METHODOLOGICAL INTERCOMPARISON OF TOPOGRAPHIC & AERIAL PHOTOGRAPHIC HABITAT SURVEY TECHNIQUES

STUDY IN LEMHI RIVER WATERSHED FOR ECO LOGICAL RESEARCH, INC.

Draft Annual Report to Eco Logical Research, Inc.

UtahStateUniversity
ECOGEOMORPHOLOGY & TOPOGRAPHIC ANALYSIS LABORATORY

Prepared by:

SARA BANGEN, *Graduate Research Assistant*

JOSEPH M. WHEATON, *Assistant Professor*

KENNY DEMEURICHY, *Surveyor and Terrestrial Laser Scanning Analyst*

Ecogeomorphology & Topographic Analysis Lab
Watershed Sciences Department
Utah State University
5210 Old Main Hill
Logan, UT 84322-5310

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EXECUTIVE SUMMARY

The Columbia River Basin was once home to one of the world's most productive anadromous salmonid fisheries. Anthropogenic effects of over-fishing and dam building in the basin to support hydro-electric power, flood control, commercial shipping, and expansive irrigation systems have negatively impacted stocks over the last century. Current populations, including wild and hatchery broods, have been estimated at 10% of historic runs. As a result of the Northwest Power Act and subsequent National Oceanic and Atmospheric Administration (NOAA) biological opinions, the Bonneville Power Administration (BPA) Fish and Wildlife Program (FWP) mitigates impacts from hydroelectric dams in the Columbia River Basin for ESA-listed salmon and steelhead populations and other species of special concern. The BPA FWP mitigation budget for Fiscal Year 2011 is estimated at $236 million with money dispersed to monitoring, restoration and conservation projects headed by federal, state, and tribal agencies as well as private contractors. With such extensive economic resources invested in mitigation, questions have arose as to which monitoring sampling strategies are most tractable at the scale of the Columbia River basin and result in datasets that allow researchers to answer meaningful questions about salmonid populations and their habitat. As a directive to answer such questions, the NOAA Integrated Status and Effectiveness Monitoring Program (ISEMP) was initiated in 2003 to develop and test strategies for determining the status and trend of salmonid populations and their stream habitat in the Columbia River basin. Currently ISEMP conducts research in four experimental watersheds (Entiat, Bridge Creek, South Fork Salmon, Lemhi) nested within three intensively monitored watersheds (Wenatchee, John Day and Salmon River).

This report is a synthesis of a study intercomparing the merits of various remotely-sensed and ground-based instream salmonid habitat survey techniques conducted in the Lemhi River basin during the summer of 2010. The project explores how viable remote-sensing and ground-based survey technologies are for characterizing instream habitat at the scale of large watersheds. Seven sample reaches of varying habitat complexity were surveyed employing eight different ground-based, boat-based and remotely sensed technologies of varying degrees of sophistication. Complete topographic and bathymetric surveys were attempted at each site using separate rtkGPS, total station, ground-based LiDaR, traditional airborne LiDaR, and imagery-based spectral correlation methods. Separate, georectified aerial imagery surveys were acquired using a tethered blimp, a drone UAV, and a traditional fixed-wing aircraft. Preliminary results from the surveys highlight that no single technique outperforms the others across the full range of conditions where stream habitat surveys are needed. The results are helpful for understanding the strengths and weaknesses of each approach in specific conditions, and how a hybrid of data acquisition methods can be used to build a more complete quantification of salmonid habitat

conditions in rivers of the Columbia River Basin. Furthermore, additional analysis and the enumeration of the monetary cost, time effort and accuracy for each technique under different habitat conditions will provide guidance to monitoring programs in appropriate survey method selection.

This project would not be possible without the collaboration of ISEMP, Eco-Logical Research Inc., Utah State University (USU) Ecogeomorphology and Topographic Analysis Lab (ETAL), USU Water Resources Lab (UWRL), and Watershed Sciences Inc. Funding for this research was provided by the Bonneville Power Administration (BPA), Eco-logical Research Inc., Trout Unlimited and the Bureau of Reclamation.

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INTRODUCTION

One of the central questions behind the development of monitoring protocols that assess the status of salmonids and their habitats is which is the best sampling approach at representative sites. Traditional habitat sampling protocols, such as those developed by AREMP (2010) and PIBO EMP (Heitke et al., 2010) tend to characterize habitat by collecting both attribute information, such as stream temperature and grain size, as well as topographic data in the form of channel cross-sections and longitudinal profiles. Data collected using traditional stream sampling protocols is generally not spatially georeferenced, and when it is cross section spacing tends to be too coarse in resolution to support creation of continuous digital elevation models. However, a host of other established and newer surveying technologies have emerged as viable methods for characterizing stream habitat that allow for fine-scale spatially referenced data. These include devices for acquiring oblique and aerial imagery from various platforms (e.g. blimps, drones, fixed-wing aircrafts), as well as techniques for acquiring topography and bathymetry (e.g. total stations, rtkGPS, ground-based LiDaR, airborne LiDaR, boat-based SONAR). Several methodological studies have assessed the uncertainty of specific surveying techniques for characterizing instream habitat such as total stations (Wheaton et al., 2010), survey-grade GPS (Dauwalter et al., 2006), high resolution aerial imagery (Marcus et al., 2003) and traditional survey techniques (Roper et al., 2010; Somerville, 2010; Whitacre et al., 2007). However, in an extensive, but non-exhaustive, search of the peer-reviewed and grey literature in this field, we found no systematic comparison of the wide array of survey techniques and their relative ability to quantify habitat quality and status. In order to make informed decisions about how best to sample habitat at specific sites, a systematic study is needed to fill the fundamental knowledge gap of accuracy and efficiency of available surveying technologies for characterizing habitat across the diversity of habitats present in most catchments. Additionally, the quantification of relative and absolute accuracies of each technique under a variety of environmental conditions is necessary to allow intercomparison of data collected at varying spatial and temporal scales.

This chapter presents preliminary results from work-to-date on a study whose purpose is to compare and enumerate the accuracy, time-effort and monetary cost of the full range of remotely-sensed and ground-based surveying techniques when applied to the diversity of stream habitats typically encountered in a watershed by field crews. The field campaign for this study has been completed, the majority of the data has been post-processed and analysis is underway. Here, we focus on reporting of the field methods employed and highlight some preliminary results at each of the seven study sites.

LEMHI STUDY SITES

The Lemhi River basin was selected to conduct this research as it is an intensely monitored watershed (IMW) under NOAA's Integrated Status and Effectiveness Monitoring Program (ISEMP) and it exhibits a broad diversity of stream types. The Lemhi River is located in eastern Idaho, flows in a northwesterly direction and is a major tributary to the Salmon River (Figure 1). The mainstem Lemhi River is characterized as a low-gradient, spring-fed system flowing through a broad alluvial valley (Good et al., 2005; IDEQ, 1999). The watershed is bordered by the Lemhi Mountains to the west and by the Beaverhead Mountains to the north and east. The basin encompasses 3260 square kilometers with elevations ranging from 1250 meters at the river's mouth to 3350 meters in the headwaters (IDEQ, 1999). Average precipitation varies from 18 cm in lower portions of the valley to 58 cm at higher elevations. Peak flows occur in June with lowest flows generally observed in August. The mean annual discharge from 1955 to 1990, measured at the gauging station located below the confluence with Hayden Creek, was 7.6 m^3/sec (IDEQ, 1999).

Land ownership in the valley is predominantly federally owned (78.7%) with a small portion held by the state of Idaho (3.1%) and the remainder privately owned (18.2%). In general, the United States Forest Service (USFS) owns lands in the highest reaches of the watershed, the Bureau of Land Management (BLM) owns most land in the foothills and private holdings dominate the valley bottom. Latter 19th century homesteader preference for the lower gradients and higher discharges found on the mainstem Lemhi are reflected in that 100% of the land adjacent to the mainstem Lemhi River is privately owned. Dominant land use includes agriculture and livestock production with the majority of the mainstem floodplain having been converted to cattle and sheep grazing lands or agricultural fields for production of alfalfa and grass (IDEQ, 1999). As a result, the largest human impacts in the basin are in the form of water diversions for irrigation. All 28 tributaries to the Lemhi River are diverted, some entirely, along some point of their course (IDEQ, 1999).

Seven sample sites of varying habitat complexity (open meadow to dense Spruce canopy) were selected from pre-existing ISEMP Lemhi River basin study reaches (Figure 1). These sites were selected to span the diversity of stream conditions present in the Lemhi basin and should be a reasonable proxy for the range of sampling challenges present throughout most of the Columbia Basin. Additionally, stream reaches were chosen in full anticipation that not all survey techniques would work at all sites and that some sites would push specific techniques to their breaking point. Thus, the diversity of site conditions was used to highlight contrasts between techniques as well as show where specific survey techniques may perform best. To further test the range of conditions for each technique, one non-wadeable Salmon River site located downstream of the confluence with the Lemhi River was also selected and surveyed, for a total of seven study sites.

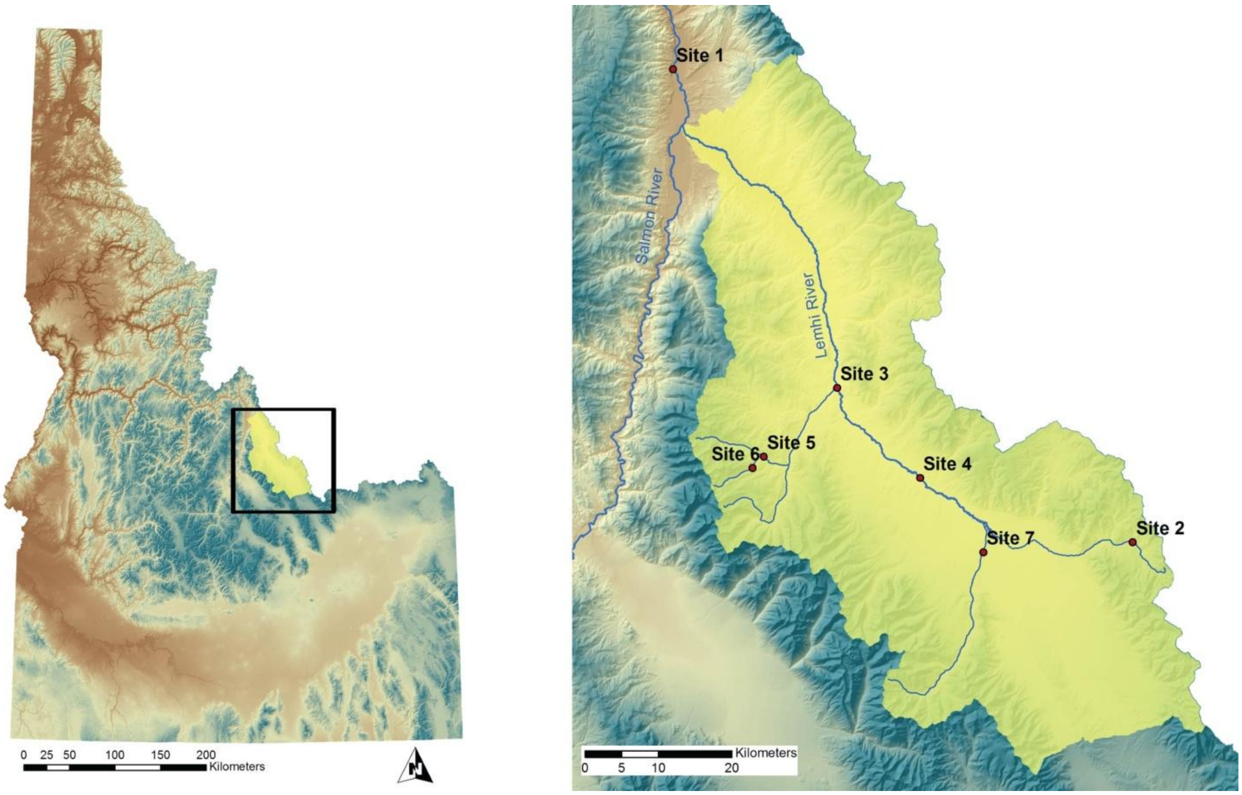

Figure 1. Lemhi River Basin sample reaches.

STUDY DESIGN

Our study design seeks to test the available range of remotely-sensed and ground-based surveying techniques (ranging from relatively inexpensive and simple to expensive and complicated) at sampling and characterizing instream habitat. Specific objectives are to:

1. Assess the absolute and relative accuracy of characterizing instream habitat through different topographic surveying and aerial image acquisition methods.

2. Estimate the quality and utility of habitat metrics derived from different field and post-processing methods under varying degrees of stream reach complexity (e.g. canopy cover, slope, roughness, logistic feasibility).

3. Quantify the cost-effectiveness relationship between quality (e.g. accuracy, data resolution, spatial extent, interpretative value) and effort (e.g. monetary cost, field-time, post-processing time) for each survey type at each site.

The sampling strategy for this project was to attempt each of eight data acquisition methods at seven sample reaches. With the exception of the 580 meter long Lemhi River reach (site 4), each survey technique was limited to 1 to 2 days per site to mimic the time constraint realistic of most monitoring programs. Habitat units and metrics will be derived from each method at each site using a variety of GIS software and tools. Metrics derived at each site will be intercompared to identify statistical differences between methods. To document effort, the length of time spent at each site sampling with each method was closely documented. Processing time effort is also being closely tracked for each site and method. Once the above objectives are met, the results of this research will be synthesized into a cost-benefit analysis that will help researchers and managers make situation-specific decisions about which habitat surveying techniques will yield the best quality data relative to available resources.

FIELD METHODS

In July through September of 2010, a major field campaign was launched to implement the above study design. Surveys were conducted during summer low flow conditions, as is typical of other monitoring protocols employed in the Columbia Basin. Study reach lengths were limited to lengths that should make most survey methods feasible in less than one to two day per site as this was considered the realistic time constraint of most monitoring programs. While each technique was attempted at each site there are gaps within the dataset due to physical limitations presented by habitat complexity (Table 1). For example, at site 6, Wright Creek, the dense spruce canopy cover inhibited satellite initialization with the rtkGPS, and inhibited safe operation of the helikite blimp. Therefore, neither the rtkGPS topographic nor blimp survey was conducted at Wright Creek.

Method	1 Salmon	2 Big Bear	3 Lemhi	4 Lemhi	5 Bear Valley	6 Wright	7 Big Timber
rtkGPS	DNS	X	X	X	X	DNS	DNS
Total Station	X	X	X	X	X	X	X
ADCP Bathymetry	X	DNS	X	X	X	DNS	DNS
Ground-based LiDaR	X	X	X	X	X	X	X
Airborne LiDaR	DNS	X	X	X	X	X	X
Blimp Aerial Imagery	DNS	X	X	X	X	DNS	X
Drone Aerial Imagery	X	X	X	X	X	X	X
Fixed-wing Aerial Imagery	DNS	X	X	X	X	X	X
ISEMP Habitat Protocol	DNS	X	X	X	X	X	X

DNS = DID NOT SURVEY

Table 1. Data collected during summer 2010 field campaign

COMMON GROUND CONTROL

Prior to field sampling, an extensive control network of survey benchmarks were established at each site by a professional surveyor (Figure 2). Matt McKeegan & Associates established intervisible azimuth pairs at each site using a Trimble rtkGPS, and then double checked each control network with a closed traverse loop with a Nikon DTM522 Total Station (Mckeegan Associates, 2010). Each azimuth pair point was occupied for a minimum of two hours to allow post-processing with the National Geodetic Survey's Online Positioning User Services (OPUS) corrections. Professionally set benchmarks were advantageous in this project as so many different field crews and flight crews were dependent on an accurate and common control network to intercompare different survey techniques. Using the same control points at all sites was necessary to ensure that differences captured between techniques are a result of differences between methods and not due to factors such as disparate control, inconsistent projections and transformations. The surveyed benchmarks were subsequently used by field crews to set additional common control points to achieve the line of site necessary for both total station and ground-based LiDaR surveys. Additional control points were established using a Leica TCRA 1203+ reflectorless total station with auto-tracking and automatic target recognition. Control points were typically set as part of an open traverse loop and occupied with a backsight tripod setup.

Figure 2. Surveyor benchmarks (A & B) were established at all sites

TRADITIONAL STICK-AND-TAPE IN-STREAM HABITAT SURVEYS

Traditional in-stream habitat surveys were conducted using the ISEMP Lemhi River Basin 2010 Instream Habitat Sampling protocol (Bouwes 2010). The protocol is a comprehensive integration of several Columbia River Basin tribal, federal and state agency protocols. Topographic data and attribute information collected included channel cross-sections (Figure 3), longitudinal profile, water surface gradient and habitat unit delineation and measurement (length, width, depth). Longitudinal profiles and cross sections were acquired with a centimeter demarcated survey rod (i.e. the ‘stick’ in ‘stick and tape’) and a tape measure (i.e. the ‘tape’). Although these transects were not accurately geo-located, the cross sections and longitudinal profiles should be comparable to those extracted from topographic surveys of the reach to allow intercomparison.

Figure 3. Traditional 'stick and tape' cross-section method for acquiring topographic data.

TOTAL STATION & REAL-TIME KINEMATIC GPS

Separate, complete topographic surveys were attempted at all sites using a Leica TCRA 1203+ reflectorless total station with auto-tracking and automatic target recognition and a Leica System 1200 rtkGPS Base and Rover. The Leica TCRA 1203+ instrument was not equipped with a robotic radio controller, so its operation required a two person crew. However, the auto-tracking and automatic target recognition features do facilitate much faster point acquisition times (e.g. 2-6 seconds per points) as compared to manual total stations (e.g. 4-10 seconds per point). The rtkGPS setup only required a single person to operate the rover. Complete total station topographic surveys were conducted at the six Lemhi sites and conducted for the shallow wadeable portions of Site 1 on the mainstem Salmon River. Due to an inability to initialize a minimum of five satellites at sites with dense canopy cover (e.g. Sites 6 & 7) as well as swiftwater conditions at the Salmon River site (Site 1), rtkGPS point data were only collected at four of seven sites.

A topographically stratified sampling design was used to collect total station and rtkGPS point data. The greatest emphasis was placed on capturing topographic changes, or breaks in slope, within the channel boundary. Point collection effort (and hence point density) was topographically stratified to be lower in areas of uniform bed shape (e.g. low-gradient riffles) and higher effort in areas of both greater channel complexity and grade breaks (e.g. pools). A code list was established and used to detail point data collected at each site**.** Points were coded as: LEW (Left-edge water), REW (Right-edge water), BF (Bankfull), Bank and Topo (In-channel topography). Points were collected to capture in-channel bed topography and extended laterally out of the wetted channel to approximately five meters beyond bankfull elevation. The edge of water on both sides of the channel was captured in order to derive surface elevations models and water depth maps.

Figure 4. Total station base unit (A) requires a line of sight to a prism-mounted survey rod (B). An rtkGPS base unit (C) sends differential position corrections to a rover unit (D) and only requires one person to operate.

BOAT-BASED SONAR

Bathymetry and velocity was collected using a Sontek River Surveyor Acoustic Doppler Current Profiler (ADCP) unit (Figure 5). The system is comprised of a sensor, floating platform (the River Board), rtkGPS unit and handheld PDA controller. The S5 model used in this study collects continuous depth and velocity measurements with a manufacturer reported accuracy of 1% of the measured depth. This system is quite flexible as it can be tethered to wade or walk shallower reaches or, in deeper reaches, towed behind a kayak and ferried from bank to bank collecting bathymetric data until complete coverage of the reach is achieved (Figure 6). However, due to the design of the platform, the sensor cannot collect reliable data in depths less than 20 centimeters. This method was not part of the original study design, but was added when a demonstration unit was generously provided by Sontek to help extend the study scope. Thus, this method was not attempted at all sites due to time constraints.

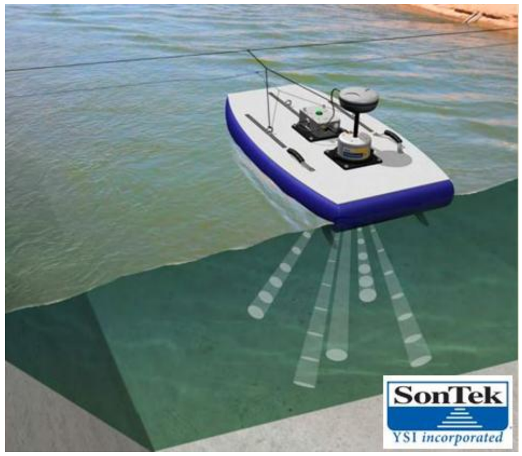

Figure 5. Sontek River Surveyor ADCP device

Figure 6. Use of Sontek River Surveyor ADCP in conjunction with kayak at Site 1.

BLIMP IMAGERY

Optical imagery was acquired using a Alsop Skyshot 2.0 Helikite tethered helium blimp (Figure 7) equipped with a digital RGB camera (Ricoh CX1 model). Flying heights, ranging between 75 and 150 meters at each site, were dependent upon wind conditions as well as the height and density of riparian vegetation. The digital camera was positioned on an interval setting recording images every 4 seconds. Ground control was set with 1 meter x 1 meter square targets spaced in rows 15-30 m apart and positioned perpendicular to the stream channel following methods described by Vericat et al. (2009). The location of each target was recorded with a Leica rtkGPS. Flights at different sites achieved varying success due to weather conditions (e.g. high winds) and the time constraint set by the study design of 1-2 days per technique.

Imagery will be post-processed and used to derive depth for the entire wetted portion of the reach. Successful flights produced between 500 and 1500 images per site. Due to platform design, pitch, roll and yaw can be higher in blimp imagery then other aerial platforms. As such, extremely oblique and blurry images result, but these can be readily discarded. Clear, near-nadir images will be clipped, geo-referenced, and mosaicked in Erdas Imagine. No atmospheric correction will be applied as images at each site were collected within one day and analysis for each site will be performed independently (Jensen, 2005). Once images are mosaicked, the wetted portion of the channel will be digitized into a polygon in ArcGIS omitting areas of shadow and high turbulence. A correlation will be derived between water depths generated from total station data points and pixel color values of the mosaicked image (Legleiter et al., 2009). Seventy-percent of points will be used to derive the correlation with the remaining 30 percent reserved for model validation. Once developed, the correlation will be used to extrapolate depths for the wetted portion of the reach. In turn, water depth maps will be used to delineate channel habitat units.

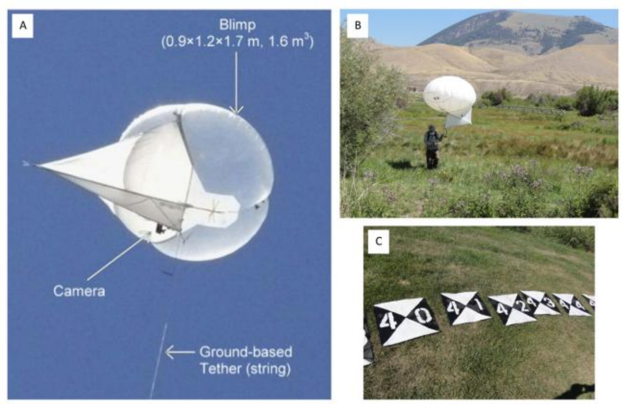

Figure 7. 'Poor man's aerial imagery' tethered helium-filled blimp (A) is a relative low-cost tool in the field (B) but requires extensive ground-control, here with 1m x 1m square targets (C).

DRONE IMAGERY

High-spatial resolution (i.e. 10 cm), multi-spectral imagery was collected for each site using an unmanned aerial vehicle (UAV) developed by Utah State University's Utah Water Research Lab (UWRL). The drone is equipped with both RGB and NIR digital cameras (Figure 8), orientation and positional sensors and is capable of executing pre-planned flight paths. The two onboard cameras were set to an interval shooting, capturing images every four seconds. The onboard GPS unit and IMU recorded the position and tilt of the UAV as each image was taken. Ground control was set with 1 m x 1 m square targets positioned over common control points set at each site for the field campaign. Ground control targets were used to correct the positional accuracy recorded by the UAV GPS unit which in turn is used in the image ortho-rectification process (Jensen et al., 2010). Data were collected in WGS84 and resulting imagery has a spatial resolution of 10 centimeters. Images were calibrated and mosaicked by the UWRL. A correlation between pixel reflectance and field-measured depth will be generated for each site as described above to derive bathymetry from imagery.

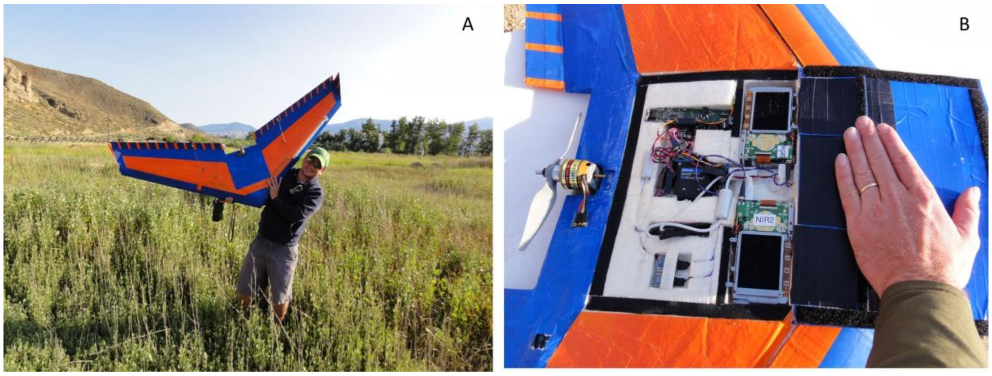

Figure 8. UAV Drone (A) equipped with RGB and NIR digital cameras (B).

FIXED-WING AERIAL IMAGERY

Fixed-wing aerial imagery was acquired by Watershed Science Incorporated (WSI) in conjunction with the airborne LiDaR flight. Imagery was collected with a 39 megapixel digital camera in the visible portion of the spectrum (RGB). Resulting imagery has a spatial resolution on the order of less than fifteen centimeters (Watershed Sciences, 2011). WSI post-processed all data including discriminating the wetted channel boundary and ortho-rectifying images. Within a range of one to three days of the LiDaR flight, field crews collected centimeter-accuracy water depths with survey rods and recorded GPS location of depth measurements taken at each site. Field measured depths will be used to derive bathymetry from imagery as described above.

GROUND-BASED LIDAR

Ground-based LiDaR surveys were conducted for each sample reach was using a Leica Geosystems ScanStation 2 terrestrial laser scanner (TLS). The ScanStation 2 has a maximum acquisition rate of 50,000 points per second, but with the dual-axis compensator enabled collects approximately 2000-10,000 points per second. The unit used in this study is a green laser (525 nm) discrete return sensor which receives a single return for each emitted pulse. Prior to scanning, each scanner set-up location was surveyed with a total station and benchmarked as described above. At each site, scanning locations were selected that ensured visual overlap between scan set-ups generating a continuous data point cloud, which would fill in most shadowing from individual setups. While scanning, survey targets of static height were placed at benchmark locations visible in multiple scans as vertical and horizontal accuracy checkpoints. Post-processing of each site will include removing vegetation data point clouds to generate bare earth DEMs. Data analysis will include extracting attribute measurements such as large woody debris length and diameter as well as attempting to derive habitat units based on surface roughness and slope.

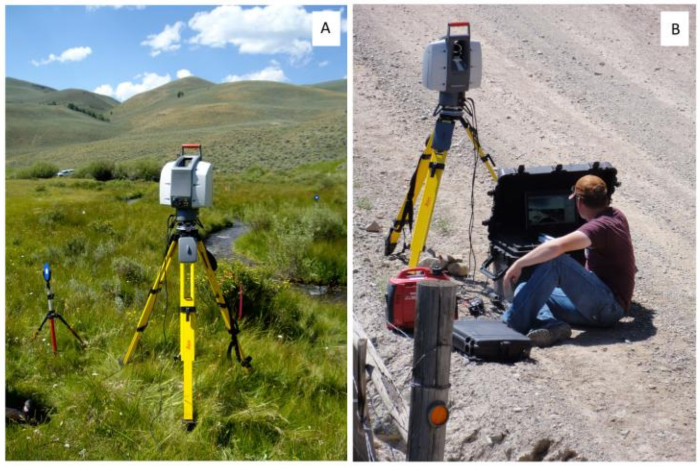

Figure 9. Ground-based LiDaR unit (A) set-up with generator and laptop (B).

AIRBORNE TERRESTRIAL LIDAR

Airborne terrestrial LiDaR was flown from September 24 to the 26th of 2010 by WSI. The fixed-wing flight was funded through both the United States Bureau of Reclamation and Trout Unlimited. The Salmon River site was not flown as it would have resulted in an additional $8,000 in acquisition costs that were not budgeted in this project. The Leica ALS50 Phase II LiDaR sensor used is a multi-return sensor, which for every signal emitted by the sensor, receives between 3 to 5 signal returns. This sensor was set to collect up to 83,000 points per second and resulted in an average density of 8 points per square meter (Watershed Sciences, 2011). WSI post-processed all data including segregating all first and last returns. This data was input into a vegetation surface model capable of differentiating vegetation return signals from bare earth return signals. The model was used to generate a 1 meter spatial resolution bare earth DEM and a 1 meter spatial resolution vegetation DEM (Watershed Sciences, 2011). First and last LiDaR signal return DEMs will be differenced to determine vegetation canopy height and volumes along each stream reach (Lefsky et al., 2002).

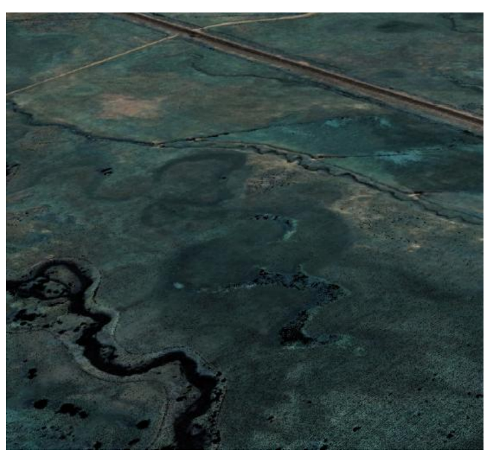

Figure 10. Fixed-wing imagery of Lemhi River draped over aerial LiDaR 3-D point cloud

PRELIMINARY STUDY RESULTS – BY STUDY SITE

Here, we present a subset of preliminary results for each of the seven study sites. Sample reach characteristics are described and survey time effort summarized for each technique. A mix of drone and fixed wing aerial imagery, as well as total station, rtkGPS and Ground-based LiDaR topographic survey results are shown.

STUDY SITE 1 – MAINSTEM SALMON RIVER

Study site 1 is a non-wadeable mainstem Salmon River sample reach located approximately 9 river kilometers downstream of the confluence with the Lemhi River. The 365 meter long reach has an average bankfull width of approximately 60 meters, a gradient of 0.3 % and a small Class I rapid at the downstream extent. This sample site was selected to test how the different survey techniques faired in a larger non-wadeable river setting.

The higher velocities and water depths presented significant survey challenges for several of the survey techniques. Some of the methods could not be employed due to the swiftwater conditions and equipment and personnel safety concerns. These included rtkGPS and the traditional instream habitat protocol surveys. Blimp aerial surveys could not be conducted due to equipment damage (this was the last reach to be surveyed by blimp and the blimp was punctured). Aerial LiDaR was not acquired due to cost constraints. Techniques successfully employed at this site included total station bathymetry survey (of the wadeable portions), ground-based LiDaR, drone aerial imagery and boat-based SONAR. The total station point data collection was restricted to channel margins (Figure 9D) due to progressively higher velocities and depths of the mid-channel portion of the reach. Boat-based SONAR data were collected by tethering the Sontek River Surveyor device behind a kayak and ferrying from bank to bank (Figure 6). The ground-based LiDaR scan stations were all located on the river-left bank due to the large time effort required to pack, drive to, unload and hike equipment to the river-right bank. The only survey methods not impeded by the physical challenges presented by this site were the boat-based SONAR and UAV drone.

Figure 11. Salmon River sample reach

Site 1 - Salmon River

Topographic Method:	No. People per Survey:	Total Hours:	No. Points :	No. Points per Hr :
Control	2	1.5	6	4
Total Station	2	6.25	1433	229
Boat-based SONAR	1	4.0	NA	NA
			No. Scans:	No. Scans per Hr:
Ground-based LiDaR	1	8.25	4	0.5
Aerial Imagery Method:	**No. People per Survey:**	**Total Hours:**	**No. Photos Collected:**	**No. Photos Collected per HR:**
UAV Drone	2	< 1	150 (RGB)	150

Table 2. Salmon River sample reach survey effort by method

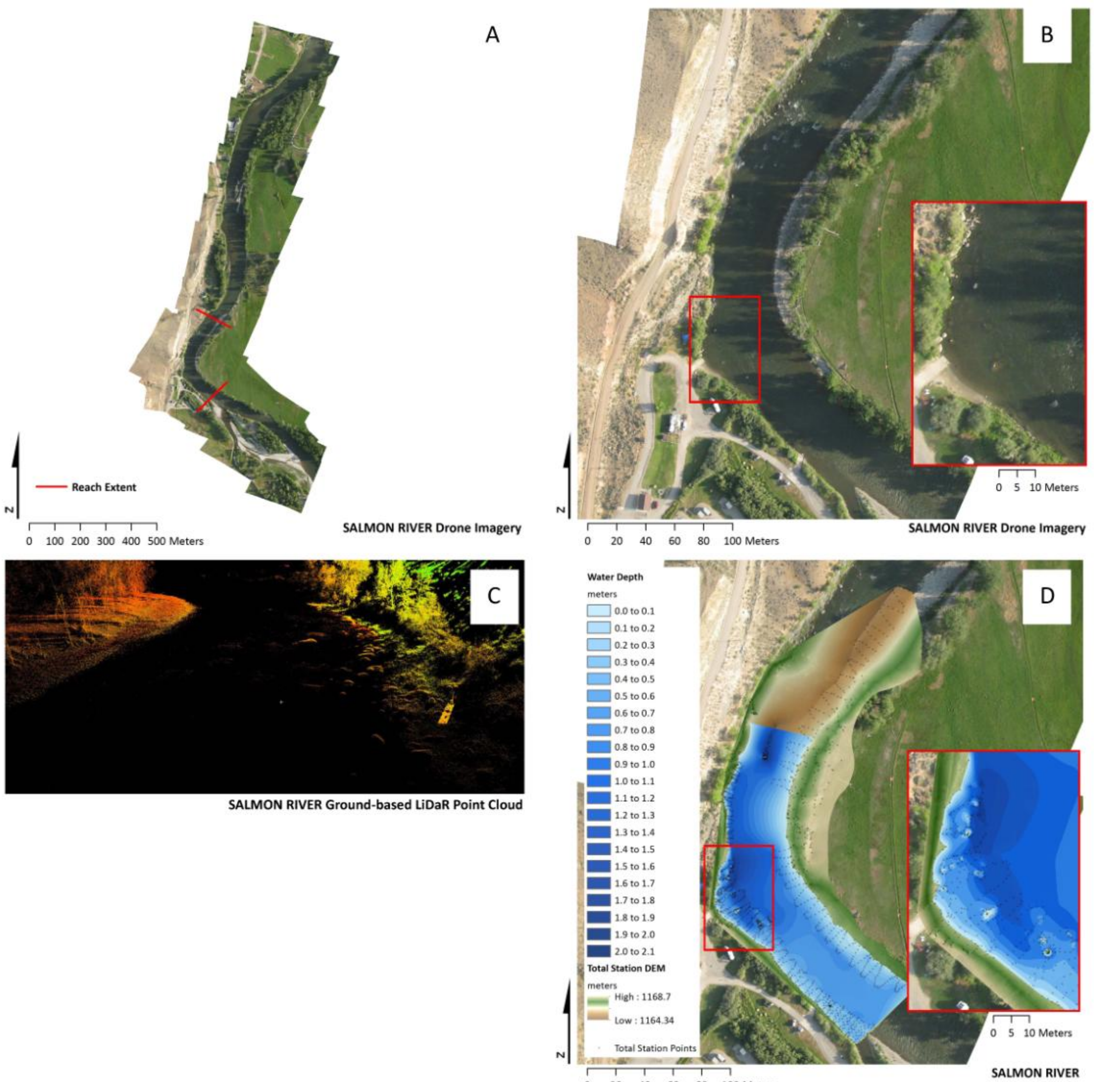

Figure 12. Salmon River drone imagery entire extent (A), reach extent (B), ground-based LiDaR scan (C) and water depth map derived from total station point data (D).

STUDY SITE 2 – BIG BEAR CREEK

Big Bear Creek is a 2nd order meandering open-meadow stream. The 160 meter reach has an average bankfull width of approximately 2 meters, a gradient of 0.95 % and minimal obstruction from vegetation. This sample site was selected to represent a control as all techniques should perform well in this environment.

As anticipated, this site presented very few survey challenges. All methods were successfully employed with the exception of boat-based SONAR. The boat-based SONAR demo unit was not used at this site as this method was a late addition to the study design. Therefore, this technique was not utilized due to time constraints and not because of challenges arising from site physical characteristics. The ground-based LiDaR survey was the most time intensive of all sampling methods. At the time of the survey there were intermittent thunderstorms. The ground-based LiDaR instrument is weather sensitive and had to be shut-down whenever rainfall commenced. Additionally, the highly sinuous channel required eleven scanning locations to make up for line-of-site limitations and gain complete coverage of the reach.

Figure 13. Big Bear Creek sample reach

Site 2 - Big Bear Creek

Topographic Method:	No. People per Survey:	Total Hours:	No. Points :	No. Points per Hr :
Control	2	1.5	11	7
Total Station	2	7.25	1949	269
rtkGPS	1	5.75	2190	381
			No. Scans:	No. Scans per Hr:
Ground-based LiDaR	1	14.75	11	0.75

Aerial Imagery Method:	No. People per Survey:	Total Hours:	No. Photos Collected:	No. Photos Collected per HR:
Blimp	1	2.25	498	221
UAV Drone	2	< 1	255 (RGB)	225

Table 3. Big Bear Creek sample reach survey effort by method

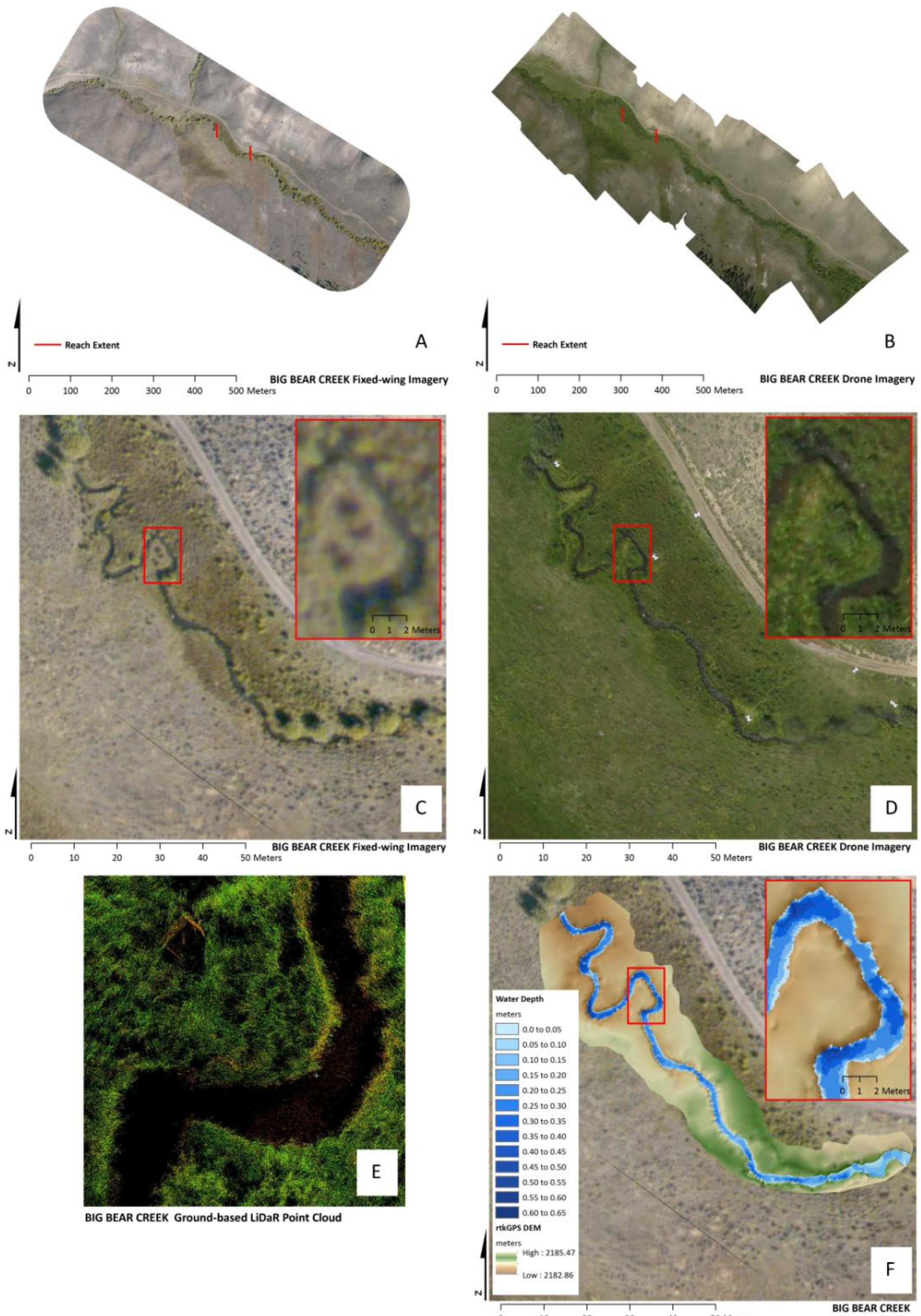

Figure 14. Big Bear Creek fixed-wing imagery extent (A), drone imagery entire extent (B), fixed-wing imagery reach extent (C), drone imagery reach extent (D), ground-based LiDaR scan (E) and water depth map derived from rtkGPS point data (F).

STUDY SITE 3 – MAINSTEM LEMHI STRAIGHT

Study site three is the downstream of the two reaches that were sampled on the mainstem Lemhi River. This site has plane-bed morphology and has been highly modified. The reach had been straightened by the construction of Hwy 28 along the river left bank and as a result there are several zones of boulder rip-rap. The 270 meter reach has an average bankfull width of approximately 15 meters, a gradient of 0.55 % and dense, mature willow cover along both banks.

All techniques were employed at this site. Field crew set control took substantial effort as this was one of the first reaches technicians were required to do so. The reach presented several survey challenges for both the total station and rtkGPS. These challenges were primarily due to the extremely dense willow cover along both banks. Throughout much of the reach willows extended several meters into the channel making the edge of water, bank and bankfull locations inaccessible. At the beginning of the total station survey attempts were made to capture point data in these locations, but at the cost of up to several minutes to attain a single point. For the sake of completing the survey within the study design allotted timeframe, it was decided to forgo surveying difficult to access edge of water points. However, good point coverage was collected outside of the channel margins and in areas of less dense willow cover.

Figure 15. Lemhi River (site 3) sample reach

Site 3 - Lemhi River

Topographic Method:	No. People per Survey:	Total Hours:	No. Points :	No. Points per Hr :
Control	2	4.0	8	2
Total Station	2	16.5	1309	79
rtkGPS	1	6.0	1569	261.5
Boat-based SONAR	1	2.0	NA	NA
			No. Scans:	No. Scans per Hr:
Ground-based LiDaR	1	7.5	5	0.67

Aerial Imagery Method:	No. People per Survey:	Total Hours:	No. Photos Collected:	No. Photos Collected per HR:
Blimp	3	3.25	776	239
UAV Drone	2	< 1	169 (RGB)	169

Table 4. Lemhi River (site 3) sample reach survey effort by method

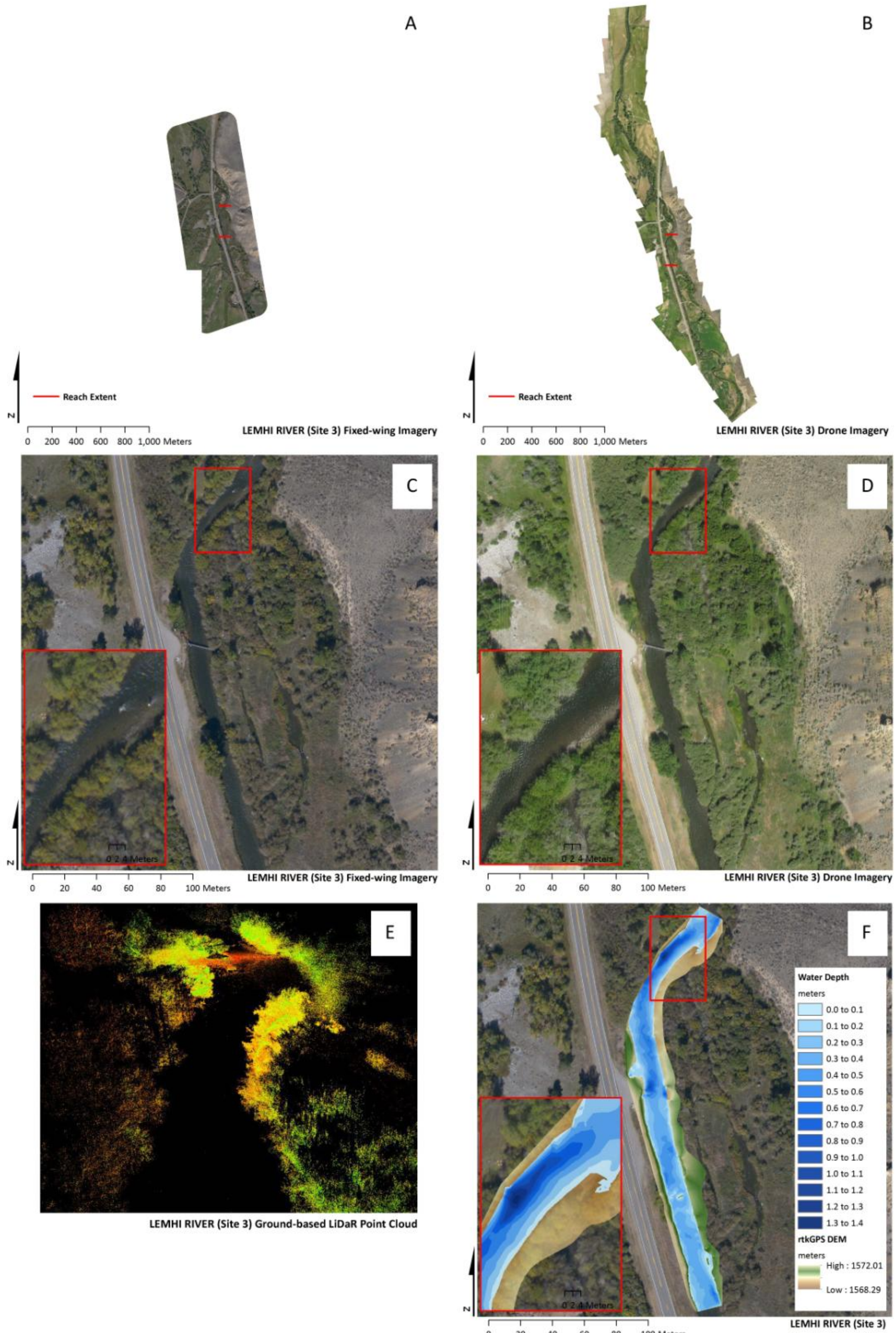

Figure 16. Lemhi River (site 3) fixed-wing imagery extent (A), drone imagery entire extent (B), fixed-wing imagery reach extent (C), drone imagery reach extent (D), ground-based LiDaR scan (E) and water depth map derived from rtkGPS point data (F).

STUDY SITE 4 – MAINSTEM LEMHI ANASTAMOSING

Study site four is the upstream of the two reaches that were sampled on the mainstem Lemhi River. This site has anastamosing morphology with varying vegetation cover and densities between channel branches. The site was selected because of the complexity of a multi-threaded channel network. By comparison to braided channels, anastomosing channels are more difficult to survey given the vegetated islands. However, both anastomosing and braided channels occur regularly throughout the Columbia River Basin, yet are systematically avoided by habitat sampling crews and under sampled. The upstream and downstream extents of the reach were chosen to fully contain the network of divergent anabranches (upstream) and their subsequent convergence downstream. The 580 meter reach has an average bankfull width of approximately 27 meters, and a gradient of 0.67 %. The combined stream length of the 3 main branches is approximately 1500 meters.

All techniques were successfully employed at this site. Due to the size of the reach, study design time effort was extended beyond the two day limit in order to attain full coverage with each technique. This was justified as many of the individual anabranches resembled the character of single thread reaches elsewhere, and the data could therefore also be sub-sampled to represent multiple reach types. Challenges encountered at this site were inclement weather which required shutting down the ground-based LiDaR unit for half a day and cancelling a planned blimp survey. Approximately half a day was lost troubleshooting when, for an unclear reason, the total station data storage card became fragmented. Such technical difficulties are a natural part of field work and the opportunities for such occurrences can increase with the increasing technical complexity of survey equipment. However, these technical difficulties are relatively rare and need to be assessed in the context of the increased efficiency, accuracy and extent of data provided the rest of the time.

Figure 17. Lemhi River (site 4) sample reach

Site 4 - Lemhi River

Topographic Method:	No. People per Survey:	Total Hours:	No. Points :	No. Points per Hr :
Control	2	8.0	26	3.25
Total Station	2	37.0	7802	211
rtkGPS	1	22.25	7640	343
Boat-based SONAR	1	5.0	NA	NA
			No. Scans:	No. Scans per Hr:
Ground-based LiDaR	1	46.5	26	0.5

Aerial Imagery Method:	No. People per Survey:	Total Hours:	No. Photos Collected:	No. Photos Collected per HR:
Blimp	3	4.0	812	203
UAV Drone	2	< 1	230 (RGB)	230

Table 5. Lemhi River sample reach survey effort by method

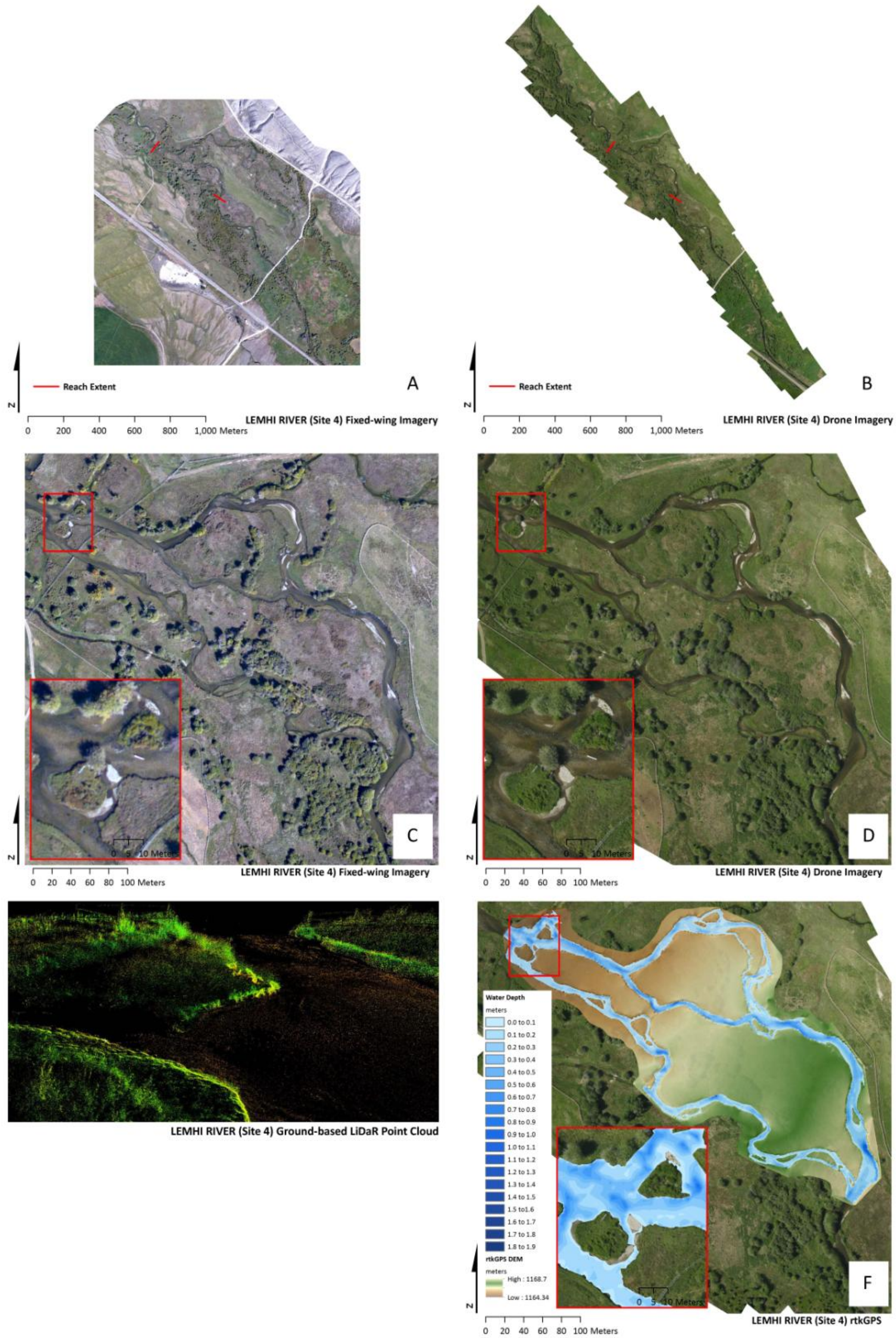

Figure 18. Lemhi River (site 4) fixed-wing imagery extent (A), drone imagery entire extent (B), fixed-wing imagery reach extent (C), drone imagery reach extent (D), ground-based LiDaR scan (E) and water depth map derived from rtkGPS point data (F).

STUDY SITE 5 – BEAR VALLEY CREEK

Bear Valley Creek is a 4^{th} order stream with meandering pool-riffle morphology. The 160 meter reach has an average bankfull width of approximately 9 meters and a gradient of 1.7 %. There are several side channels, areas with steep banks and a more complex riparian vegetation community.

All techniques were successfully employed at this site. This was the first reach sampled in the field campaign and the site at which sampling methodology issues were addressed; this is reflected the amount of time spent setting control and surveying with the total station and ground-based LiDaR. Challenges encountered were primarily in regards to the blimp survey. An initial flight had to be canceled due to high winds; the following day was fraught with down drafting wind currents resulting in several attempts until the blimp achieved suitable flying height.

Figure 19. Bear Valley Creek sample reach

Site 5 -Bear Valley Creek

Topographic Method:	No. People per Survey:	Total Hours:	No. Points :	No. Points per Hr :
Control	2	2.5	7	2.8
Total Station	2	10.5	1170	111
rtkGPS	1	7.5	2510	335
Boat-based SONAR	1	2.0	NA	NA
			No. Scans:	No. Scans per Hr:
Ground-based LiDaR	1	11.25	7	0.62

Aerial Imagery Method:	No. People per Survey:	Total Hours:	No. Photos Collected:	No. Photos Collected per HR:
Blimp	3	5.5	1196	217
UAV Drone	2	< 1	104 (RGB)	104

Table 6. Bear Valley Creek sample reach survey effort by method

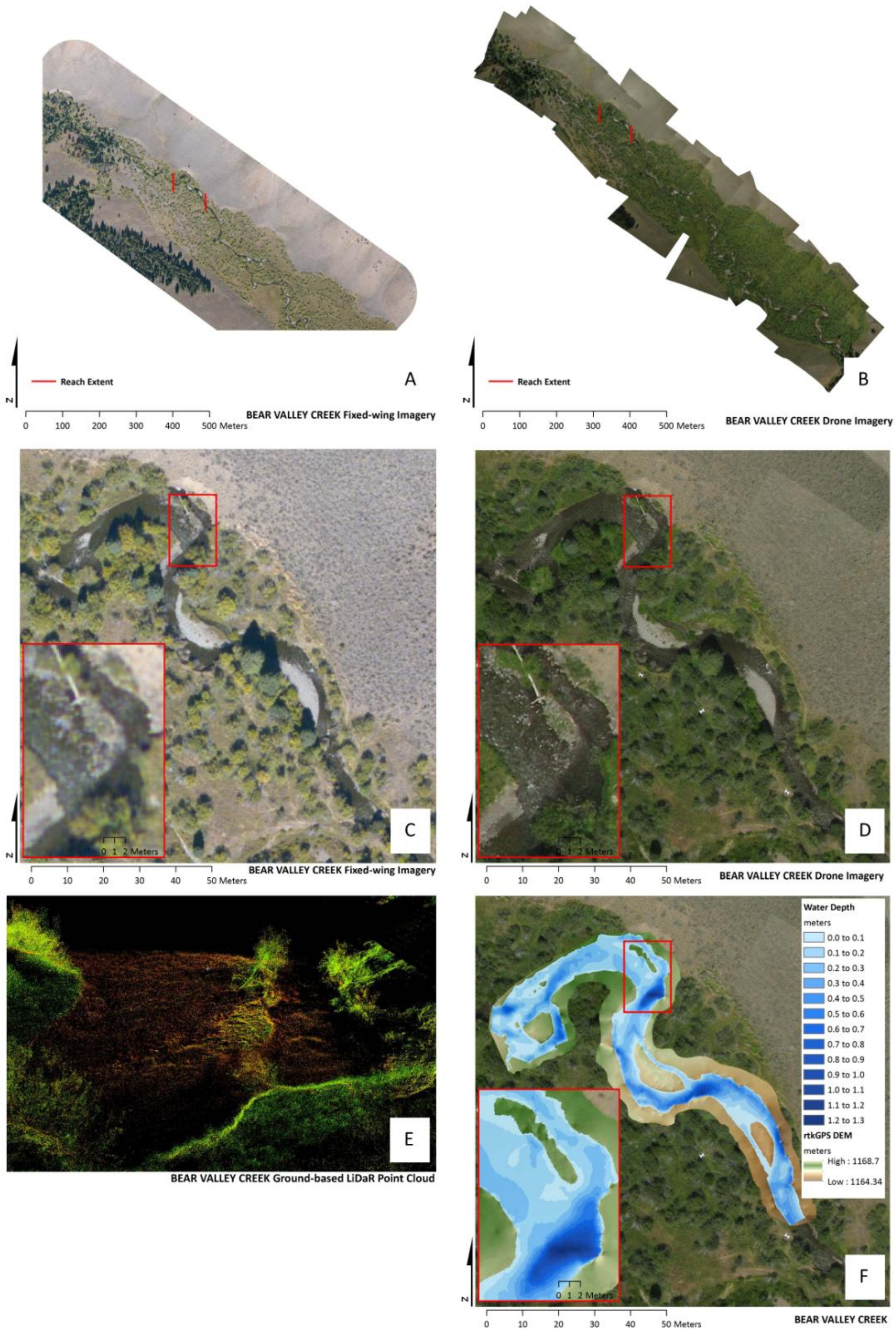

Figure 20. Bear Valley Creek fixed-wing imagery extent (A), drone imagery entire extent (B), fixed-wing imagery reach extent (C), drone imagery reach extent (D), ground-based LiDaR scan (E) and water depth map derived from rtkGPS point data (F).

STUDY SITE 6 – WRIGHT CREEK

Wright Creek is a 3rd order higher gradient reach with step-pool morphology. The 160 meter reach has an average bankfull width of approximately 5 meters and a gradient of 5.7 %. This sample site was selected to see how the different techniques performed in the closed spruce canopy setting with multiple LWD jams interspersed throughout the reach.

The closed conifer canopy presented survey challenges for several methods. Techniques successfully employed included total station, ground-based LiDaR, airborne LiDaR and UAV drone imagery. RtkGPS survey could not be conducted due to a lack of initialization with satellites due to the dense canopy. Blimp aerial imagery was not acquired due to the delicate construction material and the high likelihood the blimp would become entangled in the canopy irreversibly damaging the equipment. Boat-based SONAR was not collected due to time constraints and the difficulty of surveying with the unit in a higher velocity, boulder and LWD jam dominated reach. While fixed-wing and UAV drone imagery were acquired, the channel is not visible therefore negating the ability to derive in-stream metrics (Figure 22 C&D).

Figure 21. Wright Creek sample reach

Site 6 - Wright Creek

Topographic Method:	No. People per Survey:	Total Hours:	No. Points :	No. Points per Hr :
Control	2	2.0	8	4
Total Station	2	10.5	1931	184
			No. Scans:	No. Scans per Hr:
Ground-based LiDaR	1	11.75	8	0.68

Aerial Imagery Method:	No. People per Survey:	Total Hours:	No. Photos Collected:	No. Photos Collected per HR:
UAV Drone	2	< 1	104 (RGB)	104

Table 7. Wright Creek sample reach survey effort by method

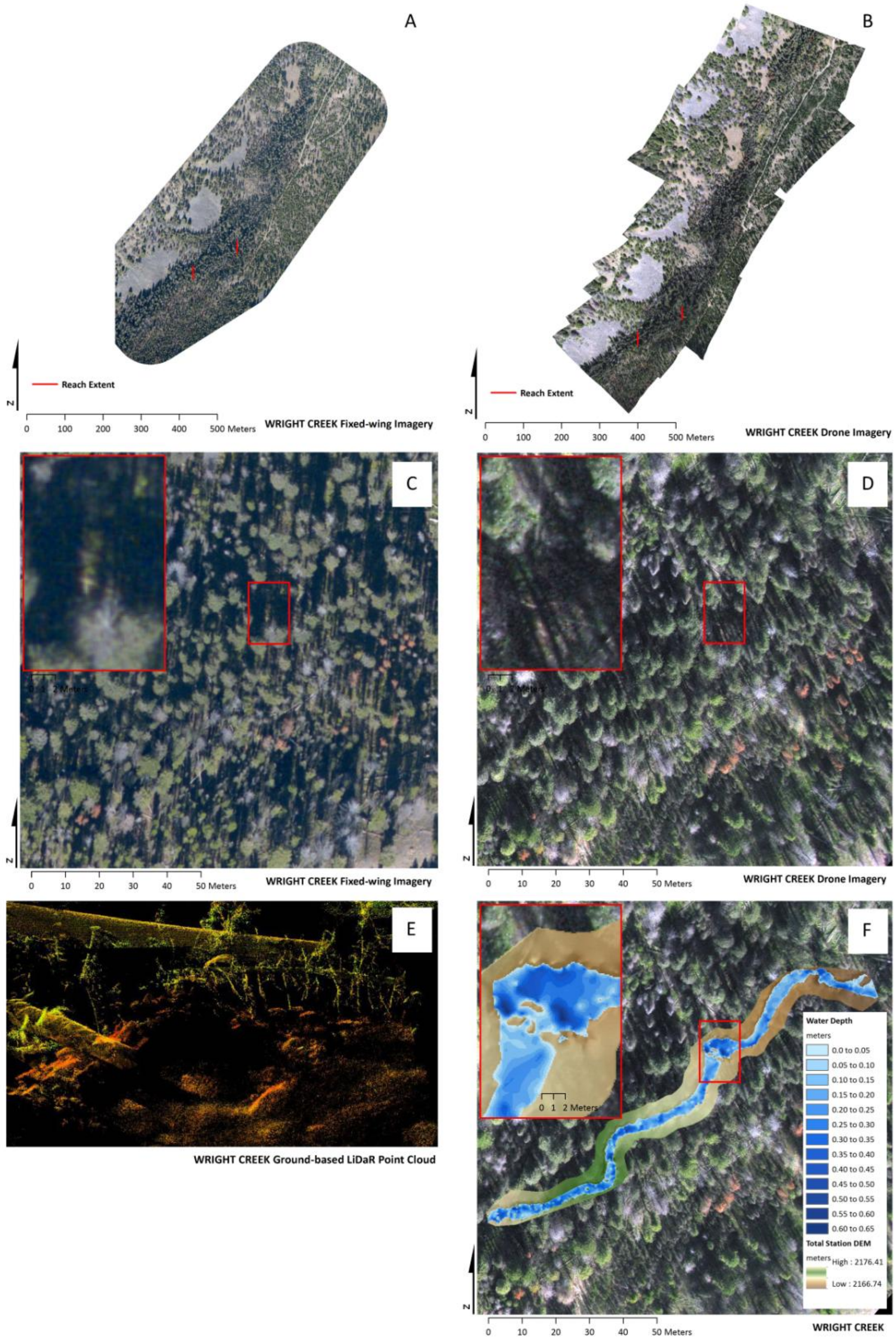

Figure 22. Wright Creek fixed-wing imagery extent (A), drone imagery entire extent (B), fixed-wing imagery reach extent (C), drone imagery reach extent (D), ground-based LiDaR scan (E) and water depth map derived from total station point data (F).

STUDY SITE 7 – BIG TIMBER CREEK

Big Timber Creek is a 4th order stream with plane-bed morphology. The 160 meter reach has a straight channel, an average bankfull width of approximately 7 meters and a gradient of 0.8 %. This sample site was selected as it has a very dense riparian corridor consisting of mature cottonwood and alder with near channel spanning vegetation at points along the reach. In addition to the thick riparian vegetation, which limits line of site for total station and ground-based LiDaR surveys, the reach was rather straight, which limits opportunities for the positioning of control points for instrument setups, which have good coverage of the reach. For these reasons, the site was an excellent representation of very typical survey challenges in densely vegetated riparian corridors.

The dense deciduous vegetation resulted in survey challenges for several methods. All techniques were employed with the exception of the rtkGPS and boat-based SONAR. While rtkGPS satellite coverage was excellent just outside the riparian corridor, initialization was lost within approximately 2 meters of the corridor. Therefore, we were not able to conduct an instream rtkGPS topographic survey. Boat-based SONAR was not employed due to time constraints as well as the shallow depths throughout this reach could not be surveyed due to the unit's design limitations and inability to survey depths less than 20 centimeters. Total station surveys for this reach required substantial time effort with leaves and un-vegetated branches interfering with the line of site between the instrument and prism.

Figure 23. Big Timber Creek sample reach

Site 7 - Big Timber Creek

Topographic Method:	No. People per Survey:	Total Hours:	No. Points :	No. Points per Hr :
Control	2	3.45	11	2
Total Station	2	10.5	1277	122
			No. Scans:	No. Scans per Hr:
Ground-based LiDaR	1	12.5	7	0.56

Aerial Imagery Method:	No. People per Survey:	Total Hours:	No. Photos Collected:	No. Photos Collected per HR:
Blimp	1	2.75	393	143
UAV Drone	2	< 1	64 (RGB)	64

Table 8. Big Timber Creek sample reach survey effort by method

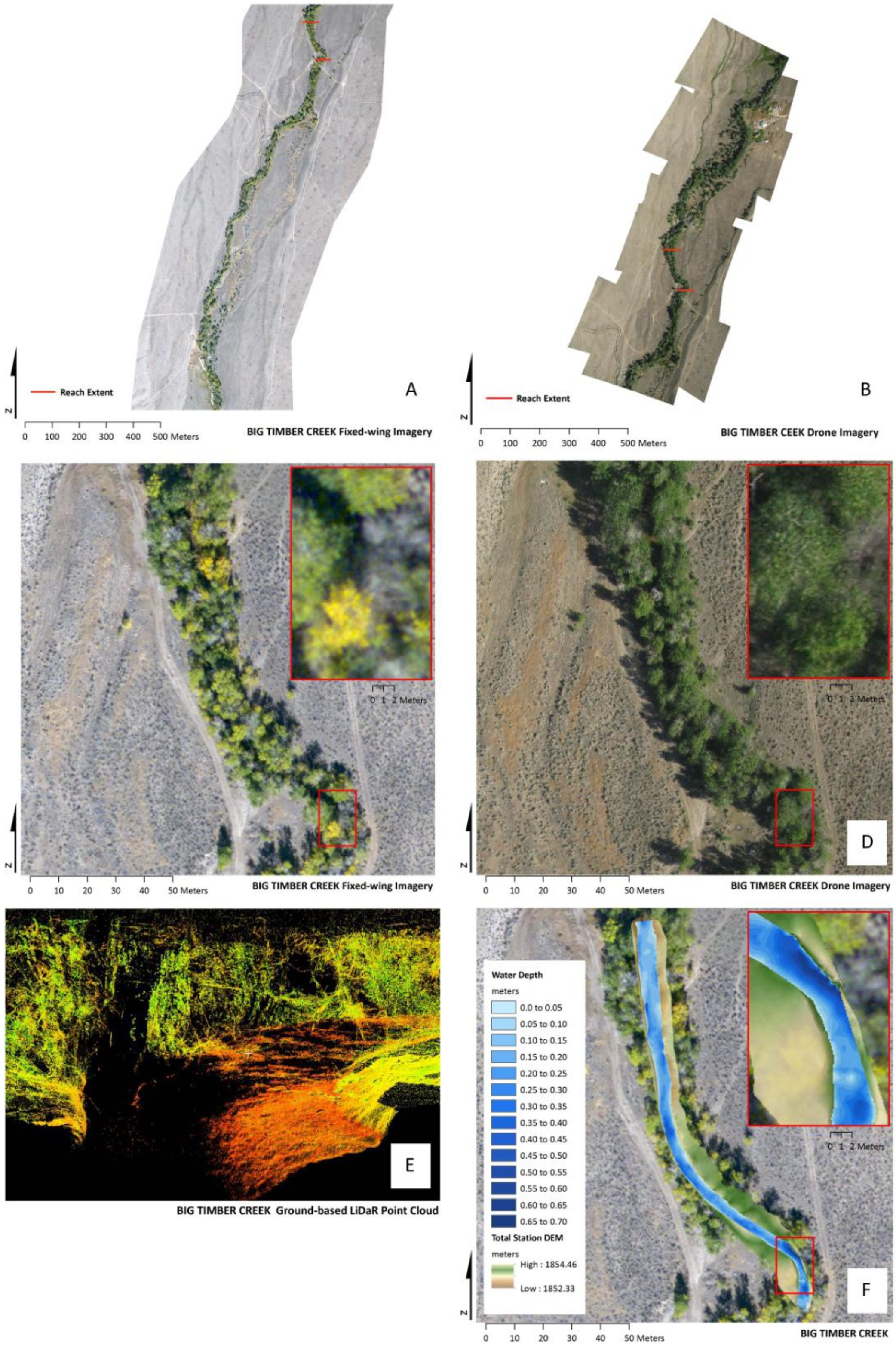

Figure 24. Big Timber Creek fixed-wing imagery extent (A), drone imagery entire extent (B), fixed-wing imagery reach extent (C), drone imagery reach extent (D), ground-based LiDaR scan (E) and water depth map derived from total station point data (F).

DISCUSSION & ONGOING WORK

Data analysis will be conducted over the next year. This includes deriving Digital Elevation Models (DEMs) for all point and scan data as well as bathymetry maps from imagery. Instream habitat units (e.g. pool, riffle), habitat unit metrics (e.g. length, width, maximum depth) and reach characteristics (e.g. slope, gradient, width-to-depth ratio) will be derived from topographic surfaces using River Bathymetry Toolkit software developed by the United States Forest Service (McKean et al. 2009). Comparative statistics, such as a 1-way ANOVA or randomized block design, will be used to discern any differences between habitat metrics derived using the eight different methods. For each reach, DEMs derived using the different methods will be differenced in pairwise combinations (e.g. total station DEM – rtkGPS DEM) with summary statistics generated for each 'differenced' 10 cm cell within the DEM. The resulting differenced DEM (Figure 25) allows us to identify areas along a reach where one technique results in higher elevations than another and spatially auto-correlate high areas of difference with physical complexity (e.g. large cottonwood). However, there is a degree of uncertainty inherent in topographic surfaces derived from point data collected in the field. This is largely a function of individual point quality, overall point density and stream reach complexity. As we will be largely deriving habitat units and metrics from topographic surfaces we want to enumerate this uncertainty. To do so we will be using a Fuzzy Inference System (FIS) model developed by Wheaton et al. (2010) that can be calibrated for each method employed. At the end of the study time effort, comprised of field data collection effort and data processing time, monetary cost and data quality will be enumerated for each method and site. We anticipate the results of this study will help elucidate the strengths and weakness of each approach in specific conditions and the cost of acquiring instream habitat data employing these tools.

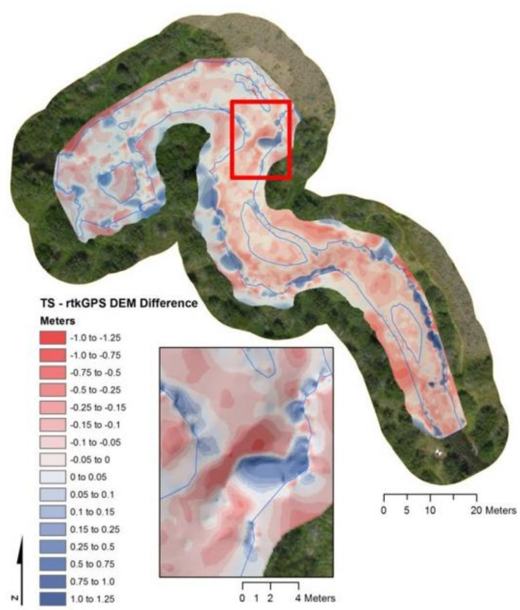

Figure 25. Bear Valley Creek DEM of difference

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