HAGER GEOSCIENCE, INC.

GEOPHYSICAL INVESTIGATION
ARMSTRONG DAM REMOVAL FEASIBILITY STUDY
BRAINTREE, MASSACHUSETTS

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Prepared for:
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EDWOSB CERTIFICATION AWARD
USWCC U.S. Women's Chamber of Commerce
EDWOSB Federal Certified Economically Disadvantaged Women-Owned Small Business

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1.0 INTRODUCTION

This report details the results of a geophysical survey conducted by Hager GeoScience, Inc. (HGI) for Gomez & Sullivan Engineers (GSE) on the Monatiquot River near the Armstrong Dam in Braintree, Massachusetts. The survey was performed to meet the following five objectives:

1. Create a bedrock profile from Armstrong Dam along the main channel to the Washington Street Bridge and locate any crossing utilities.
2. Create a bedrock profile near the upstream face of the Armstrong Dam.
3. Delineate bedrock surface information near the Plain Street, Railroad and Washington Street Bridges.
4. Determine if any previous channels are present west of the current channel.
5. Characterize the sediment west of the current channel.

2.0 DATA ACQUISITION

HGI personnel performed the survey on July 20th and 21st, 2017, using ground penetrating radar (GPR) equipment mounted in a small boat and located by GPS.

HGI collected data as much as possible along the transects of interest laid out on a site image provided by GSE. Only the area west of the Railroad Bridge was inaccessible. The locations of the survey transects are shown on Plate 1, an AutoCAD Map 3D 2016 plot created from the HGI field notes, GPS data, and Bing maps satellite image.

Discussions specific to the geophysical data collection are provided below, while Appendix A contains more general discussions of the techniques and its limitations.

2.1 GPR

All GPR data were acquired from HGI's polypropylene Porte-a-boat. HGI collected GPR data along 11 traverses over a distance of approximately 2,850 linear feet. Each traverse was selected to address one of GSE's survey priorities specified in the scope of work. As noted above, the area west of the Railroad Bridge could not be accessed with HGI's boat.

GPR data were collected using a GSSI SIR-4000 digital acquisition system using both 200- and 100-MHz antennas along the GSE-specified transects. Because a survey wheel could not be used on the water, the GPR data collected in continuous mode, with distances along the traverses determined from GPS measurements. The data were displayed in real time on the system's color monitor while being simultaneously recorded on its hard drive.

The signal-to-noise ratio of the GPR signal was variable throughout the survey areas, but reached a maximum of 10 to 12 feet below the river surface, making it difficult to reliably detect targets below these depths.

Table 1 below shows the pertinent parameters used for the GPR data collection.

Table 1. GPR Survey Acquisition Parameters

Antenna Frequency (MHz)	Range (ns)	Survey Mode	Scan Rate (per sec)	Scan Rate (per ft)	Sample Rate (samples)	Effective Signal Depth (ft)
200	300	Continuous	100	12	512	10-12
100	700	Continuous	46	10	512	30

2.2 GPS

HGI used its Sokkia RTK GNSS GRX2 GPS to locate the survey transects and select surface features for reference. The Sokkia system provided a relative accuracy of less than 0.164 feet horizontally and 0.328 feet vertically for points in the Massachusetts State Plane coordinate system.

3.0 DATA REDUCTION AND ANALYSIS

3.1 GPR

Before the data could be analyzed, significant processing was required to reduce the detrimental effects of site-specific noise associated with interfering background frequency signals, reflections from surface and subsurface structures, and buried debris. The site-specific noise also included boulders embedded within and lying on top of the unconsolidated river sediments.

Distance normalization, band-pass and spatial filters, horizontal smoothing, gain adjustments, migration, and deconvolution were performed as essential processing steps to mitigate the degree of signal attenuation caused by the high concentration of organic matter in the soil and water column.

The processed radargrams were analyzed for the location and depth of reflective horizons possibly relating to the bedrock surface. Irregular features possibly relating to fractures or other internal rock structures were also investigated, as well as features resembling boulders or other possible obstructions.

The GPR reflector boundaries and their depths were recovered from the recorded travel-time data using radar propagation velocities, estimated migration velocity analysis and established material-specific velocity tables. HGI delineated weathered and less weathered bedrock boundaries on the basis of observed structural features (e.g., fracture terminating at the interpreted bedrock horizon).

An Excel database of depth data points was compiled from the selected 200-MHz transects. Travel times were converted to depth using site-specific multi-layered signal velocity values calculated from velocity analysis of GPR data. The database of depth points was used to create 2D GPR interpreted profiles.

4.0 RESULTS

The results of the Armstrong Dam survey are discussed below, correlated to the priority order established by GSE.

Priority 1: Collect GPR data along a longitudinal profile of the main channel from the Railroad Bridge to Armstrong Dam.

A continuous profile was not possible because the river becomes too shallow for boat passage. GPR data were collected from south to north in four segments. GPR Transect 5 covers the area from the Railroad Bridge to south of Plain Street Bridge (Figures 1 & 12). Field observations in this area indicated a cobble- and boulder-dominated river bed. GPR confirmed the field observations, as well as revealing a bedrock valley (85 feet NAVD88) at the river bend. Transect 6 extends under the Plain Street Bridge (Figures 2 & 13). A small bedrock valley is present just before the Plain Street Bridge, which sits on a flat section of bedrock (86.5 feet NAVD88). Weathered bedrock, cobbles and boulders are present above the bedrock (89 feet NAVD88), with bedrock and overburden rising north along the transect away from the bridge. Transect 8 (Figures 3 & 14) follows the main channel toward the launch point in Hollingsworth Pond. Three local bedrock highs are present 60, 305 and 390 feet along the transect. After 390 feet the riverbed sediments appear to become finer, with bedrock depth at 85 feet NAVD88. Transect 15 (Figures 4 & 15) begins near the launch point in the main channel and ends on the eastern portion of Armstrong Dam. Bedrock depth along this transect decreases slightly (to approximately 84 feet NAVD88) before increasing to 86 feet NAVD88 as it approaches Armstrong Dam.

Weathered rock and boulders dominate the upstream section of the river. There is a noticeable change in the river bed bathymetry along Transect 8 after the river bend opens into Hollingsworth Pond.

North of the Plain Street Bridge, HGI located 3 utilities crossing the river (Plate 2). These were at a depth of approximately 91 feet NAVD88.

Priority 2: Map bedrock depth in front of Armstrong Dam.

The Armstrong Dam spillway is visible in Figures 5 and 16. The top of the spillway, at 91 feet NAVD88, is positioned above a local bedrock low. The footing of the spillway appears to be visible, angling out from the top and potentially at 88 feet NAVD88 extending vertically down to bedrock. The local bedrock low of 83 to 84 feet NAVD88 is centered on the spillway, with the bedrock rising from underneath it to both east and west.

Priority 3: Map bedrock around the Plain Street Bridge and Railroad Bridge abutments.

Figures 6, 7, 17 and 18 show the accessible transect areas near the bridge abutments. No direct measurements could be made of the abutments because the water level was too low, and boulders prevented the HGI crew from bringing the boat close to the abutments, so bedrock measurements were made in accessible areas 15 to 20 feet from the bridges.

Priorities 4 and 5: Attempt to characterize the area west of the main channel.

No previous river channel was observed in transects west of the current channel. Approximately two feet of sediment, cobbles and boulders overlie the bedrock west of the channel in some areas (Figure 10). Sediment thickness values for Transects 1, 2, 17 and 18 are shown on Table 1, an Excel database of GPR depth data points compiled from the 100- and 200-MHz surveys and tied to the NAVD88 datum.

At the time of the survey on July 20th and 21st, the river level was approximately 93 feet in the NAVD88 datum. The maximum bedrock depth was 83 to 84 feet NAVD88 directly under the spillway. The general trend of the weathered bedrock/till and bedrock slopes toward the Dam, with a natural local high at the dam. The main channel is in the location suggested by Gomez and Sullivan.

APPENDIX A: THE GEOPHYSICAL METHODS

A.1 Ground Penetrating Radar

A.1.1 Description of the Method. The principle of ground penetrating radar (GPR) is the same as that used by police radar, except that GPR transmits electromagnetic energy into the ground. The energy is reflected back to the surface from interfaces between materials with contrasting electrical (dielectric and conductivity) and physical properties. The greater the contrast between two materials in the subsurface, the stronger the reflection observed on the GPR record. The depth of GPR signal penetration depends on the properties of the subsurface materials and the frequency of the antenna used to collect radar data. The lower the antenna frequency, the greater the signal penetration, but the lower the signal resolution.

GPR data are collected using a Geophysical Survey Systems (GSSI) SIR 20/2000/3000/4000 ground penetrating radar system. GPR data are digitally recorded on the internal hard drive or flash memory of the system. System controls allow the GPR operator to filter out noise, attributed to both coupling noise, caused by conductive soil conditions, spurious noise caused by local EMF fields and internal system noise. For shallow surveys, we use antennas with center frequencies ranging from 200 to 400 megahertz (MHz). For deeper penetration, we use lower frequency antennas ranging from 300 to 15 MHz, depending on the anticipated depth of the target(s) and the degree of signal penetration. All of these antenna configurations can collect data in continuous mode or as discrete point measurements using signal-stacking techniques. Since there is a tradeoff between signal penetration and resolution, the highest frequency antenna that produces the best quality data is used. In some cases, data are collected with several antenna frequencies.

A.1.2 Data Analysis and Interpretation. The horizontal scale of the GPR record shows distance along the survey traverse. In the continuous data collection mode, the horizontal scale on each GPR record is determined by the antenna speed along the surface. When a survey wheel is used, the GPR system records data with a fixed number of traces per unit distance. The GPR record is automatically marked at specified distance intervals along the survey line. The vertical scale of the radar record is determined by the velocity of the transmitted signal and the recording time window or range. The recording time interval, or range, represents the maximum two-way travel time in which data are recorded. The conversion of two-way travel time to depth depends on the propagation velocity of the GPR signal, which is site specific. When little or no information is available about the makeup of subsurface materials, we estimate propagation velocities from handbook values and experience at similar sites or by CDP velocity surveys with a bi-static antenna.

After completion of data collection, the GPR data are transferred to a PC for review and processing using RADAN® 7 software. When appropriate, we prepare 3D models of GPR data, which can be sliced in the X, Y, and Z directions.

The size, shape, and amplitude of GPR reflections are used to interpret GPR data. Objects such as metallic UST's and utilities produce reflections with high amplitude and distinctive hyperbolic shapes. Clay, concrete pipes, boulders and other in-situ features may produce radar signatures of similar shape but lower amplitude. The boundaries between saturated and unsaturated materials such as sand and clay, bedrock and overburden generally also produce strong reflections.

A.1.3 Limitations of the Method. GPR signal penetration is site-specific. It is determined by the dielectric properties of local soil and fill materials. GPR signals propagate well in resistive materials such as sand and gravel; however, soils containing clay, ash- or cinder-laden fill or fill saturated with brackish or otherwise electrically conductive groundwater cause GPR signal attenuation and loss of target resolution. Concrete containing rebar or wire mesh also inhibits signal penetration.

The interpreted depths of objects detected using GPR are based on on-site calibration, handbook values, and/or estimated GPR signal propagation velocities from similar sites. GPR velocities and depth estimates may vary if the medium under investigation or soil water content is not uniform throughout the site.

Utilities are interpreted on the basis of reflections of similar size and depth that exhibit a linear trend; however, GPR cannot unambiguously determine that all such reflectors are related. Fiberglass USTs or utilities composed of plastic or clay may be difficult to detect if situated in soils with similar electromagnetic properties, or if situated in fill with other reflecting targets that generate "clutter" or signal scattering and thus obscure other deeper reflectors. Objects buried beneath reinforced concrete pads or slabs may also be difficult, but possible, to detect.

Changes in the speed at which the GPR antenna is moved along the surface causes slight variations in the horizontal scale of the recorded traverse. Distance interpolation may be performed to minimize the error in interpreted object positions. The variation in the horizontal scale of the GPR record may be controlled, to a certain extent, with a distance encoder or survey wheel. The GPR antenna produces a cone-shaped signal pattern that emanates approximately 45 degrees from horizontal front and back of the antenna. Therefore, buried objects may be detected before the antenna is located directly over them. GPR anomalies may appear larger than actual target dimensions.

GPR interpretation is more subjective than that for other geophysical methods. The interpretive method is based on the identification of reflection patterns that do not uniquely identify a subsurface target. Borings, test pits, site utility plans and other ground-truth are recommended to verify the GPR interpretations.

A.2 RTK GNSS Global Positioning System (GPS)

A.2.1 Description of the Method. The RTK GPS system consists of a base (reference) receiver and a roving receiver. The base receiver remains stationary during a survey and is mounted on a tribrach and tripod. A rover receiver is used to record points remotely and can be mounted on a staff, vehicle, or other object. The base provides real-time corrections to the rover over a radio connection. The system can produce accuracy on a centimeter scale, but the level of accuracy depends on factors that include the geometry of the transmitting satellites and the receivers' view of the horizons. (e.g., the density of buildings and trees). The data can be collected as quickly as 5 Hz or 5 readings per second.

A.2.2 Data Collection and Processing. We perform our GPS surveys using a Sokkia RTK GNSS GRX2. The base station can be set up over a known or unknown point, with the position taken from satellite information. Once the system has achieved a fixed solution for the rover receiver, data points can be collected with survey-grade (centimeter-scale) precision. When GPS points are being collected at a site where the fixed solution is constantly lost and gained, points are checked multiple times for precision. All data points are saved to a Carlson Surveyor 2 field computer.

The GPS data are corrected automatically by the base receiver in the field prior to being recorded. If the base station is located on an unknown point that is later defined, the GPS data can be corrected in the office to fit the real world coordinates.

A.2.3 Limitations of the Method. The quality of the GPS signal is site-specific. The base and rover receiver need to have clear views of the horizon and good satellite geometry to achieve the highest level of accuracy and precision. Although a fixed solution can be achieved in wooded environments or sites with taller buildings, it may take more time to achieve the solutions, the fixed solution may be lost frequently when moving the rover, and in some cases the fixed solution may be wrong. Each of these situations requires longer to locate data points accurately and precisely. When the point is too close to a building, beneath a building overhang, under a tree, or obscured by some other object, a fixed solution may not be possible.

When the base station is set up over an unknown point, the survey data location can be at least several tens of meters from the real world location. The data points will have survey grade precision relative to the location of the base station and other data points, but will have a real world accuracy discrepancy.

HGI does not guarantee to produce a surveyor-quality map from its GPS data, as this is not its profession. If survey-level accuracy is critical for a project, we recommend hiring professional surveyors for that purpose.