HIGH RESOLUTION MAPPING OF INSTREAM HABITAT

PILOT STUDY USING GROUND BASED LIDAR IN LOGAN RIVER WATERSHED

Final Report to USFS under Challenge Cost Share Agreement between Utah State University and US Forest Service: FS Agreement No. 09-CS-13000018853911

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EXECUTIVE SUMMARY

New technologies are emerging that enable researchers to measure physical environments and habitats at increasingly fine scales and over wide extents. Measurement of physical conditions at fine scales contributes to the understanding of how organisms use their environment. Most importantly, measurement can now take place at the scale individual organisms actually utilize their habitat allowing for the understanding of subtle differences in mechanistic habitat use. The technologies of ground-based LiDAR (AKA terrestrial laser scanning – TLS), Total Station (TS), and rtkGPS have been used to measure the in-stream and riparian environments of Spawn Creek and Right Hand Fork in the Logan River watershed in north eastern Utah.

In Spawn Creek, these technologies have been used to acquire high resolution topographic data over a 2500 m reach beginning at its confluence with Temple Fork. Data was gathered in the field and converted to a UTM12 coordinate system using established ground control coordinates. The combination of Total Station, rtkGPS, and ground based LiDAR have been used to create models of bathymetry and topography. This data has the potential to be further used in one and two dimensional flow models and geomorphic change detection. It can also be used to classify microhabitats used by organisms through the evaluation of metrics such as stream width, channel slope, water surface slope, cover elements, and valley constriction.

In Right Hand Fork, similar data was gathered over a 300 m section composed of a significant beaver complex. Data in this stream was again used to create models of bathymetry and topography. In this complex environment, these models not only allow for flow modeling and change detection, but enhance our understanding of how beavers engineer their environment. Metrics such as dam height, dam length, difference in water surface elevations, and the presence or absence of side channels can all be derived from these datasets to help quantitatively characterize beaver habitats. These metrics also allow for further study into how beaver altered environments affect in-stream fauna. Change detection in beaver engineered environments also provides a before and after picture of beaver occupation or abandonment of a site.

Future work with this spatial data includes its incorporation into a study on the differences in habitat use between native Bonneville cutthroat trout and invasive brown trout and brook trout. The fine scale of the data creates the opportunity to evaluate habitat use of these three species at a microhabitat level. The data will also be used to evaluate beaver dam effects on the movements of these species and whether beaver dams facilitate species segregation.
INTRODUCTION

The US Forest Service’s plan and project decisions often rely on accurate and precise descriptions of landscape features. The technologies used to collect these data are rapidly evolving (Fonstad and Marcus, 2010; Lane and Chandler, 2003). Currently, most remote sensing data are airborne and are acquired at too coarse a resolution to be useful for all decisions (Bangen et al., 2010). By contrast, much of the data traditionally collected by ground-based crews consists of the simple measurement of attributes at a sample of locations within a stream reach or cross-section (e.g. Heitke et al., 2010). Such data is coarser in resolution with an isolated extent and may not represent an entire stream system. Fine-scale ground-based measurements and analyses are needed to fully understand the processes affecting landforms and organisms in these small systems. Fine scale measurement also provides the ability to analyze systems at a scale relevant to individual organisms (Rice et al., 2010). Where traditional methods have been able to resolve habitat units at the reach scale, fine scale measurements have the capability to reveal patterns at the microhabitat scale. New remote sensing technologies are now emerging such as ground-based LiDaR and rtkGPS (Heritage and Hetherington, 2007; Hodge et al., 2009; Milan et al., 2007; U.S. Geological Survey, 2006), which permit fine-scale census of stream habitats. The amount of data and the detail of that data using ground-based remote sensing have the potential to evaluate aquatic systems at a scale providing more in depth knowledge of the physical environment and processes in aquatic environments.
The purpose of this report is to summarize the data collected as part of a cooperative agreement between the US Forest Service (USFS) Rocky Mountain Research Station (RMRS) and Utah State University’s (USU) Ecogeomorphology and Topographic Analysis Lab (ET-AL), and explain how such data will be used to evaluate these technologies for characterizing in-stream habitat. The purpose of the project was to collect data using ground-based LiDaR that could be compared against traditional habitat sampling approaches. This data is being used in ongoing studies and a masters research project (by the first author) to derive multi-scalar stream attributes and reveal what exactly can be derived from these different field methods. This data was leveraged in an NSF NCALM (National Center for Airborne Laser Mapping) seed grant proposal, which was awarded. In the summer of 2011, an airborne LiDaR flight will be flown by NCALM, so that all three monitoring methodologies can be directly compared (i.e. airborne LiDaR, ground-based surveys (including TLS, TS & GPS), vs. traditional habitat sampling (i.e. tape & level)). These data are important to the USFS because we can use their inter-comparison to provide guidance on approaches for monitoring habitat that can be used in specific situations.

Figure 1 - Components of a Ground-Based LiDaR field setup for a stream survey. Example here shown for a bedrock river using a Leica ScanStation 2 Terrestrial Laser Scanner.
STUDY SITES – LOGAN RIVER WATERSHED

The Logan River Watershed, located in the Uintah-Wasatch Cache National Forest of Utah, was selected for study sites due to logistical convenience and to maximize the utility of the data collected for supporting other ongoing research projects in the basin underway between the RMRS, USU and the Utah Division of Wildlife Resources (Figure 2).

Figure 2 – Study Site Vicinity (A) and Location maps (B & C). The two study reaches were located on Right Hand Fork and Spawn Creek.

We initially planned on surveying 20 short (i.e. < 200 m long reaches) spread throughout the watershed, but later decided to focus our efforts on two areas of larger extent and that spanned a range of challenges typically present in the monitoring of small streams. Spawn Creek, a tributary to Temple Fork within the Logan River Watershed, was chosen because it is the focus of ongoing research by USU and RMRS as well as being the site of large scale stream restoration effort through cattle exclosure fencing. The study area at Spawn Creek included a 2500 m portion with a large beaver complex in its upper reach. A major beaver dam complex at Right Hand Fork was also selected for its roadside accessibility and in-stream habitat complexity created by beavers (a logistical challenge in traditional stream habitat monitoring due to multiple channels and complex geometry). The study site at Right Hand Fork consisted of a 300 m reach containing a multiple channel network with at least five beaver dams.

SPAWN CREEK STUDY REACH

Spawn Creek is a tributary of Temple Fork which is a left-bank tributary the Logan River in north eastern Utah (Figure 3). It flows through a mountainous valley with a mix of sagebrush and aspen cover (Figure 4) and basin relief of 500 m spanning an elevation range of 1800 m to 2300 m. Most of the Spawn Creek study reach is
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relatively steep (average slope of 0.065) and could be characterized as a step-pool habitat using the Montgomery and Buffington (1998) classification. There are some shorter reaches with lower stream gradient interspersed, where the stream might be characterized pool-riffle. The annual hydrograph of Spawn Creek consists of high flows dominated by spring snow melt and stable base flows fed by springs (Siedel 2009). Land use practices from cattle grazing have affected the quality of in-stream habitat up until 2006 when an exclosure fence was built to protect over 3 km of riparian area. The exclosure was designed to protect spawning habitats of the native Bonneville cutthroat trout (*Oncorhynchus clarki Utah*). Beavers have also constructed numerous dams along in the upper reaches of Spawn Creek (Figure 5). The heterogeneous in-stream environment in Spawn Creek supports the physical and biological needs of Bonneville cutthroat trout, brown trout (*Salmo trutta*), and brook trout (*Salvelinus fontinalis*). Cutthroat and brown trout are normally found throughout the Spawn Creek while brook trout stay in the upper reaches, primarily in beaver ponds.

![Figure 3](image)

**Figure 3** – A) Location of Spawn Creek Study Reach within Temple Fork Watershed overlaid on hillshade derived from 30m USGS DEM. B) Survey extents of 2.1 km study reach overlaid on 2006 high resolution orthophoto from Utah GIS Portal.
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Figure 4 – Photographs looking upstream at Spawn Creek in middle of study reach.
RIGHT HAND FORK STUDY REACH

The Right Hand Fork watershed is also a left-bank tributary to the Logan River, but enters some 10 km downstream from the Temple Fork Confluence. This reach is similar in gradient to Spawn Creek. The relief in the Right Hand Fork watershed is 500 m and covers an elevation range of 1600 m to 2100 m. The study reach is located in the lower quarter of Right Hand Fork about 3 km upstream from the Logan River confluence at an elevation of approximately 1670 m (Figure 6). Pool-riffle sequences are more common in Right Hand Fork while step-pools are present but less frequent than in Spawn Creek. The study reach itself consists of an extensive beaver dam complex. The site was chosen because of the challenges it presents from a stream habitat monitoring perspective. At least 16 dams create and highly heterogeneous in-stream environment consisting of long, slow ponds, plunge pools, and riffles, all in multiple channels (Figures 7 & 8). Some of the dams span small channels and are only a few meters long, whereas four of the dams span at least 25% of the valley bottom and range in approximate length of 2 meters to 50 meters. While efforts to reintroduce native Bonneville cutthroat trout have taken place, this reach of Right Hand Fork primarily consists of invasive brown trout.
Figure 6 – A) Location of Right Hand Fork Study Reach within Right Hand Fork Watershed overlaid on hillshade derived from 30m USGS DEM. B) Survey extents of study area covering a large persistent beaver dam complex overlaid on 2006 high resolution orthophoto from Utah GIS Portal.
Figure 7– Upper portion of Right Hand Fork study reach in summer. Beaver dam complex is somewhat obscured by thick riparian vegetation and extends upstream and downstream throughout entire length of riparian corridor shown in photo (note areas of open water).

Figure 8 – Lower portion of Right Hand Fork study reach, showing beaver dam complex (note areas of open water) & extensive riparian vegetation in early spring.
METHODS

FIELD DATA ACQUISITION

SURVEY CONTROL

Ground survey control networks were established at Spawn Creek and Right Hand Fork to facilitate resurvey work and change detection analyses. Additionally, at Spawn Creek, GPS was used to position all survey data appropriately so that it would overlay reasonably accurately in GIS with other existing datasets. All spatial data in Spawn Creek has been projected into the UTM Zone 12N, NAD 1983 projection. The data from Right Hand Fork remains in an assumed local coordinate system.

Primary benchmarks consisting of ½” rebar and stamped red plastic caps were strategically placed to be physically stable, to maximize satellite visibility for GPS occupation, to be inter-visible for total station utilization and to be conveniently located. Control point locations were positioned to provide good lines of sight and coverage for total station and TLS setups and inter-visibility to at least two other control points to accommodate traversing.

At Spawn Creek, a Leica 1200 GPS base station with Pacific Crest radio (for transmitting real-time kinematic (RTK) differential corrections to the rover) was established over CP101 near the confluence of Spawn Creek and Temple Fork to collect RTK data. A simple ‘here’ fix in WGS84 was used initially to define the location of the base station. The base station was set to log observations for the entire duration of the survey. A Leica 1200 GPS rover operating in RTK mode was used to occupy as many benchmarks as possible. A Leica 1203+ Total Station was used to traverse through the benchmarks and in both systems.

BATHYMETRY

1 See post-processing section.
Bathymetry (topography beneath the water’s surface) was collected using a Leica 1203+ Total Station in both Spawn Creek and Right Hand Fork. In Right Hand Fork a total station was used because of the extensive riparian vegetation and confined valley setting which could have led to multipath errors. An rtkGPS would have worked well for 80% of Spawn Creek, but a total station would be necessary for particular segments and was required for the TLS survey. As such, the Spawn Creek Survey was also conducted with a total station. An extendible 4 meter high rod was helpful in allowing an expanded line-of-sight range in areas of thick riparian vegetation. The prism could be raised above the height of much of the riparian vegetation to allow measurement from the total station. The bathymetric surveys were conducted to capture the major grade breaks and geomorphic units (e.g. pools, bars, etc.) within the channel. Point spacing was semi-regular (1 point every 1-2 meters) feature-based morphologically stratified sampling scheme (Bouwes et al., 2011; Wheaton, 2008). Point densities varied spatially with higher point densities (e.g. 2-3 points/m²) in topographically complex areas and lower point densities in topographically simple areas (e.g. Figure 10). An average point density\(^2\) of 1.43 points/m² was achieved for Spawn Creek and an average point density of 0.78 points/m² for the Right Hand Fork beaver dam complex.

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\(^2\)Ground-based surveys in most wadeable rivers and streams adequately represent the topography when average point densities are in the 0.2 to 0.5 points/m² range. High point densities for such surveys are typically those in excess of 1 points/m².
Figure 10 – Example of topographically stratified semi-regular point sampling scheme used to survey bathymetry. A) Bathymetry point locations in a middle reach of Spawn Creek overlaid on aerial photography. B) The distribution of bathymetry points over the Spawn Creek study area. C) Bathymetry point locations in an upper reach of Spawn Creek.
TOPOGRAPHY

A Leica ScanStation2 terrestrial laser scanner (TLS; AKA ground-based LiDAR) was used to acquire topographic data of everything above the water surface in the vicinity of the reaches and provide some valley context topography. A TLS was used instead of a GPS or total station for a variety of reasons. First, the TLS has a point acquisition rate of between 1000 and 50,000 points per second (a fast surveyor can acquire 1 point every 3-5 seconds with a GPS or Total Station). Thus, with the same level of effort, 2-3 orders of magnitude more data can be acquired. Secondly, TLS is an emerging technology in the fluvial sciences and presents new opportunities for characterizing complex landforms, habitats and vegetation at sub-centimeter resolutions over entire reaches (Heritage and Hetherington, 2007; Heritage and Large, 2009; Hodge et al., Submitted). The methods for analyzing these volumes of data and point clouds are an area of active research and are likely to mature over the next five years. Thirdly, given the high accuracy and precision of the point cloud data, they can facilitate exceptionally low minimum levels of detection in change detection analyses. Finally, riparian vegetation, beaver dams, large woody debris and debris jams are extremely difficult to measure and characterize with traditional ground-based survey techniques like GPS and TS and cannot typically be resolved from remotely sensed airborne or satellite data. As such, TLS provides a unique opportunity to directly record and precisely measure the physical state of the features that are planned to be used in the restoration experiments. An average point density of 1700 points/m² was achieved for Spawn Creek and an average point density of 1625 points/m² for the Right Hand Fork beaver dam complex.

Figure 11 (right) - A setup of the Scanstation 2 ground based LiDAR in Spawn Creek

TLS surveys suffer from the same line-of-sight problems that total station surveys do. In some respects, TLS surveys have greater limitations because a survey rod cannot be used to get above obstacles in the foreground. Thus, in areas of thick vegetation shadows or blank areas of data are frequently encountered due to line of sight
limitations. These shadows can be filled in by scanning from different set up positions that provide different perspectives of a common survey area. For ‘complete’ coverage, generally more TLS setups are required, then to get ‘complete’ coverage with a total station survey. The Leica ScanStation 2 is a time-of-flight instrument that provides coordinate and intensity measurements for a single return (unlike airborne instruments, which collect a full waveform). This simplifies the post-processing of data and provides very reliable measurements. Scanning water from a land based instrument with a light-wave provides for a high degree of uncertainty for the collected return. The variable surface of water, angle of incidence, water density and particulate matter encountered make the path of the light wave unpredictable and thus the time of flight uncertain. It can provide returns off the water surface, but cannot reliably survey bathymetry (hence the GPS and total station surveys of bathymetry). Despite these limitations, TLS surveys can still be used to characterize instream habitat in small streams, by using water surface topography and partially submerged roughness elements (e.g. boulders, woody debris, vegetation; Heritage and Large, 2009).

At Right Hand Fork nine TLS instrument set-ups were undertaken to provide a complete coverage of the reach (Table 1). At Spawn Creek, over 60 instrument set-ups were required to cover the whole system. Each instrument setup was over a known control point (the same control points described above and used in the total station survey). The instrument was run in a traverse mode, which allowed the automatic registration of the scans from each setup together into a common point cloud, which was later geo-referenced. TLS data included 9.9 million points for Right Hand Fork and over 909 million points at Spawn Creek.

The table below summarizes the number of points surveyed at each reach, average point densities, and number of set-ups.

<table>
<thead>
<tr>
<th>Reach</th>
<th>Spawn Creek</th>
<th>RHF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Points</td>
<td>10,252</td>
<td>5073</td>
</tr>
<tr>
<td>Avg Points Density (pt/sq m)</td>
<td>1.43</td>
<td>0.787</td>
</tr>
<tr>
<td>Area Surveyed (sq m)</td>
<td>7135</td>
<td>6448</td>
</tr>
<tr>
<td>Number of Setups</td>
<td>60</td>
<td>9</td>
</tr>
<tr>
<td>Number of Points Scanned (Millions)</td>
<td>909</td>
<td>99</td>
</tr>
<tr>
<td>Avg Points Density (pt/sq m)</td>
<td>1700</td>
<td>1625</td>
</tr>
<tr>
<td>Number of Points in selected corridor after 0.1m decimation</td>
<td>15,649,200</td>
<td>-</td>
</tr>
<tr>
<td>Number of Points in selected corridor after 3m decimation</td>
<td>11,863</td>
<td>-</td>
</tr>
<tr>
<td>Number of Points in selected corridor 0.25m decimation</td>
<td>-</td>
<td>152,000</td>
</tr>
<tr>
<td>Number of Points in selected corridor after 3m decimation</td>
<td>-</td>
<td>1721</td>
</tr>
<tr>
<td>Number of Setups</td>
<td>83</td>
<td>7</td>
</tr>
<tr>
<td>Area of corridor Surveyed (sq m)</td>
<td>156,492</td>
<td>25,408</td>
</tr>
<tr>
<td>Number of Control points set</td>
<td>82</td>
<td>7</td>
</tr>
</tbody>
</table>

Table 1 – Summary of Surveys
POST PROCESSING

CONTROL

For Spawn Creek, GPS and total station data was post-processed in LGO (Leica Geomatics Office). The control survey data was transformed to a common coordinate system (UTM Zone 12N, NAD 1983 projection) using a correction from the National Geodetic Survey Online Positioning User Service (http://www.ngs.noaa.gov/OPUS/). The adjusted control was used to transform all the survey data in LGO. At Right Hand Fork, the data remains in an assumed local Cartesian coordinate system. The control network coordinates have been exported to an ASCII format (*.csv files) and should be used in future monitoring. In the future, the Right Hand Fork data, could also be transformed to UTM if the established control were recovered and occupied with rtkGPS.

BATHYMETRY

Bathymetric data for this project was post-processed in LGO and consists entirely of total station points. The data was checked for any obvious blunders or busts. The topographic data points were separated from the control points and exported from LGO in an ASCII format, which can be used to construct TINs and digital elevation models. At Right Hand Fork 5,073 bathymetry points were surveyed with an average point density of 0.78 points/m² over an area of 6,448 square meters (Figure 12). The Spawn Creek data consisted of 10,252 bathymetry points and was surveyed with an average point density of 1.43 points/m² over an area of 7135 square meters (Figure 13).

Figure 12 –Bathymetric 10 cm DEM of Right Hand Fork in an assumed coordinate system
Figure 13 - A) A Digital Elevation Model (DEM) created from total station bathymetry data only in an upper reach of Spawn Creek. B) The extent of DEM bathymetry in Spawn Creek. C) A Digital Elevation Model (DEM) in a middle reach of Spawn Creek.
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**TLS TOPOGRAPHY, TERRAIN AND FEATURES**

The TLS post-processing was completed in Leica’s Cyclone software. At Spawn Creek 909 million TLS points were collected, whereas at Right Hand Fork 99 million points were acquired. All scans in each reach were registered to a common assumed local coordinate system and then transformed onto the same coordinate system to match the control and bathymetry data (i.e. UTM Zone 12N, NAD 1983 projection for Spawn Creek; assumed for Right Hand Fork). Noise in the scan data was manually filtered to remove vehicles, people, survey equipment and other features that do not represent the landscape. Key plans were produced in Cyclone to easily visualize the survey workflow and datasets. A free Cyclone viewer has been provided with this data (see Cyclone folder), so that the databases (*.imp files) can be loaded and viewed. Due to large file sizes of the TLS databases (e.g. 10 to 100 GB), they should only be viewed with a computer with adequate free disc space, RAM, CPU and graphics card (i.e. min 4GB RAM).

**DATA REDUCTION**

To construct bare-earth DEMs from hybrid data sources (e.g. scan data and total station data) requires a high degree of post processing. Both manual and automated methods are available. Manual methods require going through point cloud data and distinguishing between ground points and vegetation points. As over 1 billion points were collected, automated methods are preferable. Automated decimation attempts to differentiate shots of the ground from those of vegetation. Minimum elevations in a vegetated area are a reasonable approximation of the ground surface, but will generally over-estimate ground elevations. Filtering techniques used for scan data are analogous to those used for airborne LiDAR data. An example of the decimation output is below.

To facilitate use of the point cloud data outside of the Cyclone software steps to reduce file size were implemented. High interest corridors were selected and data outside these corridors were not exported. Additionally the Spawn Creek data was segmented into smaller data sets. The point clouds were exported for each data set into a *.pts format, which is a generic ASCII point cloud format.

Further reduction is required for use in GIS and CAD applications. A point-cloud decimation algorithm was utilized to reduce the point clouds from an average of 1600 points/m² down to 1 point per 0.1 m x 0.1 m cell (i.e. 100 points/m²) and down to 1 point per 3 m x 3 m cell (i.e. 0.11 points/m²; e.g. figure 14). These are data densities that standard CAD and GIS packages may handle for digital terrain and elevation modeling. The decimation algorithm produces a variety of outputs:

- At the center of each cell: minimum elevation, maximum elevation, mean elevation, elevation range, standard deviation of elevation, detrended (for local slope) standard deviation of elevation, detrended mean elevation, and a point count (i.e. point density)
- It also exports the coordinate value (x,y,z) of the absolute minimum elevation point and absolute maximum elevation point
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Example of *_zmin.txt file from decimation:

- \(x, y, z_{\text{min}}\)
  - 453191.469, 4631857.500, 1894.680
  - 453191.719, 4631857.500, 1894.685
  - 453191.781, 4631857.500, 1894.573
  - 453192.281, 4631858.000, 1894.634

Example of *_zstat.txt file from decimation:

- \(x, y, z_{\text{mean}}, z_{\text{max}}, z_{\text{min}}, \text{range}, \text{stdev}, \text{stdev detrended}, z_{\text{mean detrended}}, n\)
  - 453227.719, 4631830.000, 1899.992, 1901.883, 1896.017, 5.866, 1.547, 1.557, 3.144, 45
  - 453227.719, 4631830.500, 1896.870, 1903.139, 1895.933, 7.206, 1.194, 1.852, 2.495, 499
  - 453227.719, 4631831.000, 1897.877, 1903.213, 1895.837, 7.376, 2.026, 2.023, 4.023, 132
  - 453227.719, 4631831.500, 1898.633, 1902.303, 1895.770, 6.532, 2.144, 2.165, 4.210, 66

![Figure 14](image)

**Figure 14** - Point Cloud decimated at 10 cm in a middle reach of Spawn Creek.

*Note: scan data removed outside of high priority corridor and from bathymetry.*

Each of these outputs can be used to produce surface models. For example, the elevation range is a good indication of vegetation heights, the maximum can be a good model of the tree canopy and can be used to make a terrain model (analogous to first return from airborne LiDaR), and the minimum can be a reasonable approximation of a bare earth topography where shots are penetrating through the canopy. It should be noted that penetration through the canopy from TLS data is not as good as airborne LiDaR due to the ground perspective of the scanner (i.e. low oblique angles). To acquire accurate bare earth models in dense riparian areas with TLS data requires many extra ground setups and a tremendous effort in post processing. For example, the decimation algorithm described above can perform more reliably in densely vegetated areas when some of the vegetation is manually filtered initially (i.e. ‘virtual mowing’; e.g. Figure 15).
PRELIMINARY BARE-EARTH DEMS

At Spawn Creek 909 million TLS points were collected, the point-cloud decimation algorithm was used to create a 10-cm resolution data set (15,649,200 points) and a 3 m resolution data set (18,635 points) then combined with 10252 bathymetry points to derive bare-earth TINs and DEMs. Combining of the data is accomplished after segregating the wetted channel from the rest of the data. A boundary of the wetted channel was digitized from the outline of the total station bathymetry points. Within this boundary all TLS points were discarded and only the total station bathymetry points were utilized. An example of bare-earth DEM derived using 3m decimated TLS data combined with TS bathymetry is available in figure 16.
At Right Hand Fork, 991 million TLS points were collected, the point-cloud decimation algorithm was used to create a 10-cm resolution data set (152,000 points) and a 3 m resolution data set (1721 points). Combining the 10 cm decimated data and 5073 bathymetry points, one can derive a bare-earth TINs and DEMs as in Figure 17.

Figure 16 – Bare earth DEM derived from 3 m decimated TLS data in a middle reach of Spawn Creek.

Figure 17 – Combined 10 cm DEM of Right Hand Fork derived from TLS and TS.
HABITAT VIEWS

One of the potential advantages of TLS data is its ability to acquire habitat features and elements in exceptional detail. For example, in Figure 18, we show a raw point cloud of some wood forming part of a beaver dam. Direct measurements of lengths, diameters and volumes of the wood can be made from such data. Additionally, although the bathymetric returns from TLS data are generally unreliable, the upper (or max elevation) returns in areas of water can provide reliable water surface topography as shown in Figures 19 and 20.

Figure 18 - Cyclone screenshot and accompanying photo of wood associated with a beaver dam. Cyclone screenshot depicts example of the multitude of data collected to offer measurement of physical conditions at fine scales. In the TLS data on the left, along a 0.086 meter line this log has 21 data points.

Figure 19 - Cyclone screenshot of a point cloud paired with a photo at the same location on Spawn Creek.
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**DELIVERABLES**

The deliverables from this cooperative include TLS raw point cloud data in *.imp format, decimated TLS point cloud data in *.pts format, TS bathymetry and topography in *.pts format, and various GIS derived layers such as bare earth and bathymetric DEMs. The raw data deliverables are available in a digital format and organized as follows (each group is organized into subfolders by reach):

<table>
<thead>
<tr>
<th>Path</th>
<th>File(s) or Extensions</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data\GIS_Data</td>
<td></td>
<td>-GIS shapefiles of TS points and Decimated Points for Spawn Creek and Right Hand Fork</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-GIS TIFF files of Bathymetric DEMs and Combined Bare Earth DEMs for Spawn Creek and Right Hand Fork</td>
</tr>
<tr>
<td>Data\Spawn_TLS\SpawnCreek*</td>
<td>*.imp</td>
<td>Processed TLS data (point clouds); can be viewed in free Cyclone viewer available from: <a href="http://hds.leica-geosystems.com/en/Leica-Cyclone_6515.htm">http://hds.leica-geosystems.com/en/Leica-Cyclone_6515.htm</a></td>
</tr>
<tr>
<td>Data\Spawn_TLS\SpawnCreek\ExportUTM</td>
<td>*.pts</td>
<td>Exported point cloud data in an ascii format</td>
</tr>
<tr>
<td>Data\Spawn_TLS\SpawnCreek 1\ExportUTM\Decimated_1</td>
<td>*.txt</td>
<td>These are decimated TLS point clouds and statistical filters for building bare-earth, vegetation, roughness, point density and summary surfaces in GIS (e.g. ArcGIS); Data in comma delimited ascii format and decimated to 10 cm, 25 cm and 3 m resolutions</td>
</tr>
<tr>
<td>Data\Spawn_TS_GPS</td>
<td>**_Control.csv</td>
<td>Ascii text file of control points</td>
</tr>
<tr>
<td>Data\Spawn_TS_GPS</td>
<td>**_Topo.csv</td>
<td>Ascii text file of bathymetry data</td>
</tr>
<tr>
<td>Cyclone\</td>
<td>*.exe</td>
<td>Installation file for Leica Cyclone Viewer software for visualizing TLS point cloud data</td>
</tr>
</tbody>
</table>
**SUMMARY & FUTURE WORK**

The data presented in this report summarize the first step in being able to better characterize and study instream habitat for fish and beaver. As both the data acquisition and post processing are covered here, this dataset is available to others for future research. In due course, the data will also be disseminated on OpenTopography.org’s data portal. This data is actively being used as part of the long-term monitoring of the restoration program at Spawn Creek, to support research into micro-habitat utilization of trout by a masters student, and an ongoing beaver monitoring program throughout the Logan River watershed by ET-AL. The data also serves as an excellent baseline for future change detection monitoring through repeat surveys. This summer, NCALM will fly LiDAR of the entire Temple Fork (including Spawn Creek) watershed. This and future data collected will also be disseminated on OpenTopography. As the data from these efforts goes to inform research and studies are completed, they will be published and disseminated in the peer review literature.

For any change detection monitoring, we recommend that similar field protocols to those described here be employed. We hope that the data collected here to better characterize the physical environment will be useful in making linkages to habitat utilization. For example, the ongoing masters study of microhabitat utilization of Bonneville cutthroat trout, brown trout, and brook trout in the Temple Fork watershed is using passive integrated transponder tags in these fish has created the ability to track their movements and look at habitat use over time. Preliminary data has shown that species segregation takes place between the three trout species. LiDAR, rtkGPS, and Total Station data will contribute to this research by providing microhabitat information at known habitat utilization areas. This data can be used to extract physical measurements of the environment such as slope, stream width, bank heights, and areas of refugia. Subtle differences in these metrics between species will provide a more complete picture of the physical environments used by these fish.
REFERENCES


High Resolution Mapping of Instream Habitat