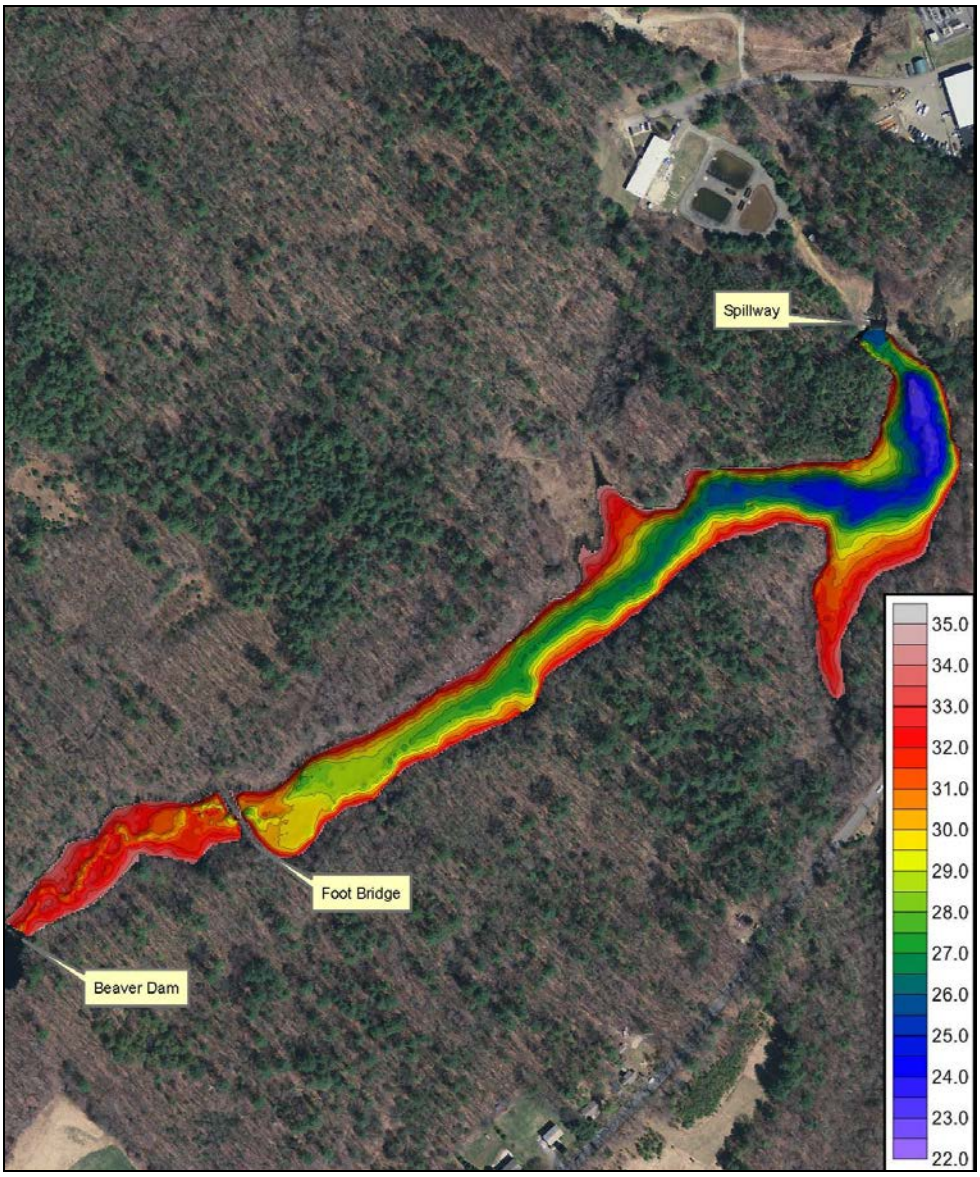
# BATHYMETRIC AND SEDIMENT THICKNESS SURVEYS
# BULL BROOK RESERVOIR
# IPSWICH, MA




***Bull Brook Reservoir Bathymetric Contour Map***

***Prepared for:***

**Town of Ipswich**
**Water Department**
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**Ipswich, MA**

***Prepared by:***

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**May 2018**

# TABLE OF CONTENTS

**Page Number**

**1.0 INTRODUCTION…….. 1**

**2.0 ACQUISISTION AND PROCESSING METHODS ……. 1**

**2.1 Survey Vessel and Navigation 1**

**2.2 Bathymetric Survey Design and Instrumentation 1**

**2.3 Sediment Thickness Design and Methods 2**

**3.0 DATA PROCESSING…… 2**

**3.1 Bathymetric Data Processing 2**

**3.2 Sediment Thickness Data Processing 3**

**4.0 BATHYMETRIC SURVEY RESULTS …..…… 3**

**5.0 SEDIMENT THICKNESS RESULTS….……. 4**

**6.0 QUALITY ASSURANCE/ QUALITY CONTROL……. 4**

**REFERENCES**

**TABLES**

**TABLE 1 Bull Brook Reservoir Elevation Datums**

**TABLE 2 Bull Brook Reservoir Sediment Thickness Data**

**TABLE 3 Bull Brook Reservoir Hypsography Data**

**FIGURES**

**FIGURE 1 Bull Brook Reservoir Sounding and Sediment Probe Distribution**

**FIGURE 2 Bull Brook Reservoir Bathymetry**

**FIGURE 3 Bull Brook Reservoir Capacity Curve**

**FIGURE 4 Bull Brook Reservoir Estimated Sediment Thickness**

# 1.0 INTRODUCTION

CR Environmental, Inc. (CR) performed bathymetric and sediment thickness surveys of the Bull Brook Reservoir in Ipswich, Massachusetts on April 11 - 12, 2018. The purposes of the surveys were to calculate reservoir holding capacity, hypsographic relationships (e.g., area/volume) and to assess sediment accumulation.

# 2.0 ACQUISITION AND PROCESSING METHODS

## 2.10 Survey Vessel and Navigation

Bathymetric and sediment thickness surveys were conducted using CR's 12-foot aluminum skiff powered by an electric motor. The skiff was equipped with a small instrument enclosure and power supplies for computers and survey electronics.

Navigation for the surveys was accomplished using a Hemisphere VS330 Real Time Kinematic Global Positioning System (RTK GPS). In fixed RTK mode, the horizontal accuracy of the system is approximately 1 centimeter with a vertical accuracy of approximately 2 cm. In Code Differential mode, horizontal accuracy is approximately 30 cm. Fixed RTK data were consistently obtained during the survey.

## 2.20 Bathymetric Survey Design and Instrumentation

The bathymetric survey design consisted of transects oriented perpendicular to the major axis of the reservoir spaced 25-feet apart augmented by perpendicular quality control cross-line transects (Figure 1). Data accuracy was assessed through the statistical comparison of soundings collected along primary and cross-line transects.

Soundings were collected using an Odom CV-100 echo sounder equipped with a 200-kHz 8-degree transducer. The minimum reliable sounding of this system is approximately 2 feet beneath the transducer, yielding defensible soundings at a minimum depth of approximately 2.5 feet beneath the water surface.

The RTK GPS and CV-100 echo sounder were interfaced to a shipboard computer running HYPACK 2015 hydrographic surveying software. During the survey, this system calculated X and Y positions in the desired grid system (MA State Plane, NAD83, US Foot), recorded the depth and navigation data, and provided a steering display for the vessel captain. Using georeferenced imagery (e.g. orthophotos) as background files HYPACK also depicted the progress of the survey, ensuring that the survey areas were adequately insonified.



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Depth data were corrected for variations in water column sound velocity using profile data acquired with a YSI, Inc. Castaway conductivity and temperature profiler. Echo sounder draft was confirmed at the start and end of the survey by comparing echo sounder water depth measurements to absolute water depths obtained using the "bar check" method, in which a metal plate is lowered beneath the echo sounder's transducer to a known distance below the water surface. "Bar-check" calibrations were consistently accurate to within 0.10 feet throughout the survey. Additional checks of sounding accuracy were obtained by comparison of staff measurements with echo sounder readings. These comparisons consistently agreed to within 0.10 ft.

### 2.30 Sediment Thickness Survey Design and Methods

Sediment thickness in Bull Brook Reservoir was measured by manually driving a steel probe to refusal at evenly spaced locations along transects approximately 100 feet apart with somewhat tighter spacing near the spillway dam (Figure 1). Sediments were probed to refusal at 120 locations. Refusal depth data were digitally recorded for comparison with sounding data on the HYPACK acquisition computer.

## 3.0 DATA PROCESSING

### 3.1 Bathymetric Data Processing

Processing of recorded reservoir depths consisted of the removal of outlying data points associated with water column interference (e.g., fish, gas, vegetation or debris), and conversion of raw depths (soundings) to NAVD88 elevations. Measured depths were converted to bottom elevations based on RTK NAVD88 water levels and observations of the water surface at the spillway. The basin was approximately 0.2 feet above full pool during the survey effort (Table 1). Processed sounding data were exported as ASCII comma delimited text files.

Georeferenced orthophotos and Light Detection and Ranging (LiDAR) terrain files surrounding the reservoir were obtained from USGS. LiDAR point data were reported relative to the NAVD88 vertical datum. LiDAR data were merged with CR's sounding data to generate seamless digital elevation models (DEMs) of the reservoir and surrounding terrestrial landscape. Inclusion of LiDAR data in the sounding database increased the accuracy of shoreline delineations and volume calculations.

A gridded surface was created from the merged elevation database of the reservoir using a 5 x 5 foot node density. A spectrum colored GeoTif image and contours were developed from the reservoir grid using a 1.0 foot contour interval. Contours have been digitally delivered in shapefile and DXF formats.



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Volumes and areas were calculated for the reservoir grid using 0.10 foot intervals. The ASCII bathymetric point data, grids, contours and GeoTIF visualizations have been provided as digital deliverables. Volumetric and hypsographic data have been delivered in tabular and graphical formats.

### 3.2 Sediment Thickness Data Processing

Sediments were probed to refusal at 120 locations in the reservoir. The locations, refusal elevations and other observations were digitally tabulated (Table 2). The bed elevation at each probe location was extracted from the bathymetric surface and compared to the refusal elevation to calculate sediment thickness. An isopach layer representing sediment thickness was created by creating a grid from observations using Kriging interpolation methods. Probe measurements of sediment thickness have been delivered in Microsoft Excel format with the survey data set.

## 4.0 BATHYMETRIC SURVEY RESULTS

Bathymetric data for the reservoir were statistically analyzed to evaluate accuracy using U. S. Army Corps of Engineers methods (USACE, 2013. EM1110-2-1003). The USACE 95th percentile confidence interval (CI) recommendation for survey bias (cross-line repeatability) is +/- 0.2 feet and "resultant elevation/depth accuracy" of individual soundings is +/- 0.8 feet.

The observed water level at the Bull Brook Reservoir was 0.2 feet above the spillway, with a resultant elevation of 34.63 feet NAVD88 (Table 1). RTK GPS elevations and the spillway elevation reported on a 1985 design drawing provided by the Town of Ipswich agreed to within 0.10 ft. Cross-line statistics for the Bull Brook Reservoir dataset yielded a mean difference of -0.03 feet and a 95% CI uncertainty of 0.38 feet (SD = 0.19 feet).

The maximum depth of the Bull Brook Reservoir was 11.8 feet (22.8 feet NAVD88) and the average depth was 4.8 feet (29.8 feet NAVD88, Figure 2). Volume calculations for the reservoir suggest a full pool capacity of approximately 16.43 million gallons (Table 3, Figure 3). Approximately 21-percent of capacity is contained in the upper 1 foot of the basin.

Digital echograms of sonar data documented minimal aquatic vegetation within the reservoir during the April survey.



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## 5.0 SEDIMENT THICKNESS RESULTS

Mapped sediment thickness at the 120 probe locations ranged from 0 to 5.4 feet (mean = 1.8 feet) (Table 2, Figure 4).

Probe penetration was generally greatest downstream, northeast of the foot bridge. Probes were hand driven to refusal and clean gray clay was frequently observed on the tip of the probe suggesting penetration beneath the surface of pre-construction soils. Notes on a 1926 design drawing provided by the Town of Ipswich, "*All mud and vegetable matter to be removed to clean hard bottom inside of contour 31*" suggest that the clean hard bottom is likely the clean gray clay layer observed at probe refusal. Therefore, it would appear that overall there has not been significant sedimentation in Bull Brook Reservoir since its creation.

## 6.0 QUALITY ASSURANCE/ QUALITY CONTROL

Data collected in the Bull Brook Reservoir on April 11-12, 2018 have been shown to comply with relevant promulgated USACE Performance Standards. CR merged these data with LiDAR data of similar vertical accuracy (i.e., +/- <0.5 feet at the 2-sigma confidence interval) to calculate full pool capacity and hypsography at 0.10 foot intervals.

CR has used technically defensible approaches to minimize errors or biases in area or depth (elevation) calculations through the use of publically available terrestrial elevation data (e.g., LiDAR) to refine volume calculations by delineating the full pool area. CR's RTK GPS elevation measurements matched LiDAR values closely at the margins of the basin. RTK GPS and spillway elevations reported by the Town of Ipswich on design drawings also matched closely (i.e., <0.10 feet difference).



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## REFERENCES

U.S. Army Corps of Engineers. 2013. *Engineering and Design Hydrographic Surveying*. EM1110-2-1003.



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**TABLE 1**

**BULL BROOK RESERVOIR ELEVATION DATUMS**
**Ipswich, Massachusetts**
**(feet)**

| NAVD88 WS EL [1] | NGVD29 WS EL [2] | BM NGVD29 [3] |
|---|---|---|
| 34.6 | 35.4 | 38.5 |

NOTES:

1. Average April 11, 2018 RTK GPS water surface (WS) elevation.
2. NAVD88 to NGVD29 conversion of surface water elevation +0.791 ft calculated using U.S. ACOE Corpscon V. 6.0.1.
3. Benchmark (BM) western abutment at the spillway dam used for daily monitoring. Estimated elevation based on March, 1985 design plans = 38.5 ft +/- (NGVD29 assumed).
4. The water surface elevation during the survey was 3.23 ft below the western abutment (~38.5 ft - 3.23 ft = 35.3 ft NGVD29).
5. The water surface was approximately 0.2 ft above the spillway.
   Full pool elevation = 34.6 ft - 0.2 ft = 34.4 NAVD88 = 35.2 ft NGVD29.

**TABLE 2**

**BULL BROOK RESERVOIR SEDIMENT THICKNESS DATA**
**April 11, 2018**

| Name | X | Y | REFUSAL Z (ft) | REFUSAL EL NAVD88 ft | REFUSAL TYPE | BED EL NAVD88 ft | Sed_Thickness (ft) |
|---|---|---|---|---|---|---|---|
| P-1 | 823501.1 | 3077690.1 | 5.5 | 29.1 | Wood | 32.5 | 3.4 |
| P-2 | 823532.6 | 3077694.7 | 2.4 | 32.2 | Gravel | 33.4 | 1.2 |
| P-3 | 823508.8 | 3077703 | 4.1 | 30.5 | Wood and Gravel | 31.2 | 0.7 |
| P-4 | 823500.7 | 3077715.8 | 4.9 | 29.7 | Clay | 32.1 | 2.4 |
| P-5 | 823545.3 | 3077756.6 | 6 | 28.6 | Sand | 31.9 | 3.3 |
| P-6 | 823520.4 | 3077769.9 | 4 | 30.6 | Wood | 32.5 | 1.9 |
| P-7 | 823568.4 | 3077721.8 | 2.7 | 31.9 | Gravel | 32.4 | 0.5 |
| P-8 | 823602.5 | 3077773.3 | 5.1 | 29.5 | Gravel | 31 | 1.5 |
| P-9 | 823575.5 | 3077796.3 | 3.5 | 31.1 | Sand | 31.6 | 0.5 |
| P-10 | 823624.2 | 3077755.8 | 3 | 31.6 | Gravel | 32.3 | 0.7 |
| P-11 | 823642.6 | 3077798.9 | 4.4 | 30.2 | Gravel | 30.8 | 0.6 |
| P-12 | 823649.1 | 3077781.8 | 2.4 | 32.2 | Gravel | 32.5 | 0.3 |
| P-13 | 823617.2 | 3077821 | 3.2 | 31.4 | Sand | 32.9 | 1.5 |
| P-14 | 823670.1 | 3077855.9 | 6 | 28.6 | Clay | 31.1 | 2.5 |
| P-15 | 823690.2 | 3077807.2 | 3.9 | 30.7 | Clay | 32.1 | 1.4 |
| P-16 | 823643.5 | 3077888.1 | 4.2 | 30.4 | Sand | 32.4 | 2 |
| P-17 | 823709.1 | 3077889.9 | 4.8 | 29.8 | Wood | 32.3 | 2.5 |
| P-18 | 823688.9 | 3077914.1 | 5 | 29.6 | Clay | 32.5 | 2.9 |
| P-19 | 823725.1 | 3077862.7 | 4.4 | 30.2 | Gravel | 31.9 | 1.7 |
| P-20 | 823742.5 | 3077938.9 | 5.8 | 28.8 | Gravel | 30.6 | 1.8 |
| P-21 | 823755.9 | 3077891.1 | 2.3 | 32.3 | Rock | 32.6 | 0.3 |
| P-22 | 823729.8 | 3077966.2 | 4.1 | 30.5 | Clay | 33.2 | 2.7 |
| P-23 | 823806.5 | 3077928.2 | 4.7 | 29.9 | Clay | 31 | 1.1 |
| P-24 | 823823.9 | 3077880 | 2.5 | 32.1 | Sand | 33.1 | 1 |
| P-25 | 823784.5 | 3077997.2 | 2.6 | 32 | Clay | 33.3 | 1.3 |
| P-26 | 823863.9 | 3077933.3 | 7 | 27.6 | Gravel | 31 | 3.4 |
| P-27 | 823873.3 | 3077880.7 | 2.7 | 31.9 | Gravel | 32.5 | 0.6 |
| P-28 | 823850 | 3077984.1 | 3.3 | 31.3 | Clay | 31.8 | 0.5 |
| P-29 | 823917 | 3077930.1 | 6.5 | 28.1 | Gravel | 31.5 | 3.4 |
| P-30 | 823927.5 | 3077870.2 | 3.2 | 31.4 | Clay | 32.6 | 1.2 |
| P-31 | 823902.4 | 3077994.7 | 3.4 | 31.2 | Sand | 32.8 | 1.6 |
| P-32 | 823958.8 | 3077947.8 | 6.4 | 28.2 | Gravel | 31 | 2.8 |
| P-33 | 823973.6 | 3077903.6 | 2.6 | 32 | Clay | 33 | 1 |
| P-34 | 823947.4 | 3078001.9 | 6.5 | 28.1 | Clay | 31.4 | 3.3 |
| P-35 | 824019 | 3077955.1 | 7 | 27.6 | Gravel | 30.5 | 2.9 |
| P-36 | 824029.5 | 3077925.9 | 3.1 | 31.5 | Rock | 33.2 | 1.7 |
| P-37 | 823974.5 | 3078017.7 | 4.3 | 30.3 | Rock | 32.9 | 2.6 |
| P-38 | 824078.2 | 3077965.3 | 9.2 | 25.4 | Clay | 30.8 | 5.4 |
| P-39 | 824073.6 | 3078006.6 | 5.5 | 29.1 | Clay | 31.4 | 2.3 |
| P-40 | 824112 | 3077920.2 | 8.8 | 25.8 | Gravel | 30.1 | 4.3 |
| P-41 | 824188.5 | 3077996.4 | 9.7 | 24.9 | Gravel | 29.6 | 4.7 |
| P-42 | 824167.4 | 3078029.7 | 8.9 | 25.7 | Gravel | 27.9 | 2.2 |
| P-43 | 824199.5 | 3077952.5 | 7 | 27.6 | Sand | 29.6 | 2 |
| P-44 | 824283.4 | 3078028.9 | 9.8 | 24.8 | Gravel | 28.7 | 3.9 |
| P-45 | 824268.2 | 3078052.3 | 10.5 | 24.1 | Wood | 28.7 | 4.6 |
| P-46 | 824252.4 | 3078085.1 | 9.2 | 25.4 | Gravel | 28.6 | 3.2 |
| P-47 | 824357 | 3078102.6 | 10 | 24.6 | Clay | 28.7 | 4.1 |
| P-48 | 824334.9 | 3078134.9 | 5.6 | 29 | Gravel | 30.6 | 1.6 |

**TABLE 2**

**BULL BROOK RESERVOIR SEDIMENT THICKNESS DATA**
**April 11, 2018**

| Name | X | Y | REFUSAL Z (ft) | REFUSAL EL NAVD88 ft | REFUSAL TYPE | BED EL NAVD88 ft | Sed_Thickness (ft) |
|---|---|---|---|---|---|---|---|
| P-49 | 824378.3 | 3078065 | 8.2 | 26.4 | Clay | 29.2 | 2.8 |
| P-50 | 824443.7 | 3078150.7 | 8.4 | 26.2 | Gravel | 27.9 | 1.7 |
| P-51 | 824423.2 | 3078169 | 7.8 | 26.8 | Sand | 29.3 | 2.5 |
| P-52 | 824453.3 | 3078121.9 | 7.8 | 26.8 | Clay over wood | 29.2 | 2.4 |
| P-53 | 824528.1 | 3078191.2 | 9.6 | 25 | Sand | 28 | 3 |
| P-54 | 824499.5 | 3078226.8 | 6 | 28.6 | Wood | 29.8 | 1.2 |
| P-55 | 824532.7 | 3078175.7 | 8.5 | 26.1 | Sand - gravel | 29 | 2.9 |
| P-56 | 824612.6 | 3078240.3 | 9.1 | 25.5 | Gravel | 27.2 | 1.7 |
| P-57 | 824642.7 | 3078207.7 | 5 | 29.6 | Sand | 29.9 | 0.3 |
| P-58 | 824606 | 3078274.1 | 8.2 | 26.4 | Clay | 29 | 2.6 |
| P-59 | 824684.8 | 3078336.4 | 8.5 | 26.1 | Gravel | 27.6 | 1.5 |
| P-60 | 824700.7 | 3078284.4 | 10.5 | 24.1 | Clay, bottom 2 ft | 27.1 | 3 |
| P-61 | 824720.3 | 3078258.9 | 8.7 | 25.9 | Gravel | 28 | 2.1 |
| P-62 | 824771.1 | 3078372.2 | 9 | 25.6 | Clay | 28.3 | 2.7 |
| P-63 | 824744.9 | 3078405 | 9.6 | 25 | Clay | 28.3 | 3.3 |
| P-64 | 824782.6 | 3078345 | 4 | 30.6 | Gravel | 31 | 0.4 |
| P-65 | 824844.8 | 3078431.3 | 8.5 | 26.1 | Clay | 27.9 | 1.8 |
| P-66 | 824829.9 | 3078461.2 | 7.9 | 26.7 | Clay | 27.9 | 1.2 |
| P-67 | 824879.8 | 3078411.6 | 5 | 29.6 | Sand | 30.6 | 1 |
| P-68 | 824919.9 | 3078505 | 9.3 | 25.3 | Gravel beneath clay | 26.9 | 1.6 |
| P-69 | 824891.9 | 3078534.2 | 4.3 | 30.3 | Sand | 30.8 | 0.5 |
| P-70 | 824956.7 | 3078463 | 5.5 | 29.1 | Clay | 29.9 | 0.8 |
| P-71 | 825019.3 | 3078533.8 | 10.1 | 24.5 | Clay | 27.4 | 2.9 |
| P-72 | 824994.1 | 3078566 | 9.5 | 25.1 | Clay | 26.9 | 1.8 |
| P-73 | 824964.1 | 3078610.9 | 6.2 | 28.4 | Clay | 30.1 | 1.7 |
| P-74 | 824942 | 3078683 | 3 | 31.6 | Gravel | 32 | 0.4 |
| P-75 | 825057.6 | 3078669.7 | 8.8 | 25.8 | Clay | 28.3 | 2.5 |
| P-76 | 825080.9 | 3078621.6 | 9.5 | 25.1 | Clay | 26.9 | 1.8 |
| P-77 | 825093.5 | 3078594.4 | 6.7 | 27.9 | Gravelly Clay | 29.2 | 1.3 |
| P-78 | 825162.5 | 3078652.8 | 5.3 | 29.3 | Sand | 30.2 | 0.9 |
| P-79 | 825151.7 | 3078688.7 | 9.6 | 25 | Clay | 26.8 | 1.8 |
| P-80 | 825139.8 | 3078729.2 | 10.7 | 23.9 | Clay | 26.2 | 2.3 |
| P-81 | 825120.7 | 3078751.2 | 4.8 | 29.8 | Gravel | 30.9 | 1.1 |
| P-82 | 825245 | 3078764.3 | 10.4 | 24.2 | Gravel | 27.4 | 3.2 |
| P-83 | 825256.2 | 3078722.3 | 8.8 | 25.8 | Gravel | 26 | 0.2 |
| P-84 | 825261.6 | 3078696.1 | 7.6 | 27 | Clay | 28.2 | 1.2 |
| P-85 | 825358.8 | 3078686.6 | 5.3 | 29.3 | Gravel | 30.6 | 1.3 |
| P-86 | 825350.1 | 3078738.2 | 10 | 24.6 | Gravel | 25.1 | 0.5 |
| P-87 | 825354.4 | 3078776.2 | 7.3 | 27.3 | Clay | 28.3 | 1 |
| P-88 | 825445.4 | 3078770 | 11 | 23.6 | Clay | 25.7 | 2.1 |
| P-89 | 825454 | 3078717 | 11.5 | 23.1 | Clay | 24.7 | 1.6 |
| P-90 | 825468.8 | 3078655.9 | 8.5 | 26.1 | Clay | 26.8 | 0.7 |
| P-91 | 825487.7 | 3078600.1 | 6.6 | 28 | Clay | 29.2 | 1.2 |
| P-92 | 825479.4 | 3078535.7 | 4.3 | 30.3 | Sandy clay | 30.9 | 0.6 |
| P-93 | 825446.3 | 3078483.6 | 4.7 | 29.9 | Clay | 31.3 | 1.4 |
| P-94 | 825435.3 | 3078427.9 | 3.9 | 30.7 | Clay | 31.9 | 1.2 |
| P-95 | 825429.9 | 3078391.3 | 3.9 | 30.7 | Clay | 32.4 | 1.7 |
| P-96 | 825615.8 | 3078589.2 | 4.6 | 30 | Sand | 32 | 2 |

**TABLE 2**

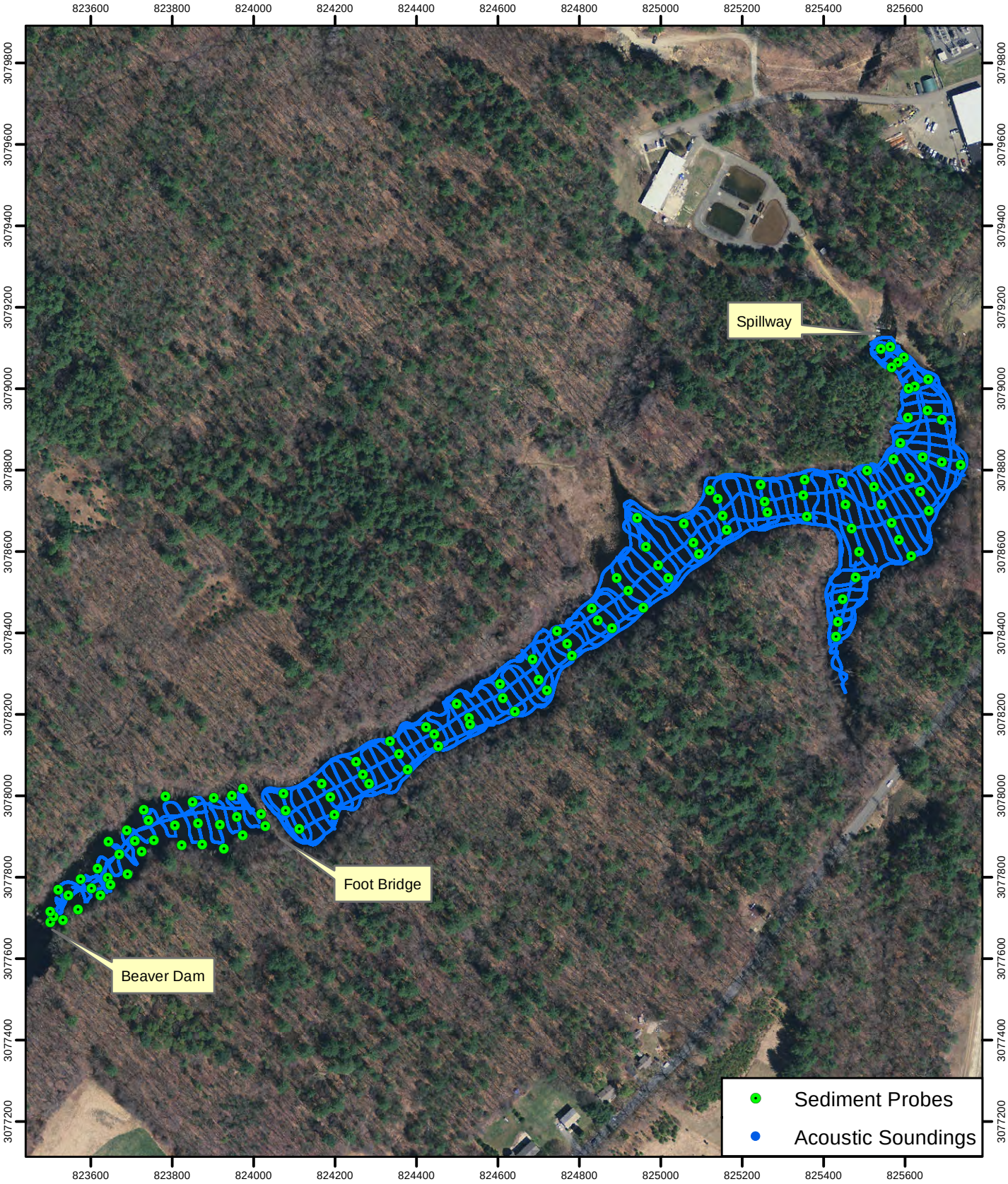
**BULL BROOK RESERVOIR SEDIMENT THICKNESS DATA**
**April 11, 2018**

| Name | X | Y | REFUSAL Z (ft) | REFUSAL EL NAVD88 ft | REFUSAL TYPE | BED EL NAVD88 ft | Sed_Thickness (ft) |
|---|---|---|---|---|---|---|---|
| P-97 | 825585.6 | 3078630.1 | 5.7 | 28.9 | Sand | 29.9 | 1 |
| P-98 | 825567.2 | 3078671.5 | 8 | 26.6 | Clay | 27 | 0.4 |
| P-99 | 825542.3 | 3078715.5 | 11.3 | 23.3 | Gravel | 24.4 | 1.1 |
| P-100 | 825523.5 | 3078759 | 10.2 | 24.4 | Clay | 28.2 | 3.8 |
| P-101 | 825507.4 | 3078799.7 | 4.8 | 29.8 | Gravel | 30.7 | 0.9 |
| P-102 | 825571.4 | 3078825.9 | 6.3 | 28.3 | Clay | 29.5 | 1.2 |
| P-103 | 825612.5 | 3078781.6 | 9.1 | 25.5 | Clay | 26.9 | 1.4 |
| P-104 | 825636.7 | 3078745.5 | 11.4 | 23.2 | Gravelly clay | 24.6 | 1.4 |
| P-105 | 825659.3 | 3078699.8 | 10 | 24.6 | Clay | 26.4 | 1.8 |
| P-106 | 825736.8 | 3078813.6 | 9.5 | 25.1 | Clay | 28.5 | 3.4 |
| P-107 | 825690.5 | 3078820 | 14 | 20.6 | Clay | 23.5 | 2.9 |
| P-108 | 825643.6 | 3078833.4 | 9.7 | 24.9 | Clay | 25.6 | 0.7 |
| P-109 | 825589.6 | 3078866.5 | 9.1 | 25.5 | Clay | 26.7 | 1.2 |
| P-110 | 825607.4 | 3078929.6 | 8.5 | 26.1 | Clay | 27.1 | 1 |
| P-111 | 825656.1 | 3078946.1 | 12.1 | 22.5 | Gravel | 23.2 | 0.7 |
| P-112 | 825690.8 | 3078925.3 | 11 | 23.6 | Clay | 24.4 | 0.8 |
| P-113 | 825656.7 | 3079022.8 | 9.9 | 24.7 | Clay | 27.3 | 2.6 |
| P-114 | 825624.4 | 3079005.8 | 10.1 | 24.5 | Gravel | 25 | 0.5 |
| P-115 | 825608.1 | 3079000.9 | 7 | 27.6 | Gravel | 29.1 | 1.5 |
| P-116 | 825597.3 | 3079076 | 5.2 | 29.4 | Gravel | 29.4 | **0** |
| P-117 | 825582.8 | 3079064.3 | 9.7 | 24.9 | Gravel | 26.7 | 1.8 |
| P-118 | 825566.5 | 3079053 | 7.8 | 26.8 | Gravel | 27.6 | 0.8 |
| P-119 | 825563.2 | 3079102.4 | 9.7 | 24.9 | Gravel | 25.7 | 0.8 |
| P-120 | 825539.7 | 3079098.7 | 9.8 | 24.8 | Gravel | 25.7 | 0.9 |

**TABLE 3**

**BULL BROOK RESERVOIR HYPSOGRAPHY**
**April 11, 2018**
**(Reference Figure 3)**

| | Water Surface EL (ft) | Water below Spillway (ft) | Water below Abutment BM (in) | Volume (Gallons) | Planar Area (acres) |
|---|---|---|---|---|---|
| **Observed 4/11/18** | 34.6 | -0.2 | 38.8 | 17,143,000 | 10.80 |
| | 34.5 | -0.1 | 40.0 | 16,787,000 | 10.78 |
| **Full Pool** | 34.4 | 0.0 | 41.2 | 16,432,000 | 10.75 |
| | 34.3 | 0.1 | 42.4 | 16,080,000 | 10.71 |
| | 34.2 | 0.2 | 43.6 | 15,730,000 | 10.66 |
| | 34.1 | 0.3 | 44.8 | 15,382,000 | 10.60 |
| | 34 | 0.4 | 46.0 | 15,037,000 | 10.53 |
| | 33.9 | 0.5 | 47.2 | 14,694,000 | 10.46 |
| | 33.8 | 0.6 | 48.4 | 14,354,000 | 10.38 |
| | 33.7 | 0.7 | 49.6 | 14,017,000 | 10.29 |
| | 33.6 | 0.8 | 50.8 | 13,682,000 | 10.21 |
| | 33.5 | 0.9 | 52.0 | 13,351,000 | 10.11 |
| | 33.4 | 1.0 | 53.2 | 13,023,000 | 10.01 |
| | 33.3 | 1.1 | 54.4 | 12,698,000 | 9.91 |
| | 33.2 | 1.2 | 55.6 | 12,377,000 | 9.81 |
| | 33.1 | 1.3 | 56.8 | 12,059,000 | 9.70 |
| | 33 | 1.4 | 58.0 | 11,745,000 | 9.58 |
| | 32.9 | 1.5 | 59.2 | 11,434,000 | 9.46 |
| | 32.8 | 1.6 | 60.4 | 11,128,000 | 9.33 |
| | 32.7 | 1.7 | 61.6 | 10,826,000 | 9.20 |
| | 32.6 | 1.8 | 62.8 | 10,528,000 | 9.06 |
| | 32.5 | 1.9 | 64.0 | 10,236,000 | 8.91 |
| | 32.4 | 2.0 | 65.2 | 9,948,000 | 8.75 |
| | 32.3 | 2.1 | 66.4 | 9,666,000 | 8.58 |
| | 32.2 | 2.2 | 67.6 | 9,389,000 | 8.43 |
| | 32.1 | 2.3 | 68.8 | 9,116,000 | 8.29 |
| | 32 | 2.4 | 70.0 | 8,848,000 | 8.15 |
| | 31.9 | 2.5 | 71.2 | 8,585,000 | 8.00 |
| | 31.8 | 2.6 | 72.4 | 8,327,000 | 7.86 |
| | 31.7 | 2.7 | 73.6 | 8,073,000 | 7.69 |
| | 31.6 | 2.8 | 74.8 | 7,826,000 | 7.51 |
| | 31.5 | 2.9 | 76.0 | 7,584,000 | 7.32 |
| | 31.4 | 3.0 | 77.2 | 7,348,000 | 7.16 |
| | 31.3 | 3.1 | 78.4 | 7,117,000 | 7.00 |
| | 31.2 | 3.2 | 79.6 | 6,892,000 | 6.83 |
| | 31.1 | 3.3 | 80.8 | 6,672,000 | 6.68 |
| | 31 | 3.4 | 82.0 | 6,457,000 | 6.53 |
| | 30.9 | 3.5 | 83.2 | 6,246,000 | 6.39 |
| | 30.8 | 3.6 | 84.4 | 6,040,000 | 6.26 |
| | 30.7 | 3.7 | 85.6 | 5,838,000 | 6.14 |
| | 30.6 | 3.8 | 86.8 | 5,640,000 | 6.02 |
| | 30.5 | 3.9 | 88.0 | 5,446,000 | 5.90 |
| | 30.4 | 4.0 | 89.2 | 5,255,000 | 5.79 |
| | 30.3 | 4.1 | 90.4 | 5,068,000 | 5.68 |
| | 30.2 | 4.2 | 91.6 | 4,885,000 | 5.58 |
| | 30.1 | 4.3 | 92.8 | 4,705,000 | 5.47 |
| | 30 | 4.4 | 94.0 | 4,529,000 | 5.34 |
| | 29 | 5.4 | 106.0 | 2,985,000 | 4.23 |
| | 28 | 6.4 | 118.0 | 1,813,000 | 3.03 |
| | 27 | 7.4 | 130.0 | 980,000 | 2.07 |
| | 26 | 8.4 | 142.0 | 451,000 | 1.22 |
| | 25 | 9.4 | 154.0 | 156,000 | 0.67 |
| | 24 | 10.4 | 166.0 | 28,000 | 0.20 |
| | 23 | 11.4 | 178.0 | 0 | 0.00 |

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Ipswich, Massachusetts

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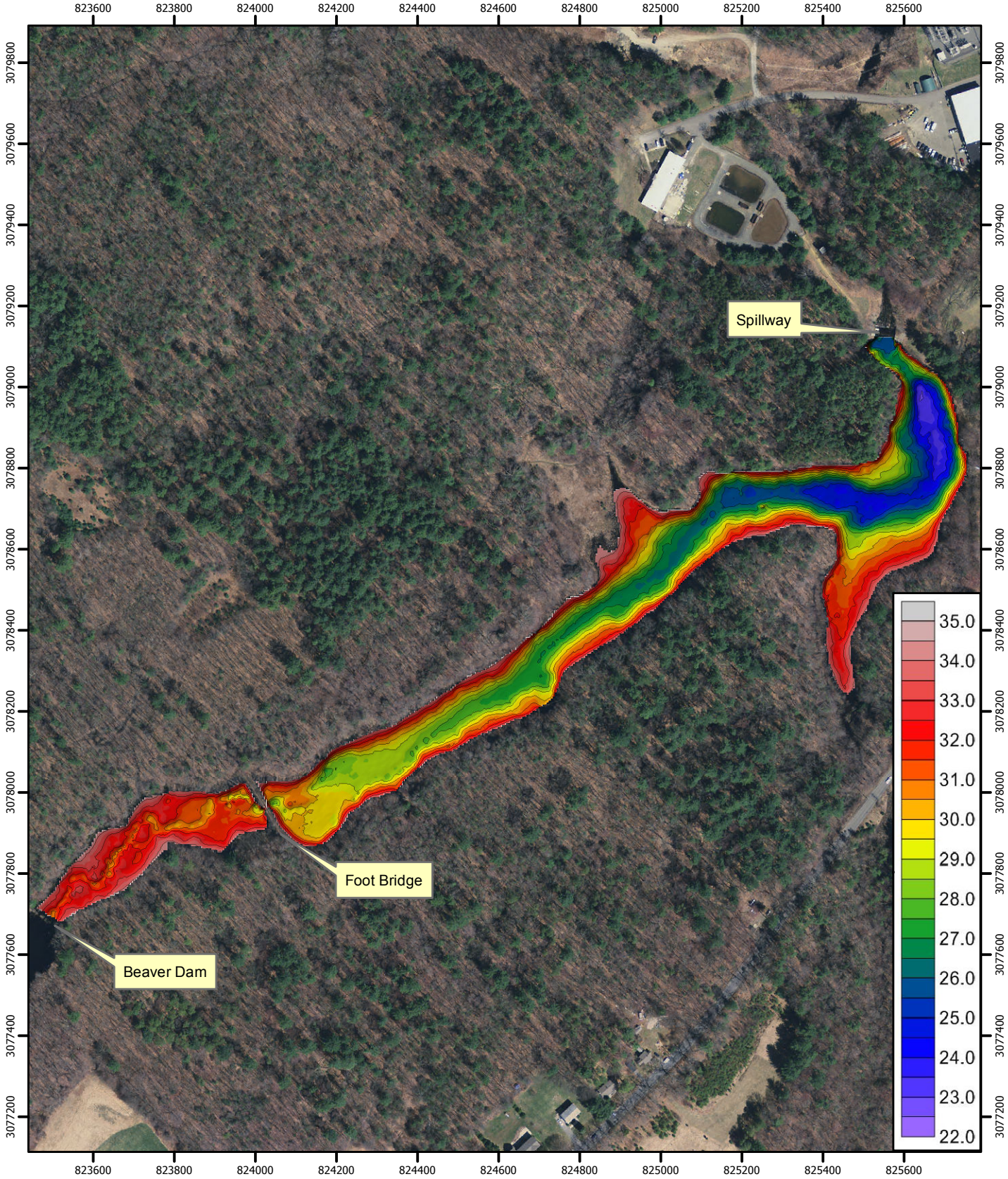
NOTES:
1) Survey conducted April 11, 2018.
2) Grid MA State Plane, NAD 83, US Foot.

Feet
0 200 400

Figure 1

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1.0-Foot NAVD88 Elevations
Ipswich, Massachusetts

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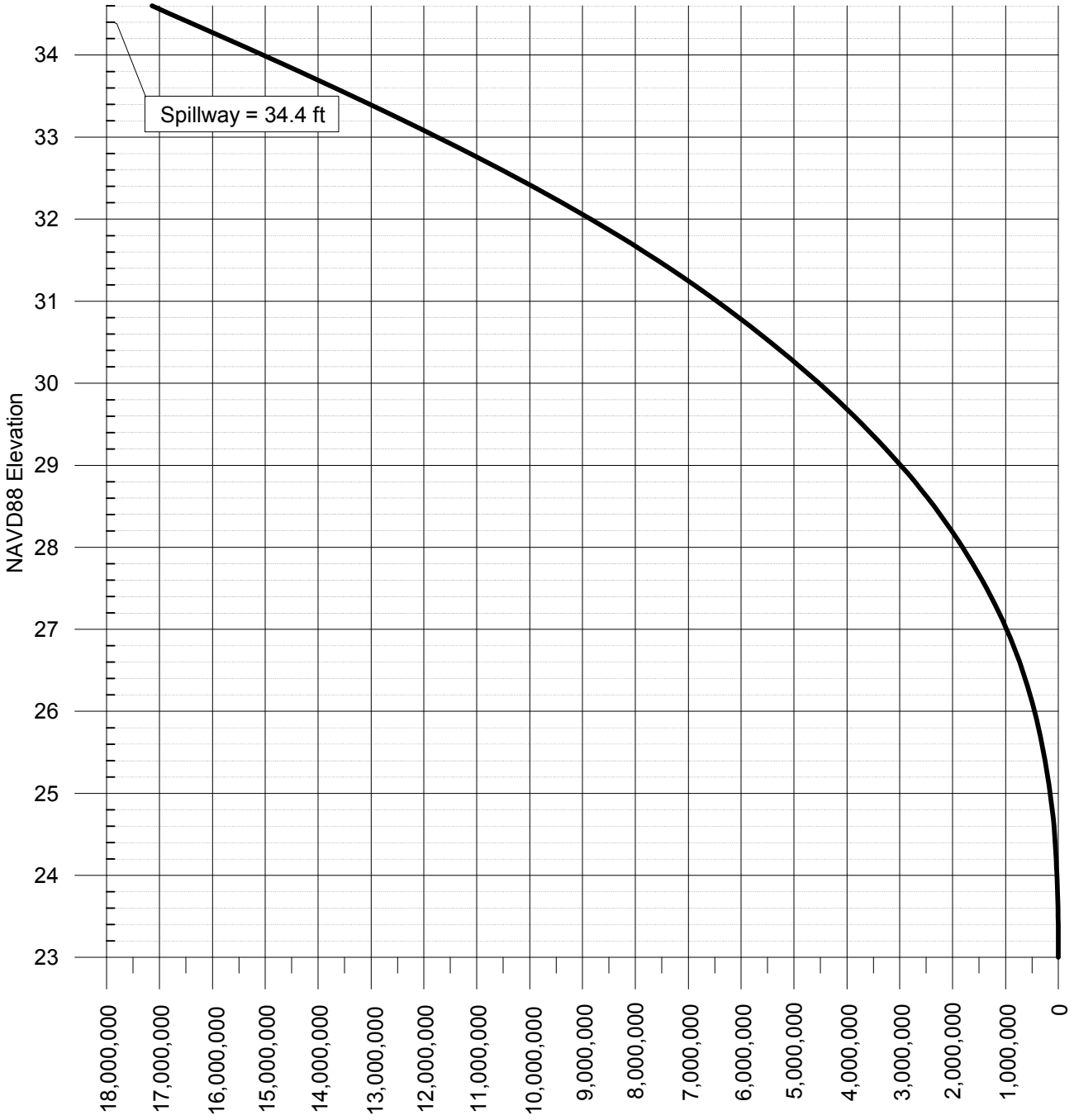
NOTES:
1) Survey conducted April 11, 2018.
2) Grid MA State Plane, NAD 83, US Foot.

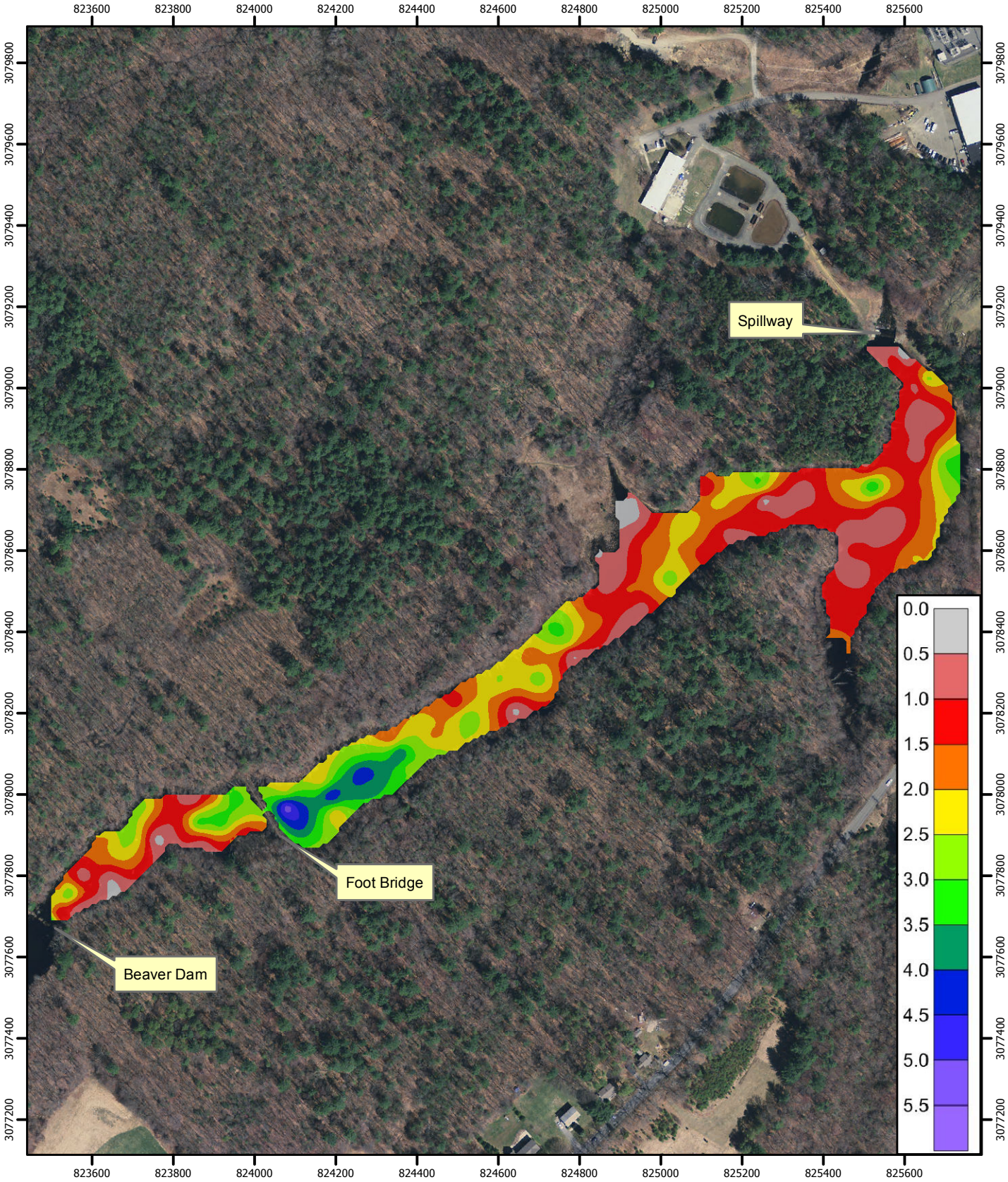
Feet
0 200 400

Figure 2

**FIGURE 3**

**BULL BROOK RESERVOIR CAPACITY CURVE**
**April 11, 2018**



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ESTIMATED SEDIMENT THICKNESS
0.5-Foot Contour Interval
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NOTES:
1) Survey conducted April 11-12, 2018.
2) Grid MA State Plane, NAD 83, US Foot.

Feet
0 200 400

Figure 4