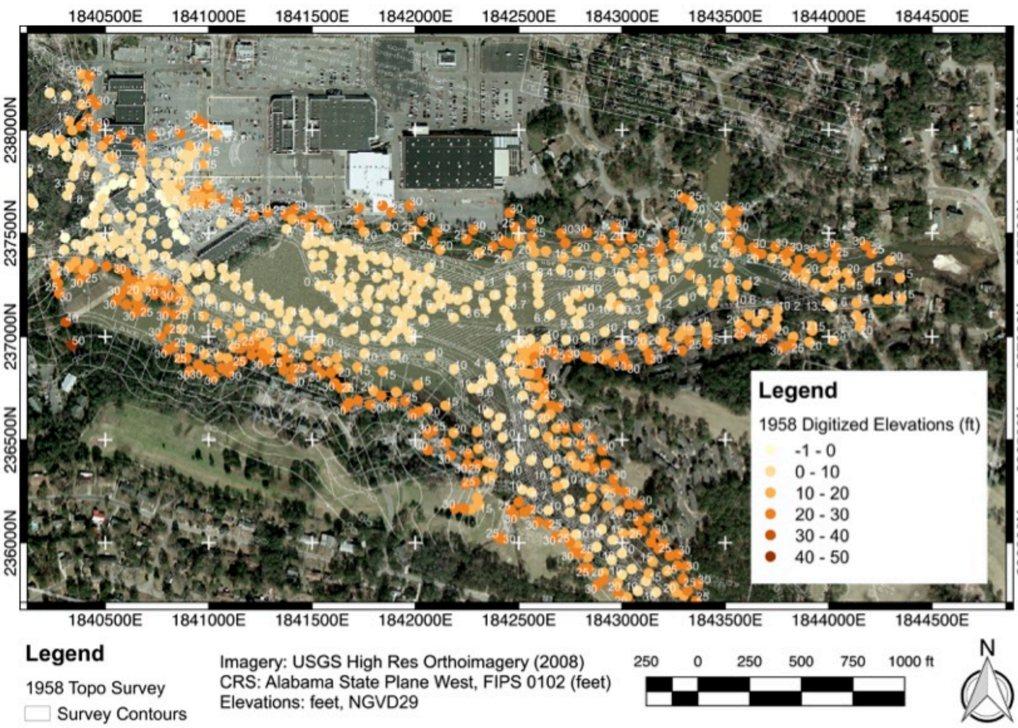

Figure 8. Map showing the distribution, and values, of elevations digitized from the 1958 survey.

Mapping Procedures

After reviewing all survey data for errors, a common horizontal reference system (Alabama State Plane, West FIPS 0102) and vertical datum (NAVD88) were selected and the data transformed/corrected as needed. These data were subsequently triangulated within the study area boundary to create two-dimensional digital elevation raster images. Coordinate transformations and triangulation were performed within GIS software.

Error Analysis

Errors are ubiquitous in this type of work. It is possible, however, to identify common sources of error and minimize them wherever practical. Instrumentation errors are the most obvious sources for the topographic and bathymetric mapping performed in this study. These can be, and have been, eliminated by reviewing data samples and eliminating points with unacceptably large errors. For example, large HRMS and/or VRMS values (i.e., > 0.25 ft) in RTK GNSS data, large pitch/roll values (i.e., > 5°) in the ADP data, and/or large beam standard deviations in the ADP depth samples were identified and removed.

Other relevant sources of errors addressed in this analysis are those associated with the unknown vertical datum of the 1958 topographic survey. A logical assumption is that survey elevations were reported in the NGVD29 vertical datum. The local difference between NGVD29 and NAVD88 is only 0.15 ft. Cumulatively, that difference would constitute an error of less than 6% in the subsequent calculations of volumes in this report. The 1958 elevations were transformed to NAVD88 in order to eliminate that possible source of error. On the other hand, if the elevations were measured relative to the 1958 mean sea level (MSL) tidal datum, the potential error is much larger at 0.56 ft. That value represents the difference between the 1958 MSL datum and NAVD88. That potential difference would constitute a 22% error in the subsequent volume calculations.

A final source of error that is readily identified, but difficult to assess, is associated with georeferencing and digitizing the 1958 topographic survey. Great care was taken to minimize errors associated with horizontal positioning of the 1958 map on the underlying aerial imagery. Errors associated with digitizing would be much less important as that process was easily repeatable and did not require any subjectivity.

Results

The results of this study are presented in this section, mostly in the form of maps derived from the survey data. Analysis of the mapping data will be presented in the discussion section that follows.

Discrete Elevation Data

The primary results of the mapping exercise are those related to the five primary objectives stated previously. These are essentially the discrete topographic and bathymetric elevation data collected in Lake Forest and the deltas of Tiawasee and D'Olive Creeks. A map of all 12,000+ data points is provided in Figure 9. The subsequent figures show detailed overviews of data collected near the deltas of Tiawasee Creek (

Figure 10. Detailed overview of survey data collected near the Tiawasee Creek delta.

) and D'Olive Creek (Figure 11). Recall that the normal pool elevation of the lake is just less than +19 ft NAVD88.

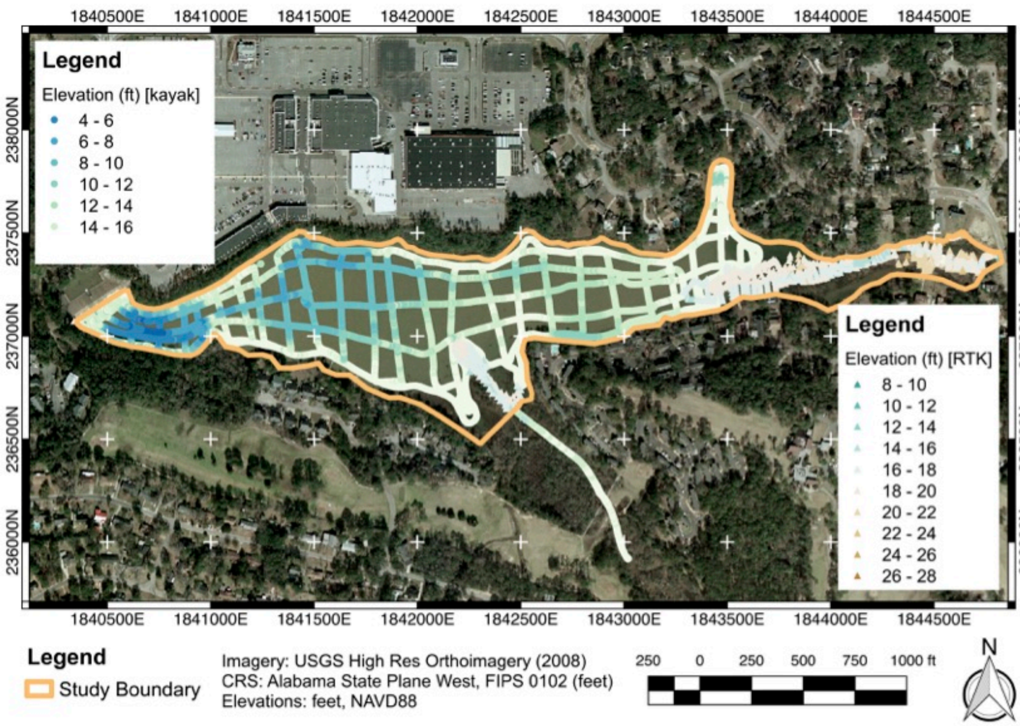

Figure 9. All topographic and bathymetric survey data collected in the Lake Forest mapping study.

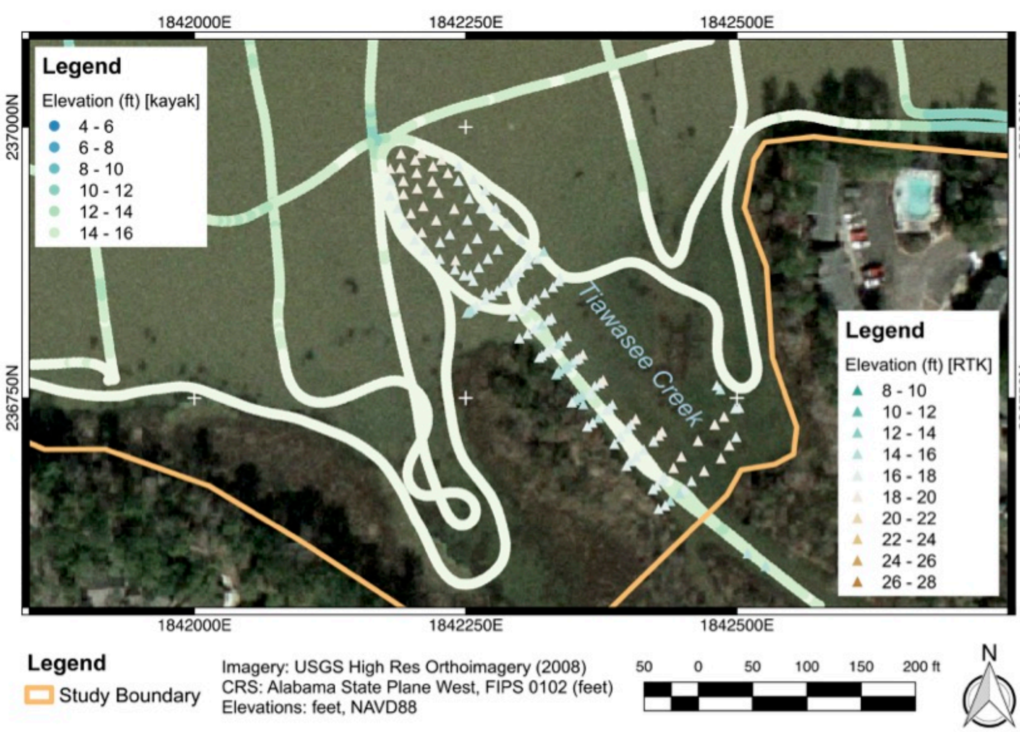

Figure 10. Detailed overview of survey data collected near the Tiawasee Creek delta.

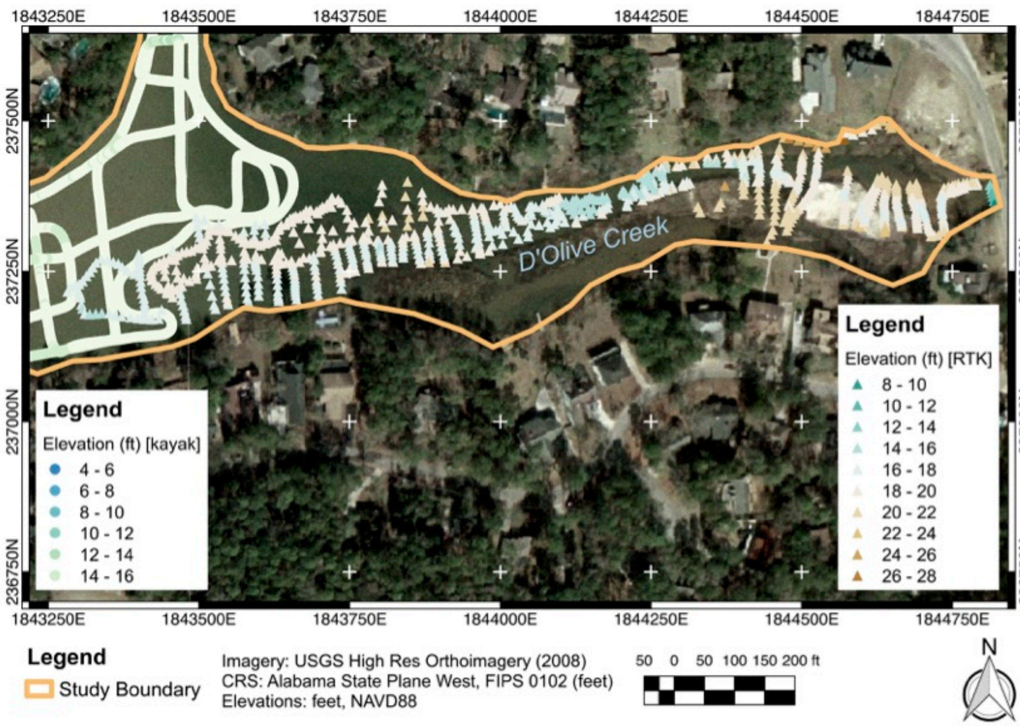

Figure 11. Detailed overview of survey data collected near the delta of D'Olive Creek.

Two-Dimensional Elevation Maps

The discrete elevation data presented in Figure 8 - Figure 11 were interpolated to regularly spaced points and then triangulated within the study area boundary to create two-dimensional digital elevation raster images, or Digital Elevation Models (DEMs). The interpolation and triangulation of the elevation data were performed within GIS software. The resulting 1958 and 2016 DEMs are shown in Figure 12 and Figure 13, respectively. The same contour scale was used in each figure to aid in direct comparison of lake bed elevations.

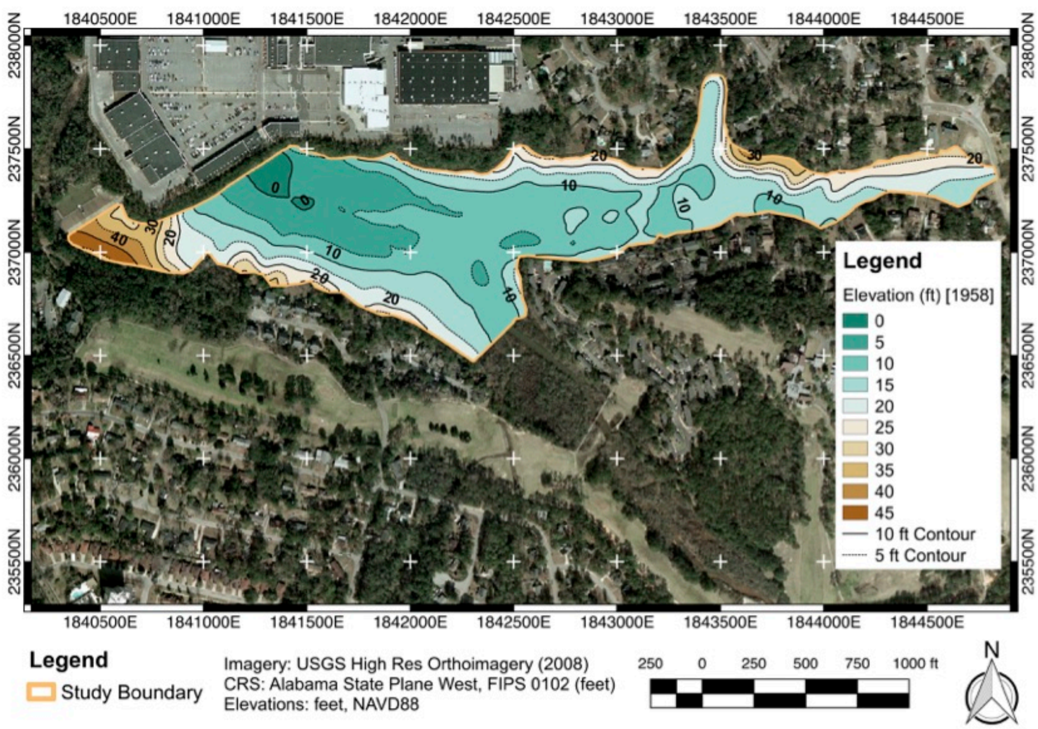

Figure 12. Triangulation of the digitized 1958 topographic survey data.

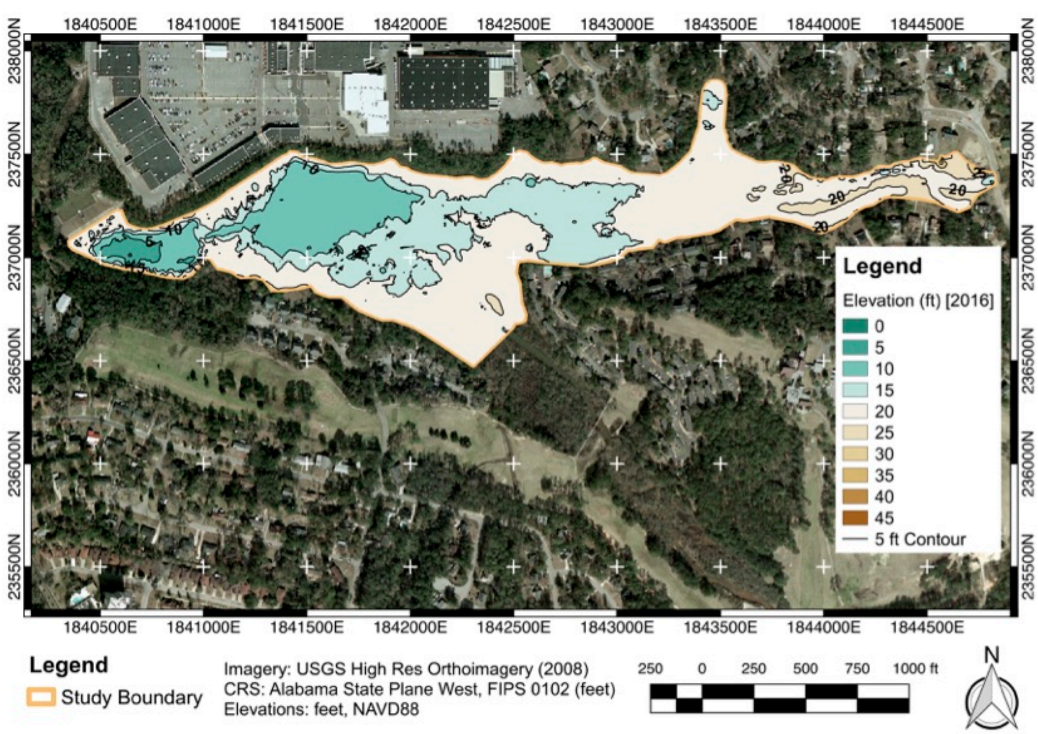

Figure 13. Triangulation of the 2016 discrete elevation data within the study area.

Two-Dimensional Depth Map - 2016

The 2016 elevation map shown in Figure 13 was converted to show lake depths by subtracting the lake bed elevations from the approximate normal pool elevation of +19 ft NAVD88. This process results in water depths having positive values and ground heights (relative to the normal pool elevation) having negative values. The resulting map of lake depths is shown in Figure 14.

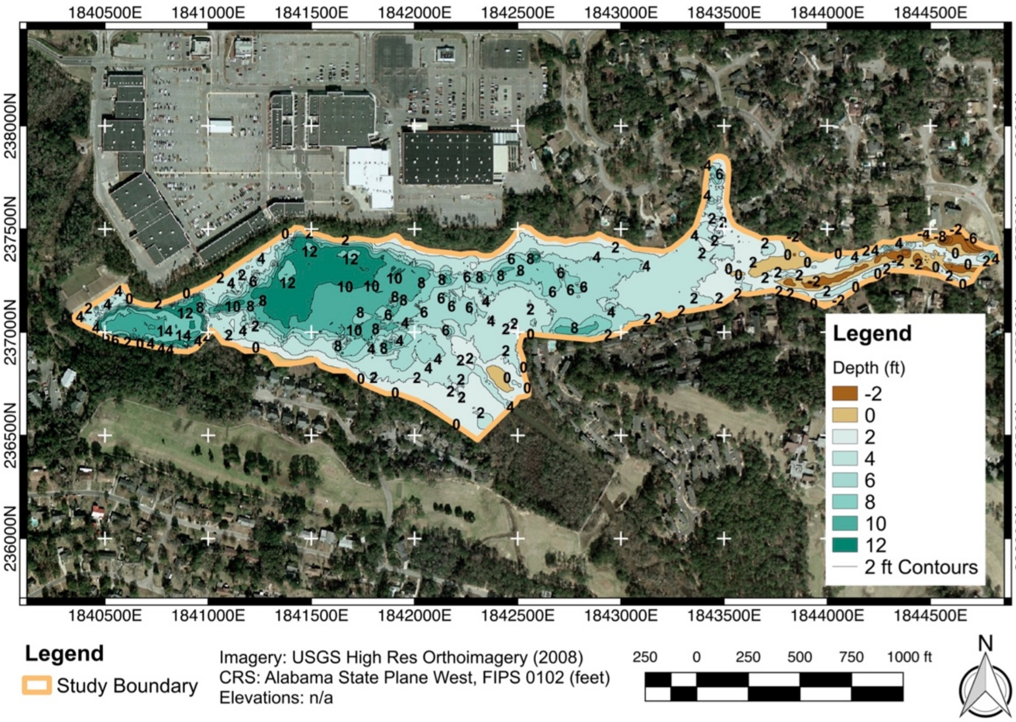

Figure 14. Two-dimensional map of 2016 lake depths (colors, numbers).

Survey Elevation Profiles

Lake bed elevation profiles were extracted from the 1958 and 2016 DEMs at regularly spaced intervals of 250 ft. The resulting elevation profiles clearly show changes in lake bed elevation since construction of the dam in 1973. An overview map and the elevation profiles are provided in Appendix A of this report.

Discussion

Prior studies by Isphording (1981), Douglass (1994), and Cook (2010) have speculated on the magnitude of shoaling within Lake Forest based on very limited lake bed elevation data. When combined with the 1958 survey map, the new elevation data collected in this mapping study provides an opportunity to more objectively, and more accurately, estimate shoaling volumes within the lake as well as the remaining pool volume for the purpose of flood control. Many of these aspects are described in this section.

Changes in Lake Bed Elevation

A direct comparison of the 1958 (Figure 12) and 2016 (Figure 13) DEMs can be used to determine changes in lake bed elevations since construction of the dam in 1973 (43 years prior). By subtracting the two elevation surfaces, increases and decreases in bed elevation can easily be seen. These differences are shown in Figure 15. In this analysis the 1958 elevations were subtracted from the 2016 elevations. As such, the resulting values shown in Figure 15 are positive (brown color) in areas where the bed elevation has increased due to shoaling, and negative (green color) in areas where the bed elevation has lowered due to erosion, regrading, and/or mechanical excavation. As shown, a majority of the lake bed has increased in elevation by 5 to 15 ft due to shoaling and the trapping of sediment within the lake. Very few areas by comparison have deepened. The *net* volume change between the two surfaces was 170,232 yd^3. This accounts for all additions and subtractions of sediment in the study area between the two surveys.

The extent of shoaling within the lake is demonstrated for two specific thresholds: areas that have shoaled by more than 5 ft, and areas that have shoaled by more than 10 ft (i.e., about one-half of the original lake depth). Maps of these areas are shown in Figure 16 and Figure 17. These figures demonstrate that much of the lake has decreased in depth by at least 5 ft, with some areas decreasing in depth by at least 10 ft. The excessive shoaling of 10 ft or more has occurred mainly near the Tiawasee Creek delta. The extent of shoaling as a function of accretional (shoaling) depth, for the entire study area, is summarized in Figure 18. This figure shows, for example, that 19 acres of the study area have shoaled by at least 5 ft. Recall that the area within our study boundary is approximately 43 acres. The figure also shows that some amount of shoaling has occurred over nearly 34 acres, or approximately 78% of the total study area.

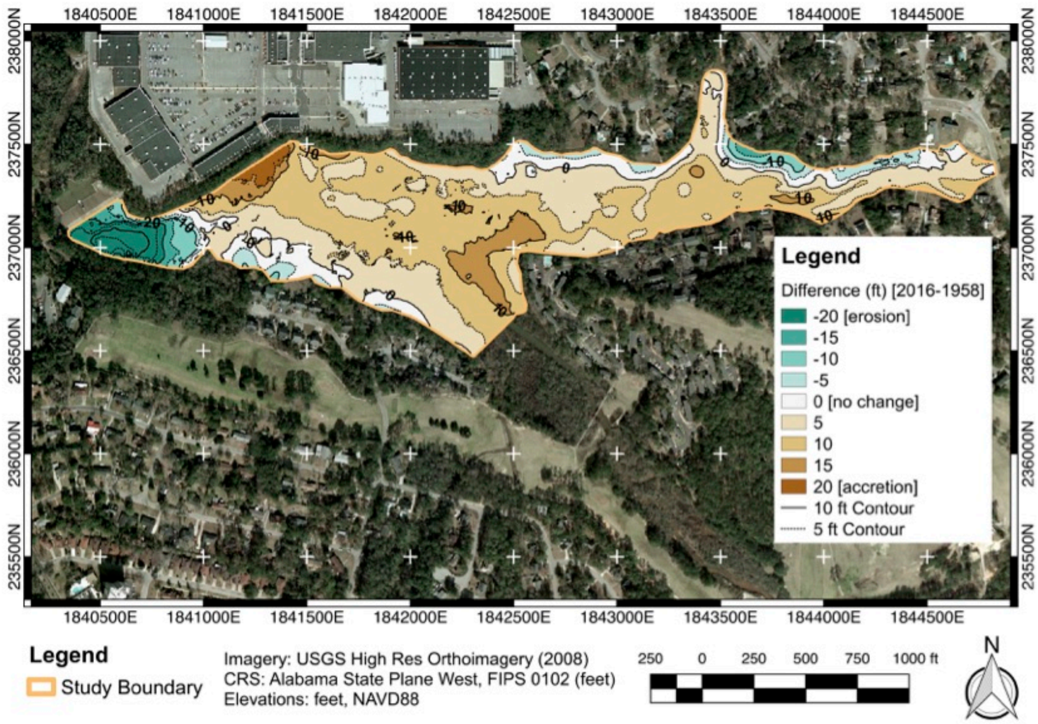

Figure 15. Elevation differences between 1958 and 2016. Positive values (browns) represent shoaling or shallowing of the lake. The negative values (greens) indicate areas where the lake has deepened since 1958.

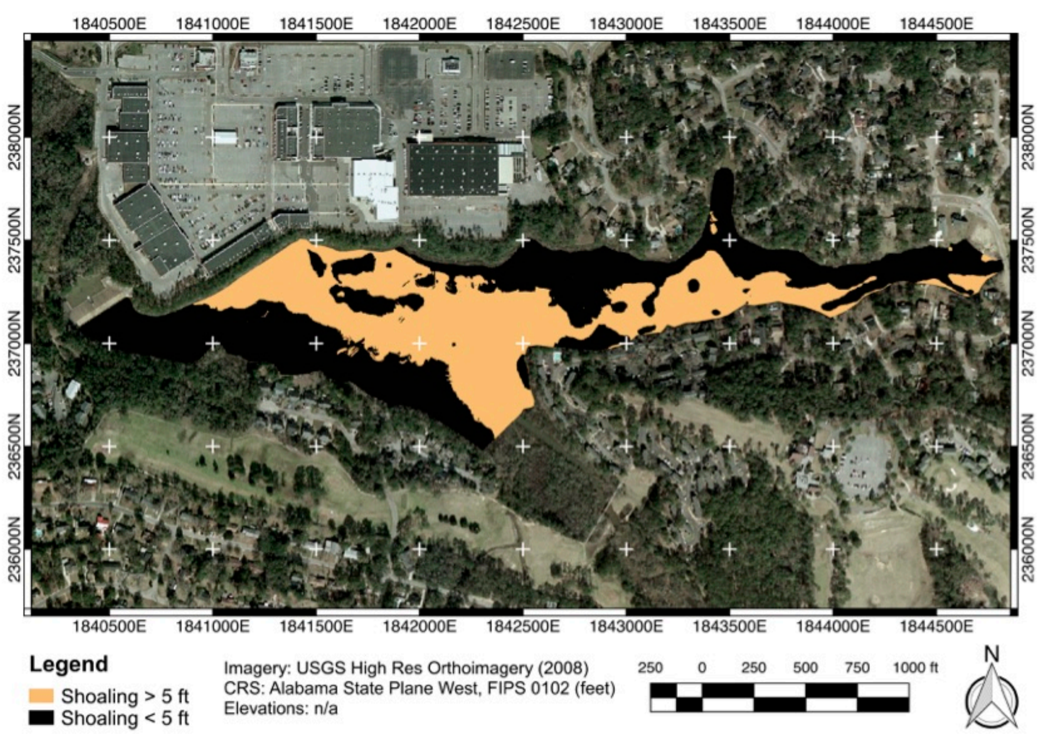

Figure 16. Areas of the lake indicating shoaling greater than (orange) or less than (black) 5 ft since 1973.

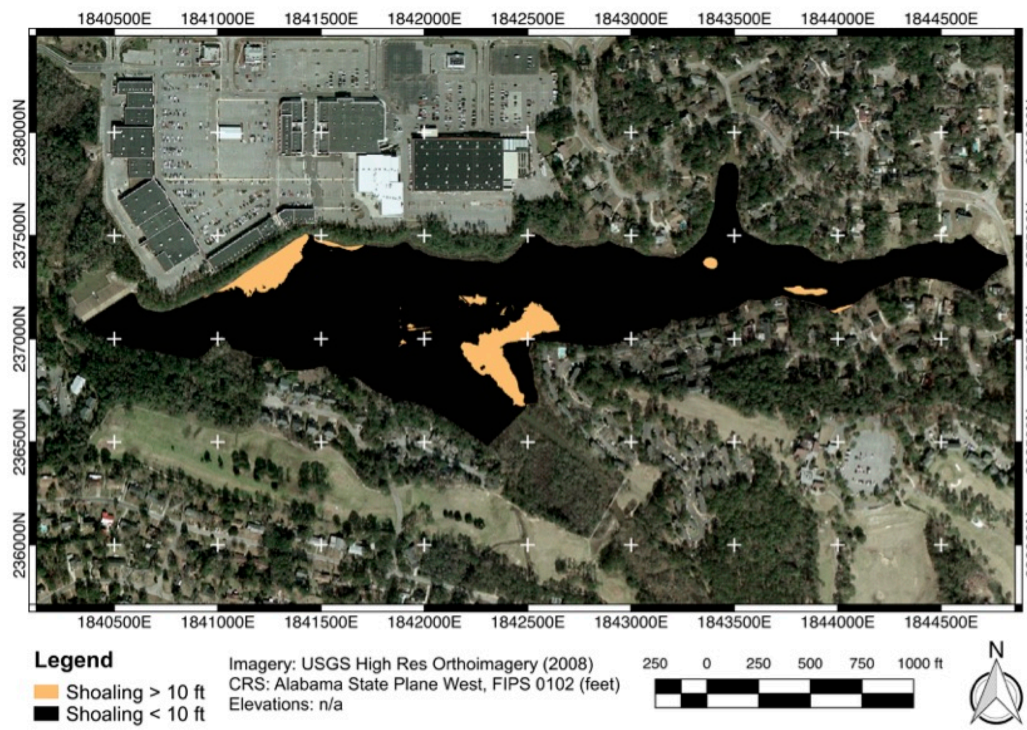

Figure 17. Areas of the lake indicating shoaling greater than (orange) or less than (black) 10 ft since 1973.

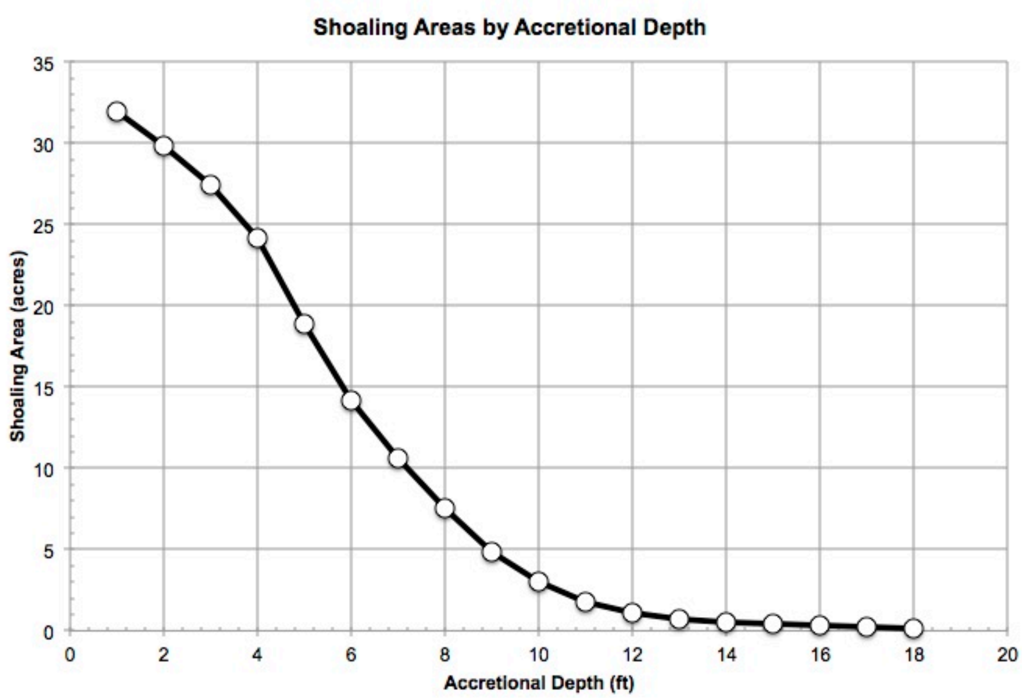

Figure 18. Estimation of shoaling areas by accretional depth over the period 1958 to 2016.

Sediment Volume and Weight

There has been some interest in dredging the lake for many years (Douglass, 1994). This is still true today, now with an eye toward using lake sediments as part of ongoing stream restoration projects in the D'Olive watershed (MBNEP, 2010). Therefore, an estimate of sediment volumes within the study area was developed based on the 1958 and 2016 survey data. An estimated 313,296 yd^3 of sediment has shoaled in the lake since construction of the dam in 1973. Assuming standard values for sediment specific gravity, that volume equates to 699,704 tons of sediment. Over the 43-yr period since dam construction, these values translate to shoaling rates of 7,276 yd^3/yr and 16,272 tons/yr.

The estimated sediment volume contained within the study area boundary of Lake Forest is shown in two different ways. First, Figure 19 shows the estimated sediment volumes, in cubic yards, in terms of height above the pre-construction elevations. For example, approximately 310,000 yd^3 of sediment has shoaled or deposited above the pre-construction (1958) elevations within the study area boundary. As one moves higher in elevation above the pre-construction surface, available sediment volumes decrease. It is possible that considerably more sediment is available as one moves upstream in D'Olive and Tiawasee Creeks.

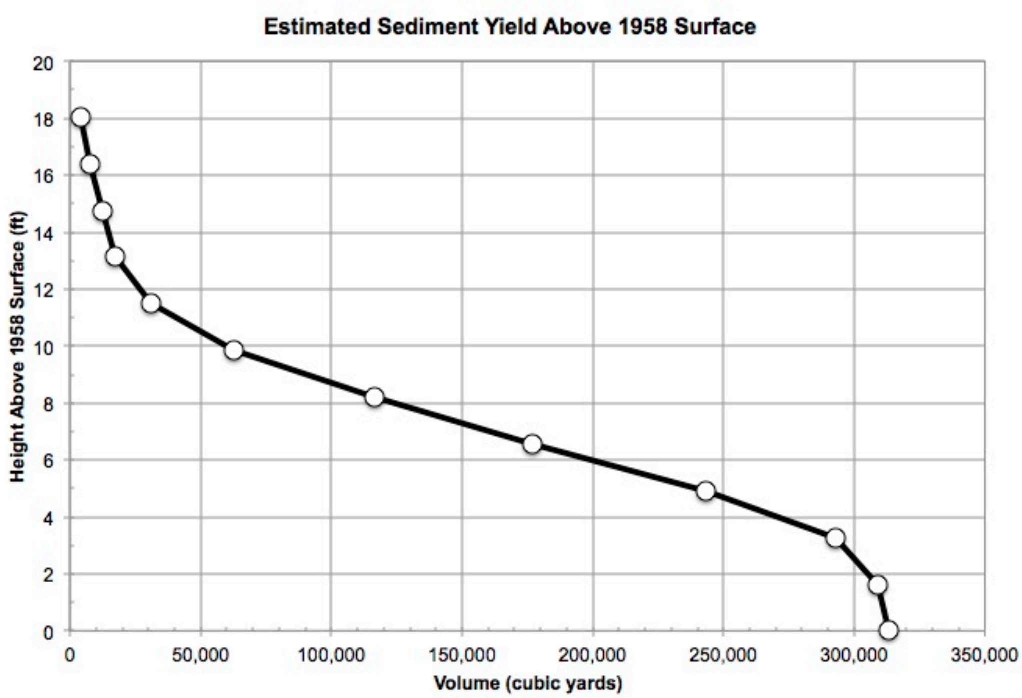

Figure 19. Estimated sediment volume yield by height above the pre-construction land surface.

Second, Figure 20 shows estimated sediment volumes by vertical, orthometric elevation (NAVD88) within the study area boundary. There is a considerable amount of sediment below the pre-construction elevations if one were to over-excavate. For example, over 1,000,000 yd^3 of sediment is found above an elevation of 0 NAVD88 within the study area boundary. This information is provided only as general knowledge and does not imply a recommendation that over-excavation should ever be performed. Deepening the lake too much could very well result in extremely poor water quality from time to time.

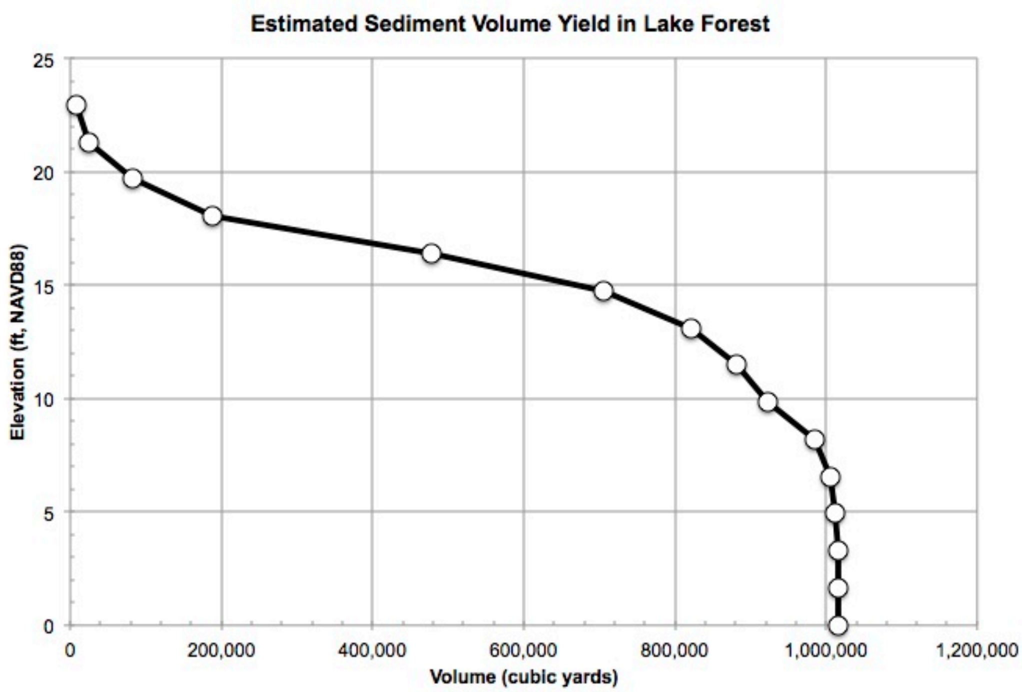

Figure 20. Estimated sediment volume yield by elevation within the study boundary.

Estimated Pool Volumes

The pool volume, or the volume of water, is a very important operational metric for a reservoir. It represents the capacity of that facility to detain flood water and slowly release it through the outfall structure. Reductions in pool volumes generally translate to increased flood elevations around the lake during design storm events. With the shoaling that has occurred in the lake since 1973, the available pool volume has obviously decreased.

Using the 1958 and 2016 DEMs, we estimate that the lake has lost approximately 45% of its original pool volume within the defined study area boundary. The 1958 pool volume was estimated as 356.03 acre-feet. The 2016 pool volume has reduced to 196.7 acre-feet. Both of these estimates are relative to the pool elevation of +19 ft NAVD88.

The lake has actually lost more than 45% of its original pool volume. Our study area boundary does not extend the considerable distance upstream in Tiawasee Creek to which open water existed prior to dam construction. As previously stated, the open water surface area of the lake in 1974 was 61.6 acres. Our study area boundary, corresponding to the present day extent of open water, used in this analysis yielded an area of 43.3 acres. Based on average pre-construction elevations in the upstream sections of Tiawasee Creek, the additional 1958 pool volume not captured in this analysis is estimated as 145 acre-feet. Therefore, the total pre-construction pool volume may have been closer to 500 acre-feet, which means that the reduction in original pool volume may be closer to 60%.

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Appendices

Appendix A

This appendix provides the composite topo-bathy elevation profiles described in the section of this report labeled Survey Elevation Profiles. Elevation profiles were extracted along north-south oriented polylines spaced at 250 ft as shown in Figure **Error! Reference source not found.**. The elevation profiles were extracted from the 1958 and 2016 DEMs for direct comparison at each location. Each elevation profile is labeled with its Easting coordinate (Alabama State Plane, West FIPS 0102). The elevation profiles are presented from east to west in Figure A- 2 thru Figure A- 19 below.

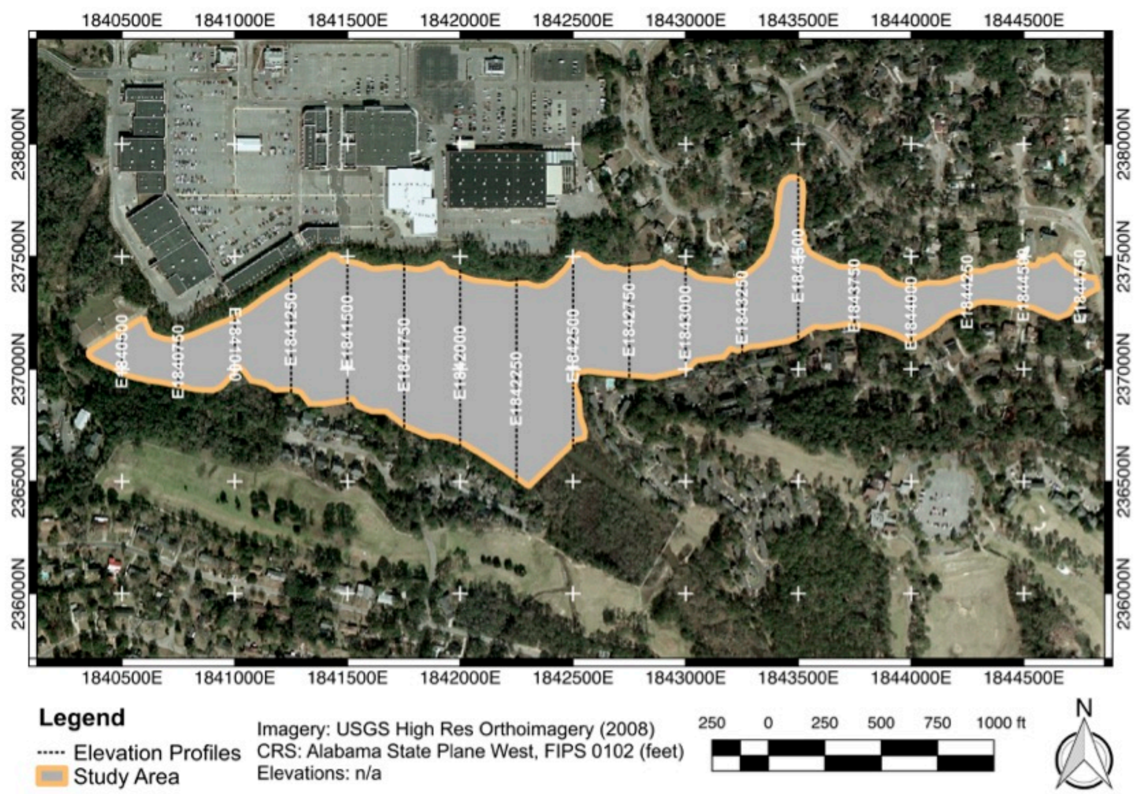

Figure A- 1. Location and identification of elevation profiles within the study area. Profiles are labeled by easting coordinate.

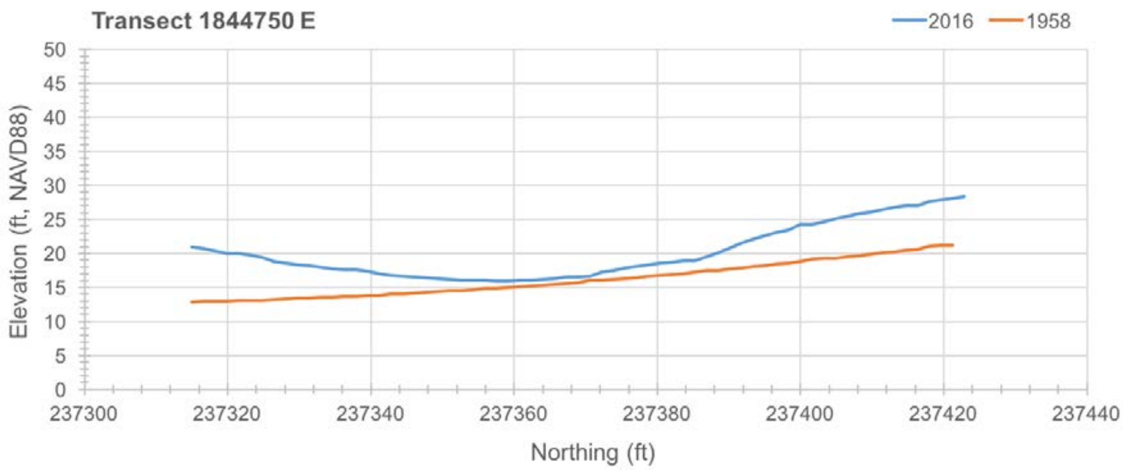

Figure A- 2. Elevation profiles at transect E1844750. View is of an observer looking to the west.

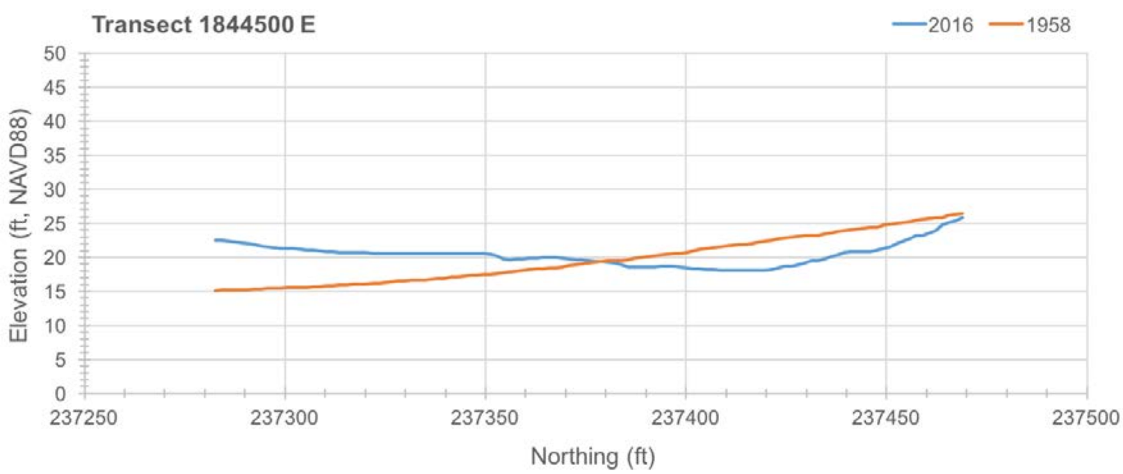

Figure A- 3. Elevation profiles at transect E1844500. View is of an observer looking to the west.

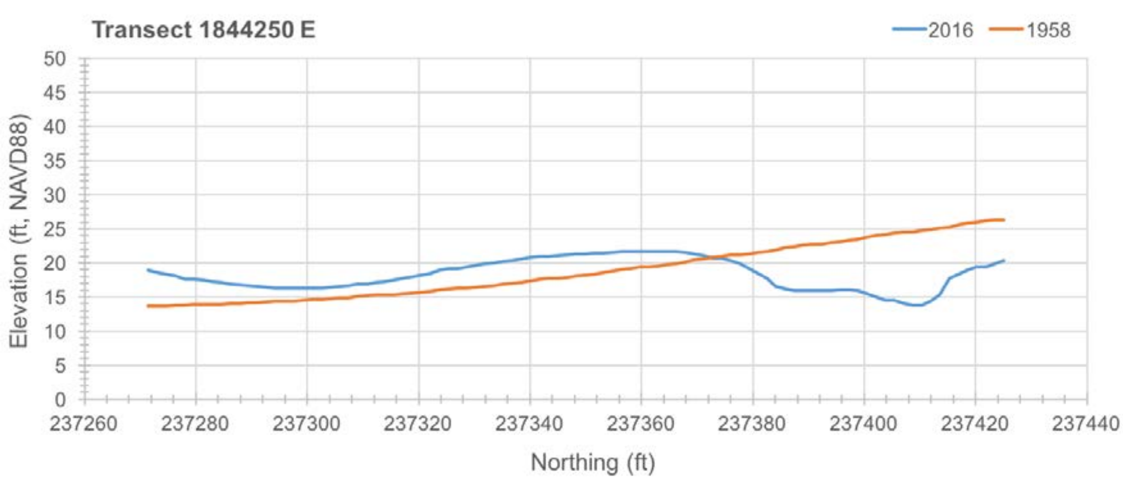

Figure A- 4. Elevation profiles at transect E1844250. View is of an observer looking to the west.

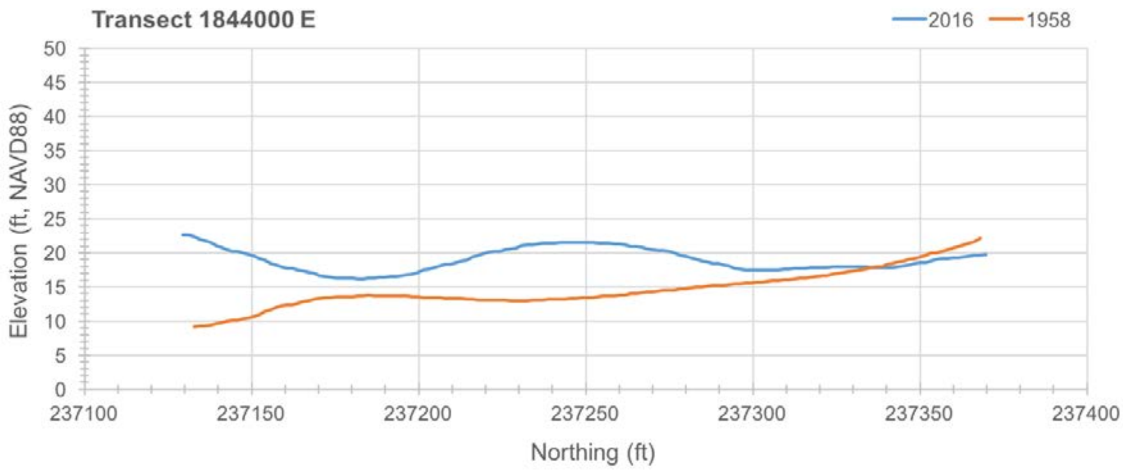

Figure A- 5. Elevation profiles at transect E1844000. View is of an observer looking to the west.

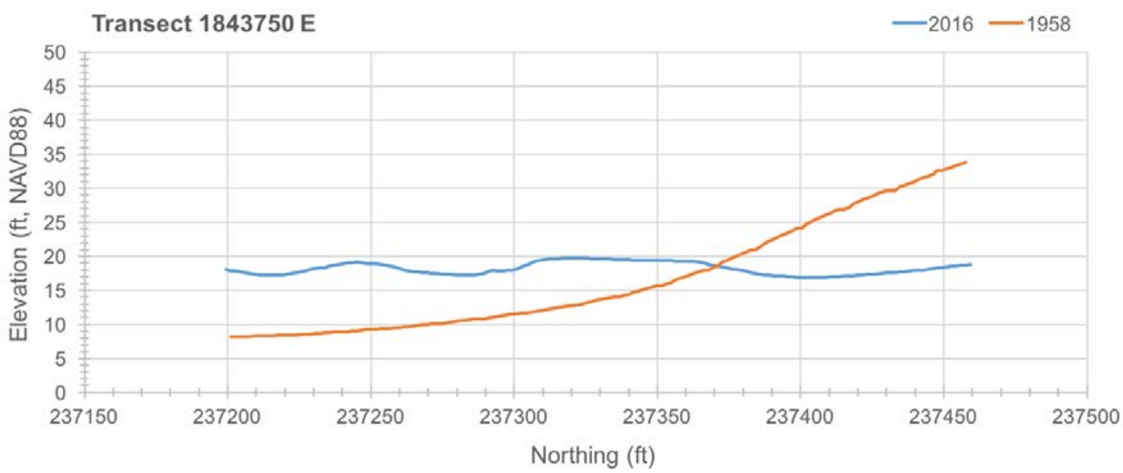

Figure A- 6. Elevation profiles at transect E1843750. View is of an observer looking to the west.

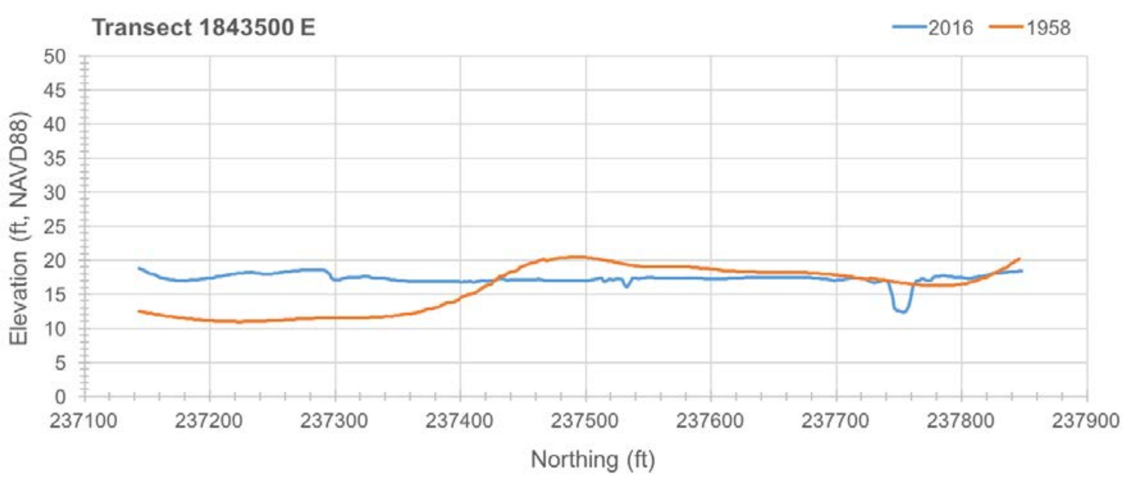

Figure A- 7. Elevation profiles at transect E1843500. View is of an observer looking to the west.

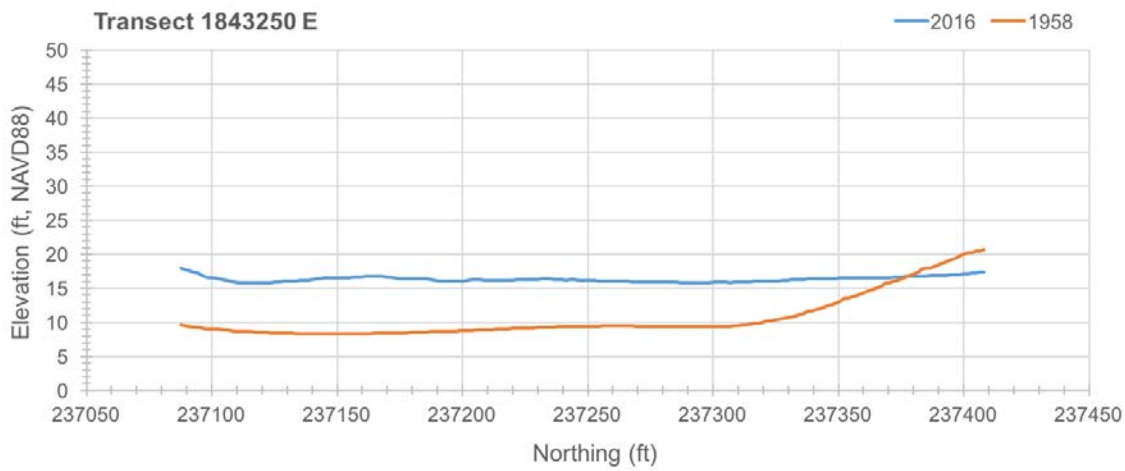

Figure A- 8. Elevation profiles at transect E1843250. View is of an observer looking to the west.

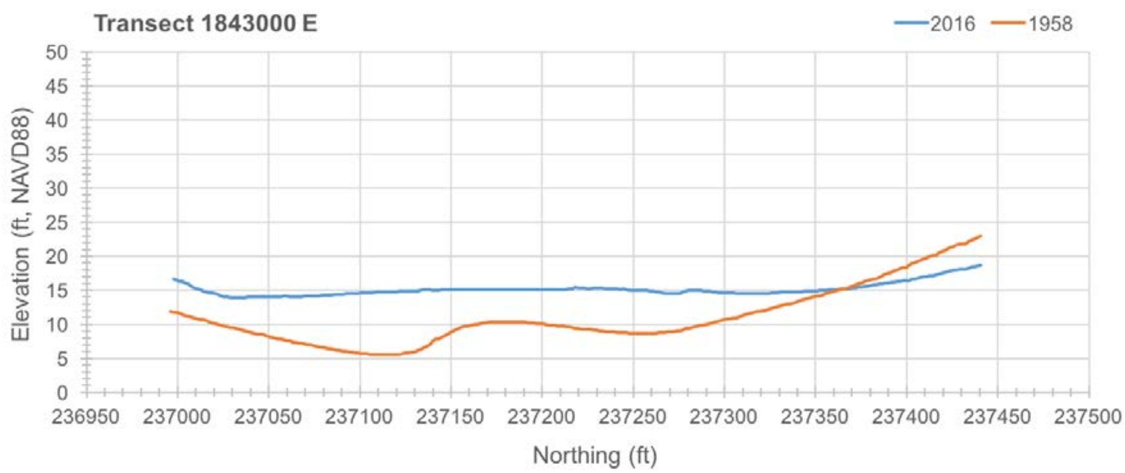

Figure A- 9. Elevation profiles at transect E1843000. View is of an observer looking to the west.

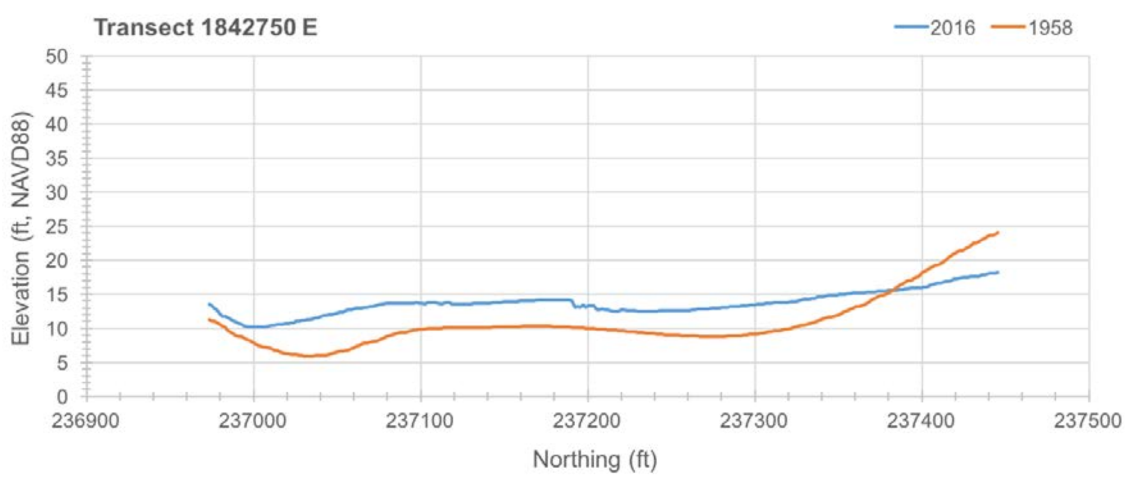

Figure A- 10. Elevation profiles at transect E1842750. View is of an observer looking to the west.

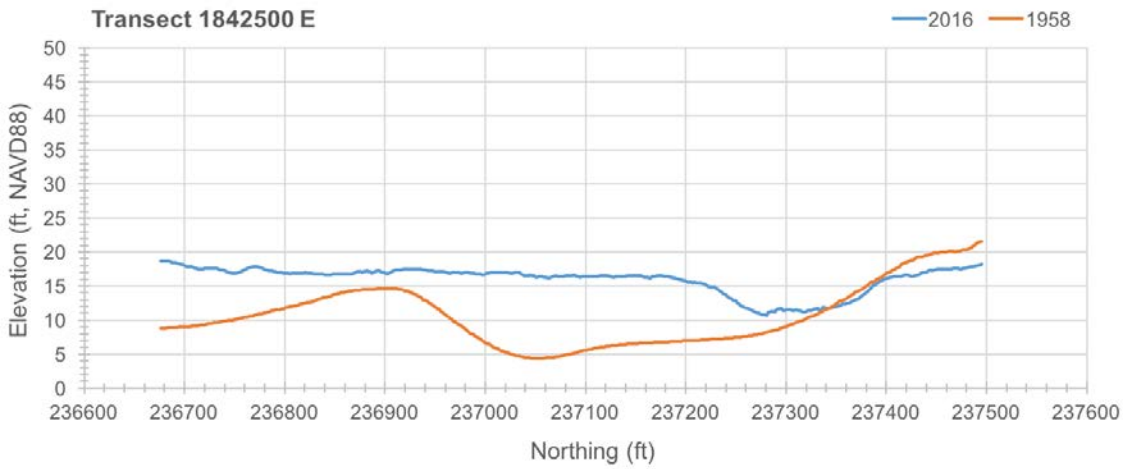

Figure A- 11. Elevation profiles at transect E1842500. View is of an observer looking to the west.

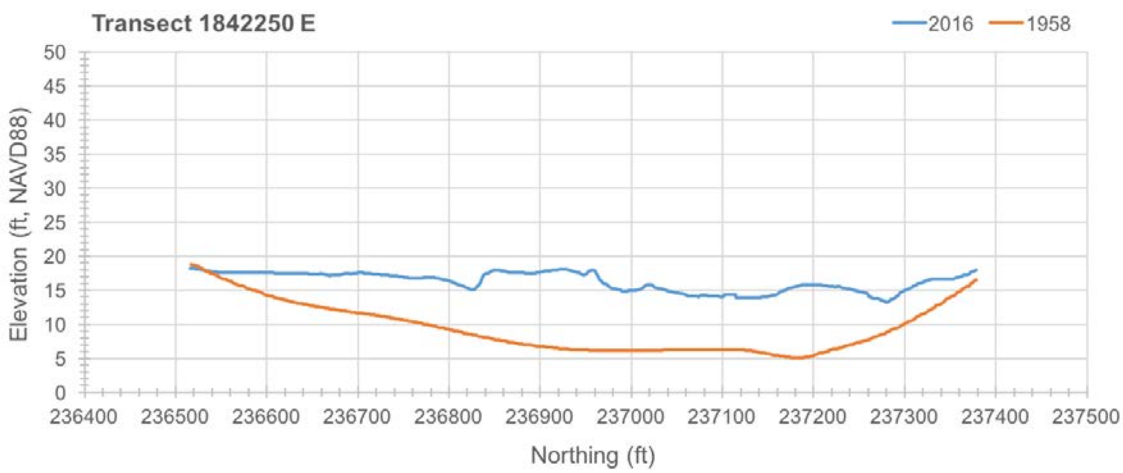

Figure A- 12. Elevation profiles at transect E1842250. View is of an observer looking to the west.

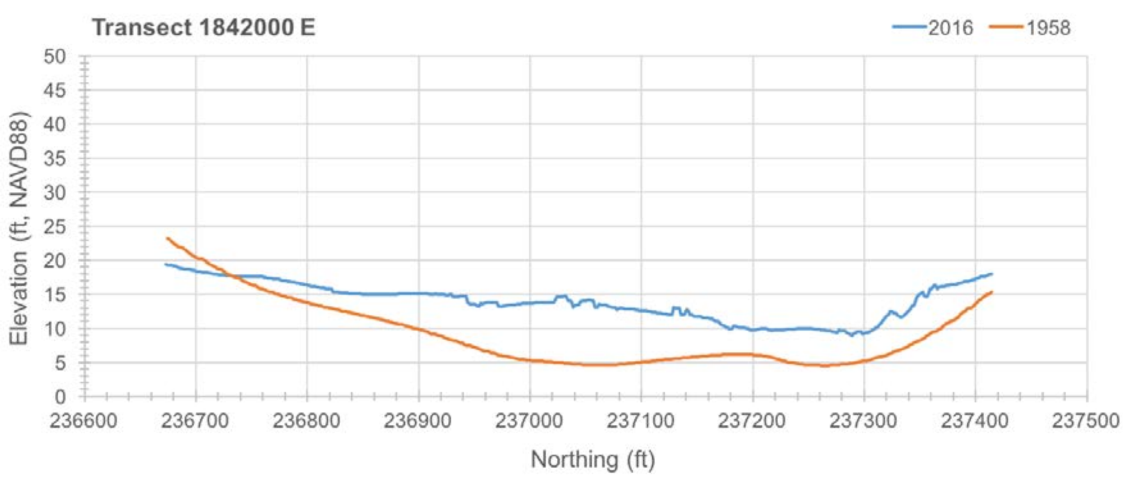

Figure A- 13. Elevation profiles at transect E1842000. View is of an observer looking to the west.

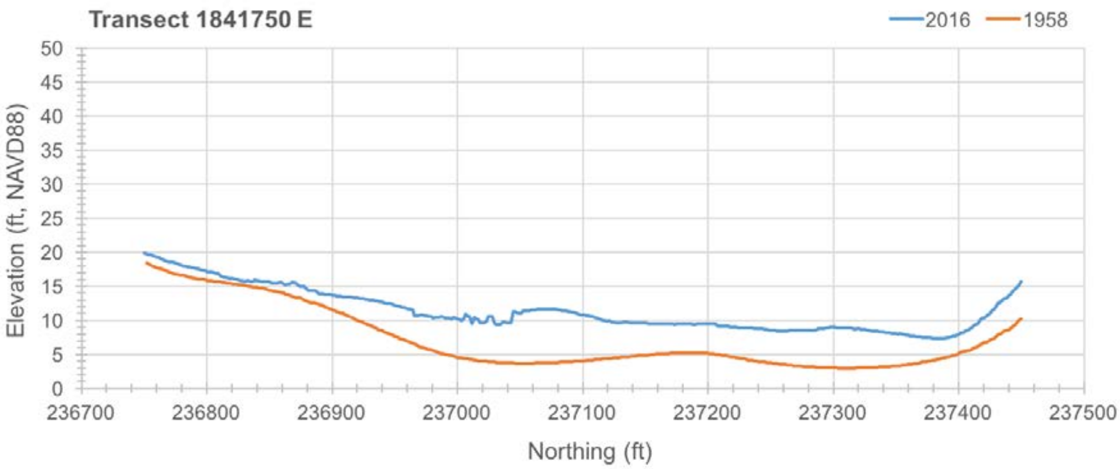

Figure A- 14. Elevation profiles at transect E1841750. View is of an observer looking to the west.

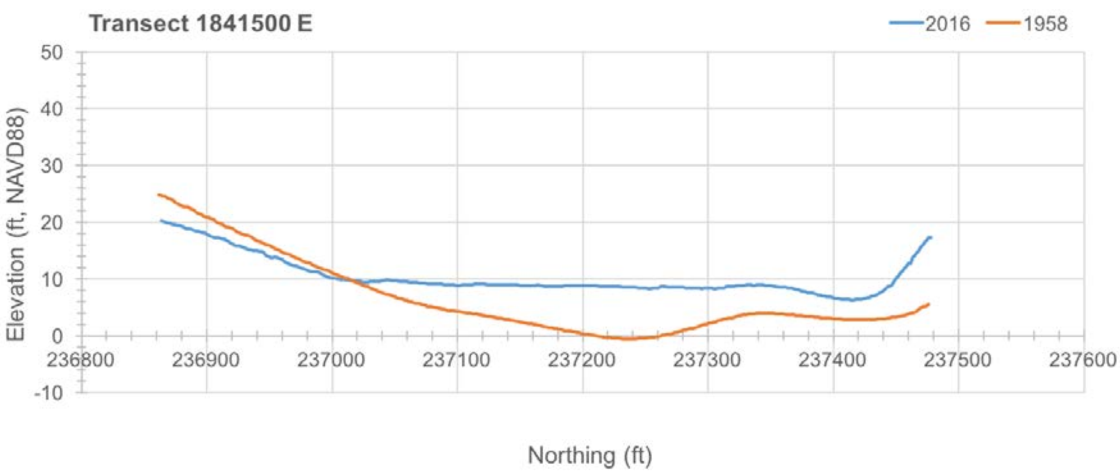

Figure A- 15. Elevation profiles at transect E1841500. View is of an observer looking to the west.

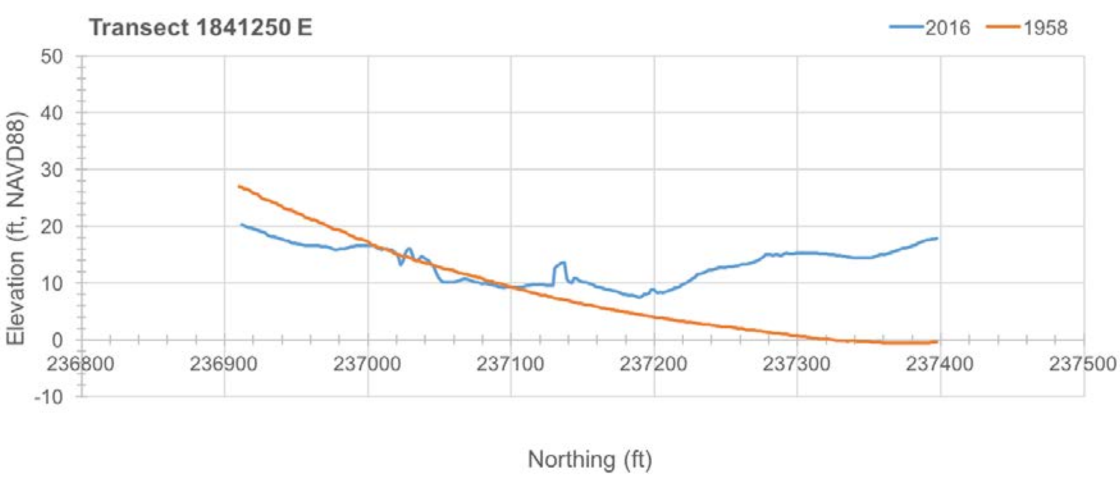

Figure A- 16. Elevation profiles at transect E1841250. View is of an observer looking to the west.

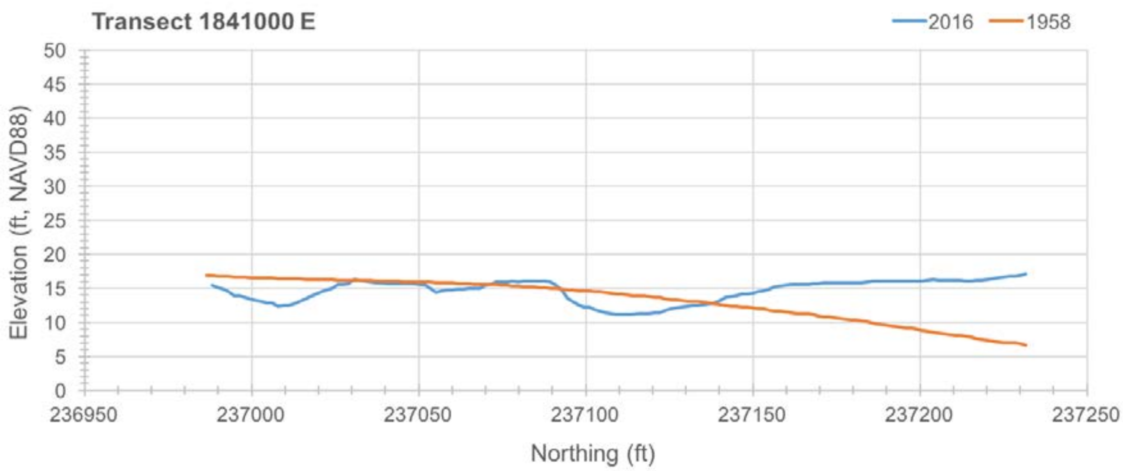

Figure A- 17. Elevation profiles at transect E1841000. View is of an observer looking to the west.

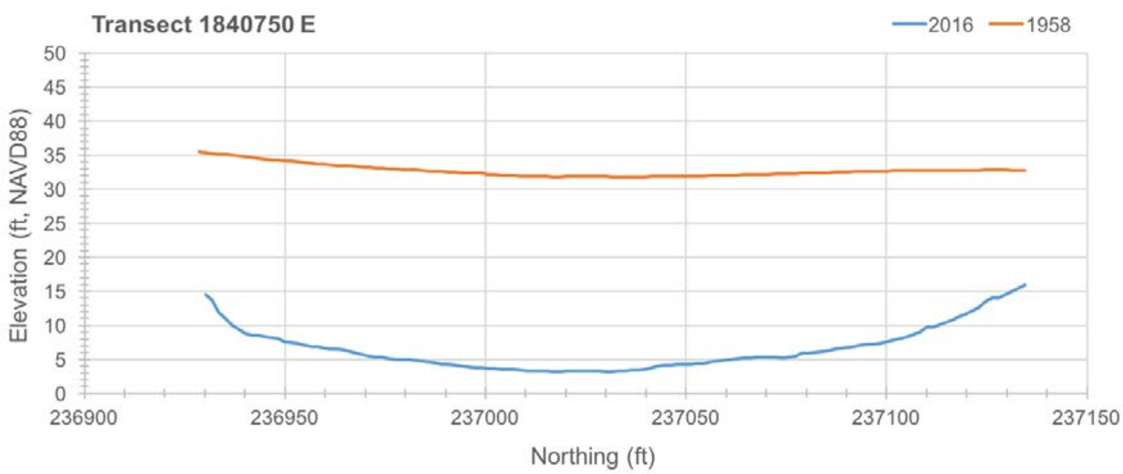

Figure A- 18. Elevation profiles at transect E1840750. View is of an observer looking to the west.

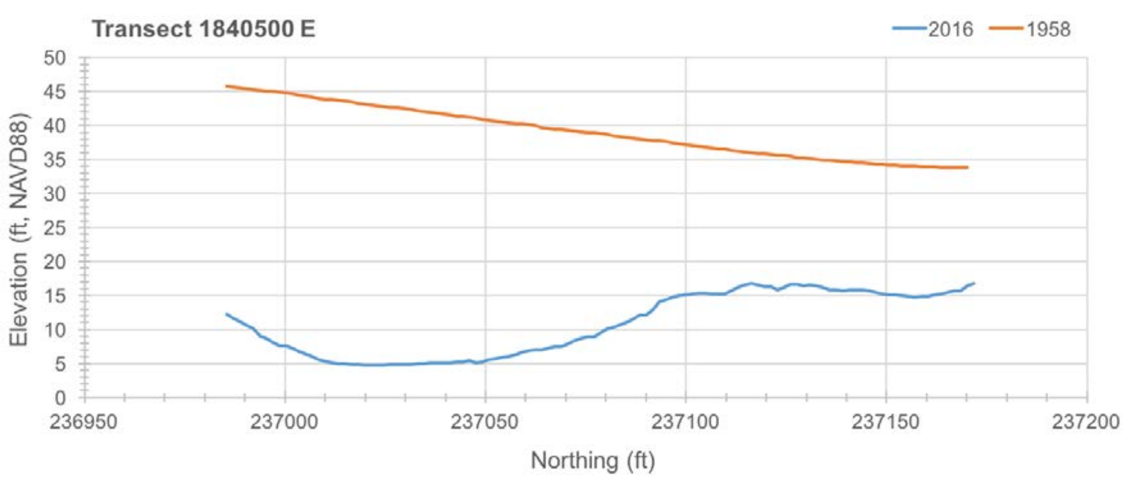

Figure A- 19. Elevation profiles at transect E1840500. View is of an observer looking to the west.

Appendix B

Some limited sampling of sediment characteristics was performed in Lake Forest on July 18, 2016. Shallow push cores were used to sample the top 6 to 12 inches of surface sediments in eight unique locations throughout the study area. The sampling locations were generally along D'Olive Creek downstream of the Bayview Drive bridge, in Tom's Cove, and where Tiawasee Creek empties into Lake Forest. The sampling locations are identified by white circles and sample identification names in Figure B- 1.

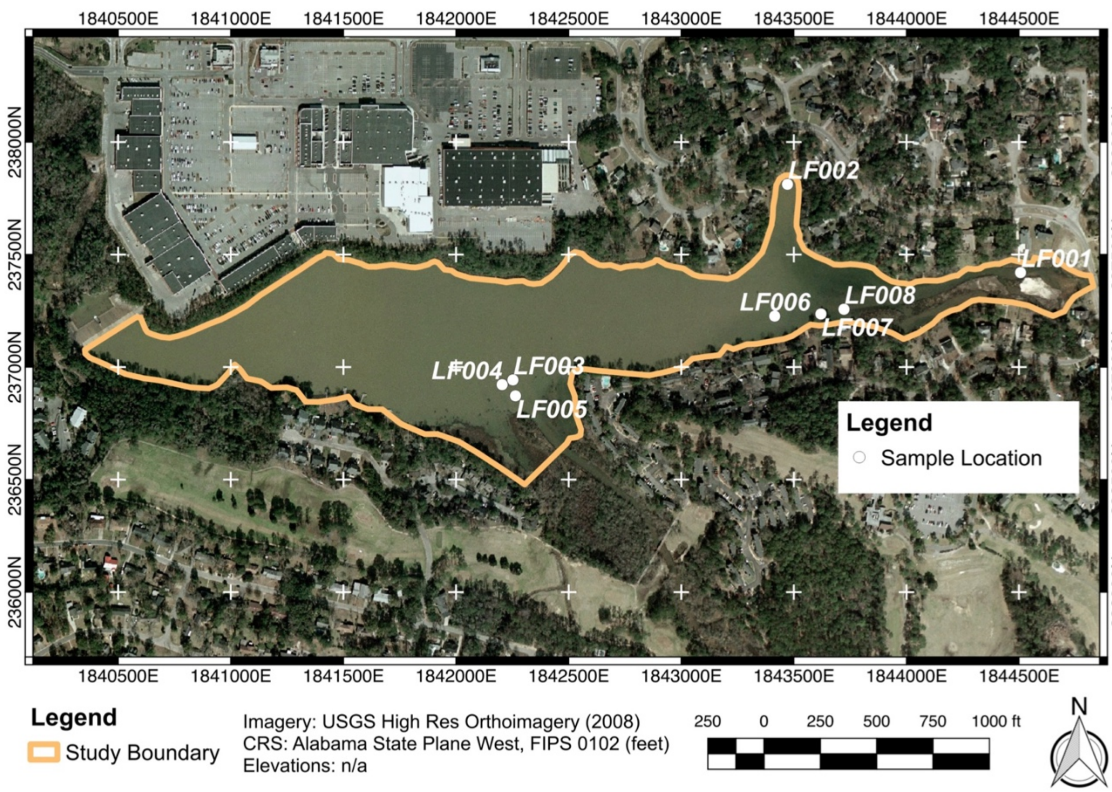

Figure B- 1. Sediment sample location (white circles) map.

Eight (8) sediment samples (see Figure B- 2) were analyzed to determine their grain size distributions. The samples were dried to constant weight in an oven for 15 hours and then left to air dry for another 72 hours (see Figure B- 3). The grain sorting was performed using a standard stack of geotechnical sieves (i.e., 4, 10, 30, 40, 50, 60, 80, 100, 140, 200) set in a Ro-Tap® and allowed to shake for at least 10 minutes.

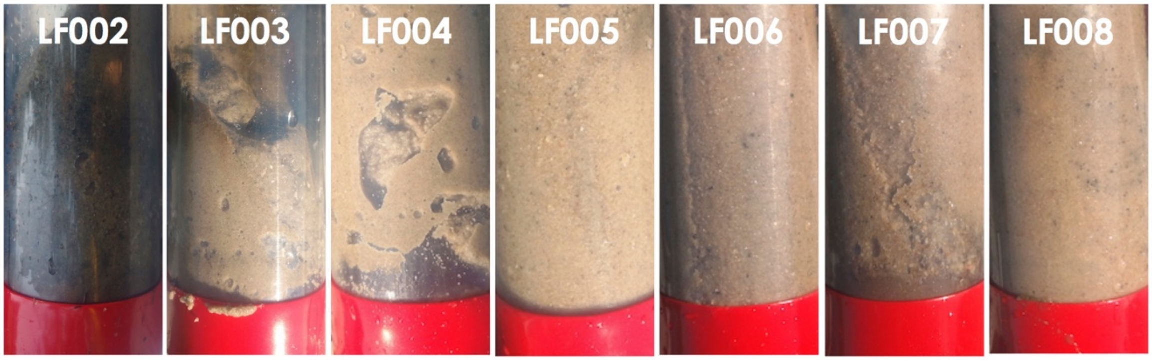

Figure B- 2. Wet sediment core samples obtained from Lake Forest.

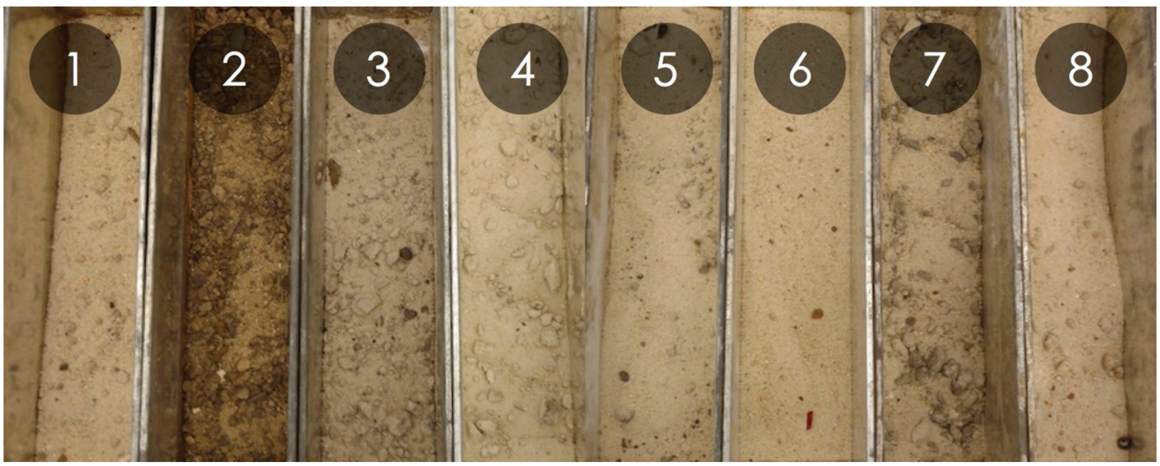

Figure B- 3. Oven and air dried sediment core samples (numbering is LF00x).

All of the sediment samples exhibited similar qualities in terms of sediment size, character, and sorting. The median sediment diameters (D_{50}) ranged from 0.30 mm to 0.50 mm. Grain size distributions and histograms for all samples are shown in Figure B- 4 and Figure B- 5, respectively. The samples were characterized as moderately well sorted, well sorted, or very well sorted. In terms of skewness, six of the samples were coarse skewed, one sample was fine skewed (LF004), and one was near symmetrical (LF003). The samples generally did not contain a high percentage of fines (i.e., silt-size particles); six samples had less than 1% of material (by mass) passing the 200 sieve, whereas the remaining samples had 2.0% (LF007) and 2.2% (LF002) passing the 200 sieve. The relevant sediment analysis results for all samples are summarized in Table B- 1. Individual sample data and graphical analyses are provided in Figure B- 6 – Figure B- 13 below.

One sample, obtained in Tom's Cove (LF002), contained a higher fraction of organic material (visual observation), which gave the sediment a darker color as compared to the other seven samples. The samples otherwise did not contain much notable organic material and were consistent in color and texture.

Table B- 1. Summary of grain size parameters for Lake Forest sediment core samples.

Location	Sample ID	D10	D30	D50	D60	Passing 200 Sieve	Sorting	Skewness
		mm	mm	mm	mm	% Mass		
Tom's Cove	LF002	0.18	0.28	0.38	0.44	2.2	MWS[1]	CS[4]
D'Olive	LF001	0.23	0.31	0.39	0.44	0.17	WS[2]	SCS[5]
	LF006	0.31	0.40	0.50	0.55	0.09	WS	SCS
	LF007	0.26	0.35	0.46	0.55	2.0	MWS	CS
	LF008	0.30	0.35	0.40	0.42	0.20	VWS[3]	SCS
Tiawasee	LF003	0.18	0.23	0.30	0.33	0.85	VWS	SYM[6]
	LF004	0.19	0.31	0.35	0.37	0.74	VWS	FS[7]
	LF005	0.30	0.37	0.44	0.48	0.30	VWS	CS

1. MWS: Moderately Well Sorted
2. WS: Well Sorted
3. VWS: Very Well Sorted
4. CS: Coarse Skewed
5. SCS: Strongly Coarse Skewed
6. SYM: Near Symmetrical
7. FS: Fine Skewed

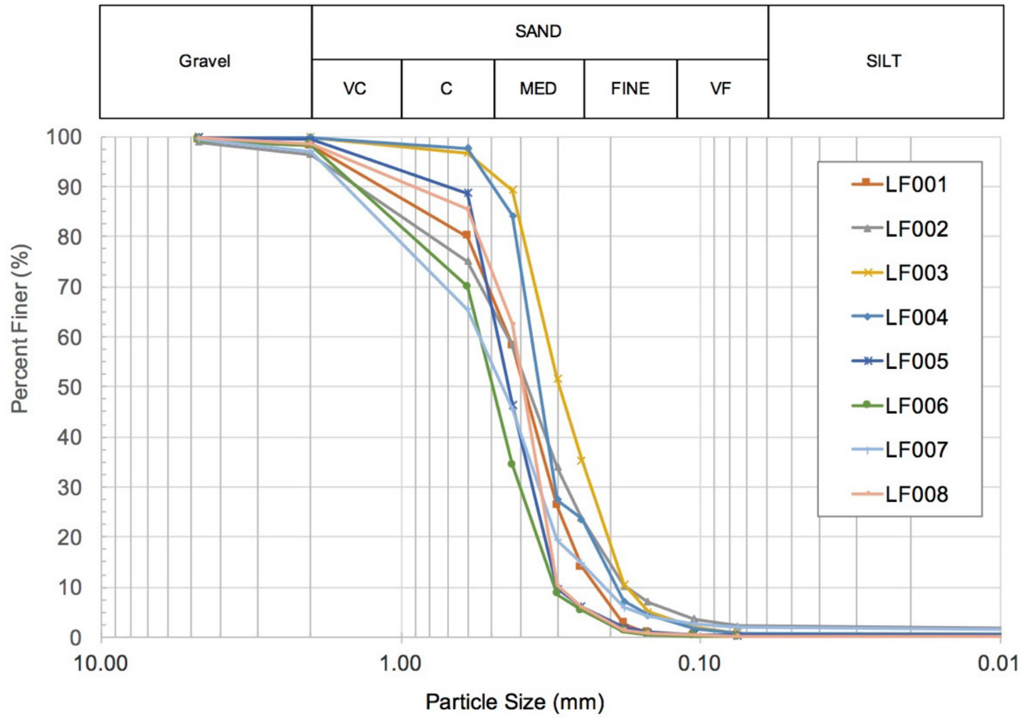

Figure B- 4. Grain size distributions for all Lake Forest sediment core samples.

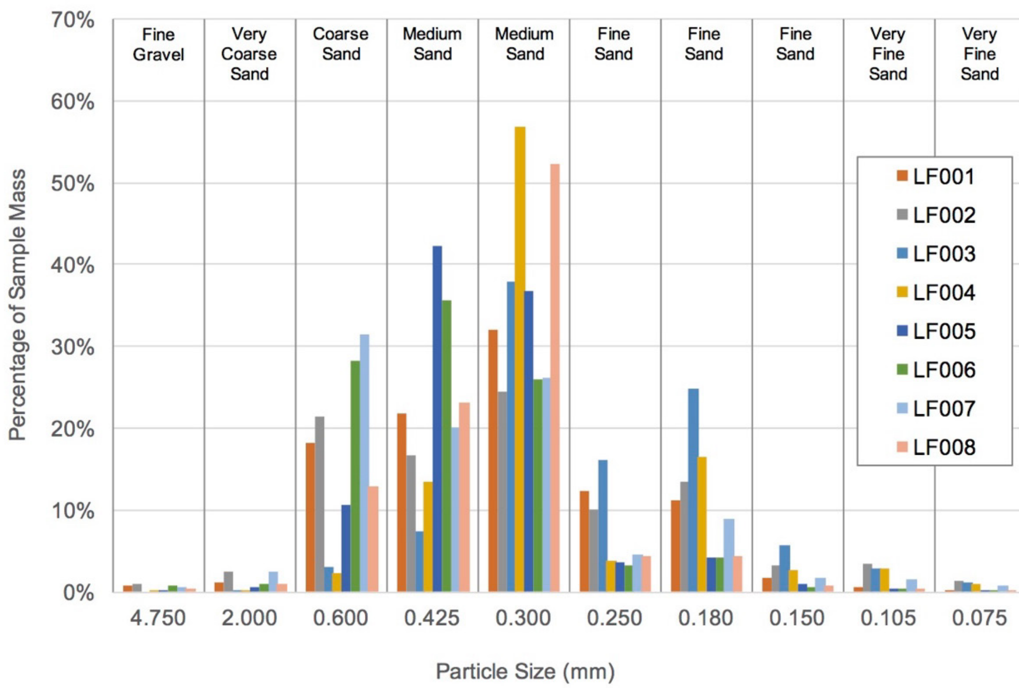

Figure B- 5. Grain size histograms for all Lake Forest sediment core samples.

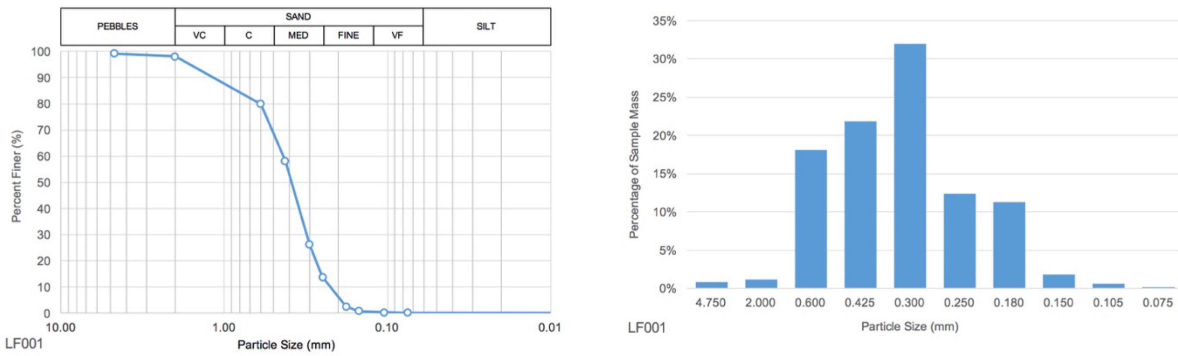

Figure B- 6. Grain size distribution (left) and histogram (right) for Lake Forest sample LF001.

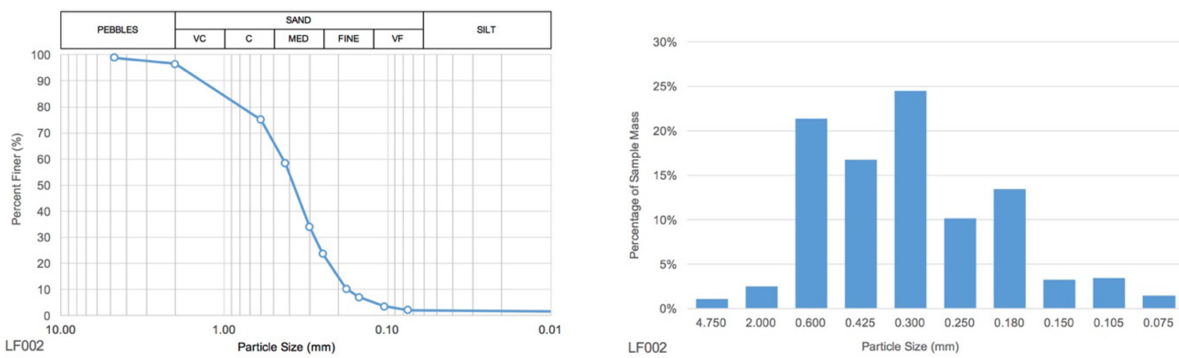

Figure B- 7. Grain size distribution (left) and histogram (right) for Lake Forest sample LF002.

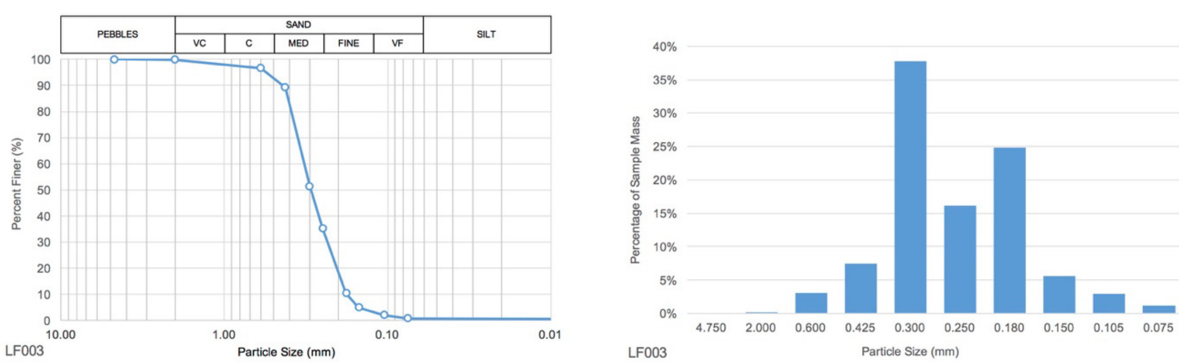

Figure B- 8. Grain size distribution (left) and histogram (right) for Lake Forest sample LF003.

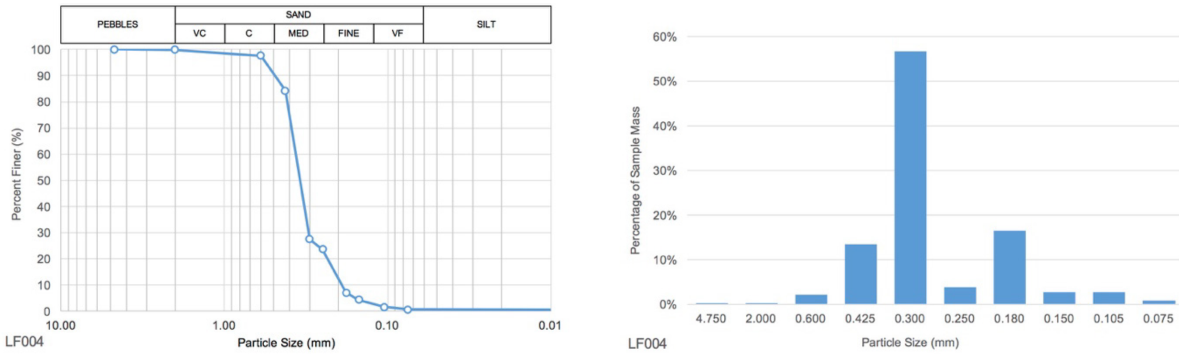

Figure B- 9. Grain size distribution (left) and histogram (right) for Lake Forest sample LF004.

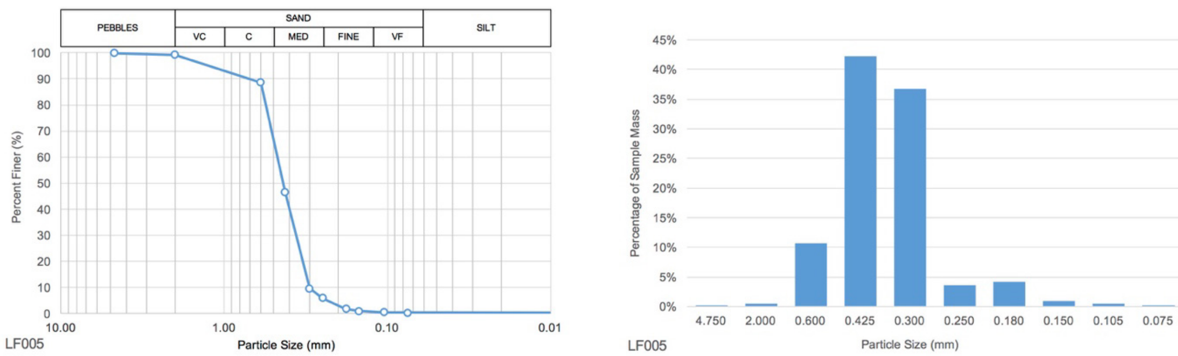

Figure B- 10. Grain size distribution (left) and histogram (right) for Lake Forest sample LF005.

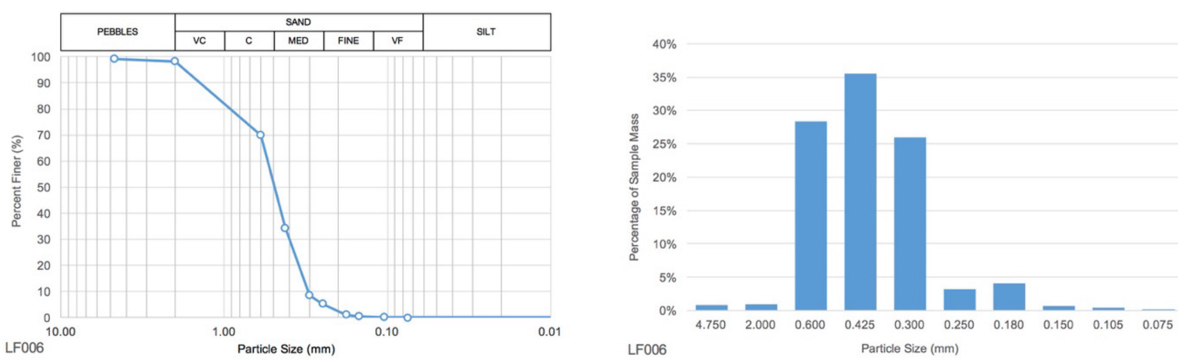

Figure B- 11. Grain size distribution (left) and histogram (right) for Lake Forest sample LF006.

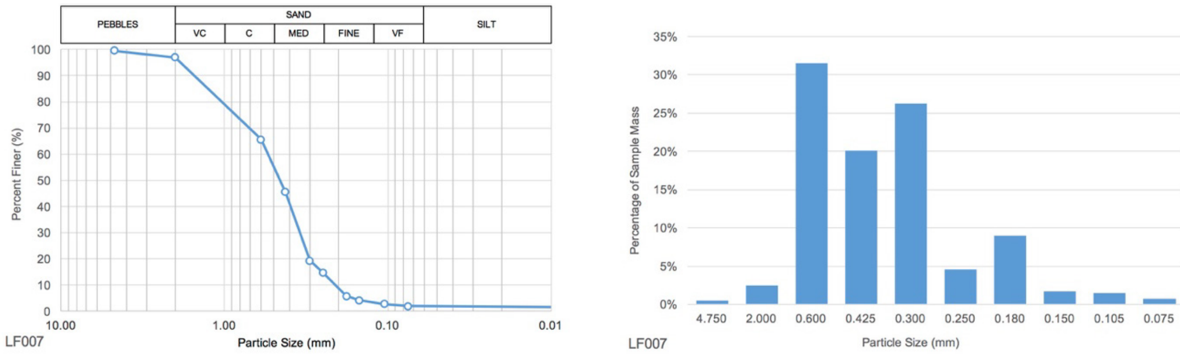

Figure B- 12. Grain size distribution (left) and histogram (right) for Lake Forest sample LF007.

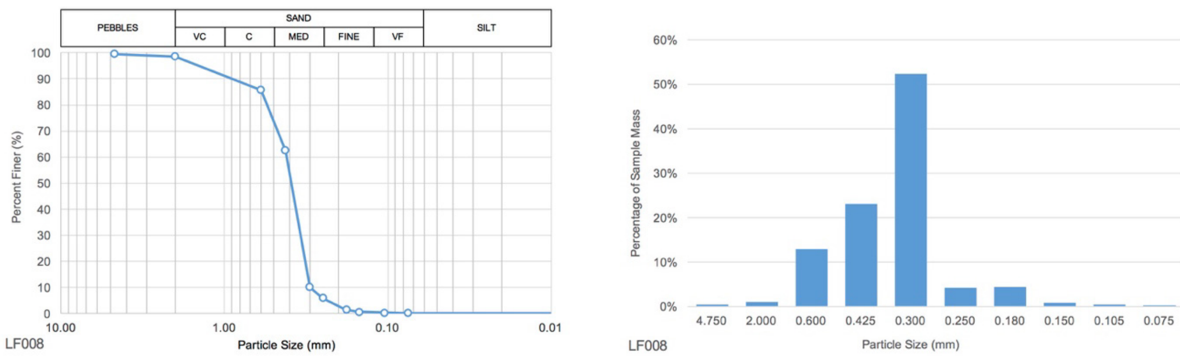

Figure B- 13. Grain size distribution (left) and histogram (right) for Lake Forest sample LF008.