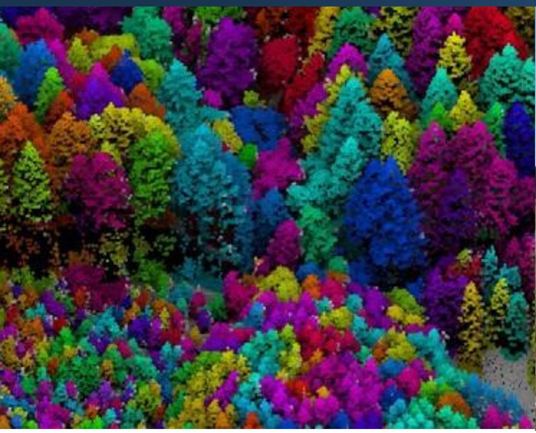
Applied
Remote Sensing
and Analysis

September 20, 2013



Project Execution Plan

Wasatch Front LiDAR Elevation Data Survey 2013 – 2014

- State of Utah Automated Geographic Reference Center (AGRC)
- National Geospatial Technical Operations Center (NGTOC)

Applied
Remote Sensing
and Analysis

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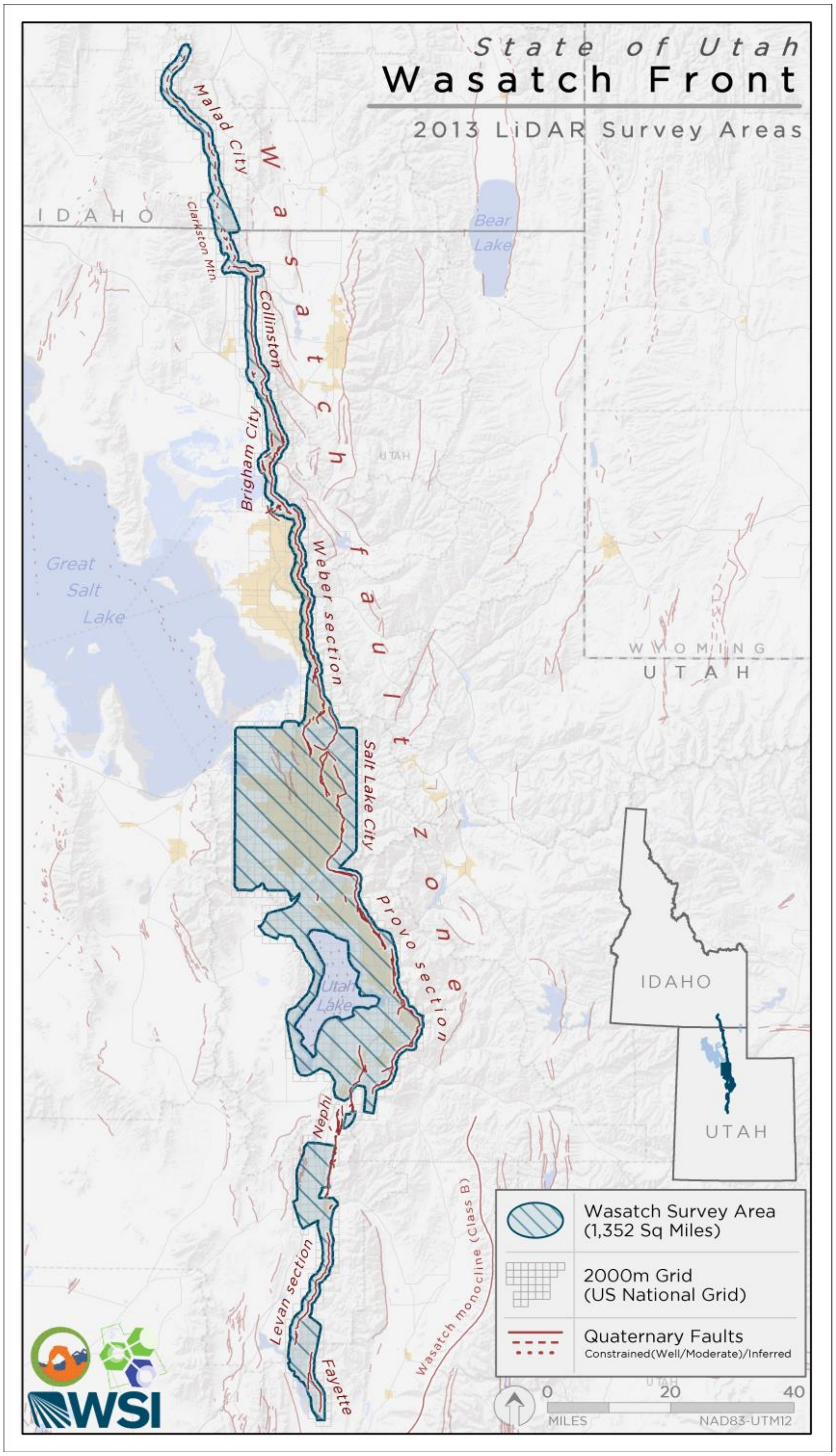
1. Overview

The State of Utah Automated Geographic Reference Center (AGRC) and the USGS National Geospatial Technical Operations Center (NGTOC) have contracted with WSI for a leaf-off, no-snow, remote sensing survey for LiDAR data along the Wasatch Front geographic area in the greater Salt Lake County, greater Utah County and areas along the Wasatch Front for the 2013-2014 winter season.

This document is intended to serve as the Project Execution Plan (PEP) by Watershed Sciences, Inc. (WSI) for LiDAR data and derivative products (classified LiDAR point clouds, DEMs, intensity images, vector data) and to provide a comprehensive workflow for all phases of the remote sensing survey project. Our partners at WHPacific will provide oversight of the GPS ground operations and post-processing, including independently collected RTK check points for evaluation of the WSI calibrated dataset. All planning, data acquisition, and data processing will be conducted by employees of WSI and WHPacific. We are committed to providing high quality data, maximizing the benefit of AGRC & NGTOC's significant investment in this project. Moreover, our team is dedicated to successful on-time completion of acquisition, processing, and finalization of the Wasatch project area data.



AGRC & NGTOC's investment will also be maximized through 100% on-shore production, promoting job stimulation and employee professional development that goes back into the U.S. economy. WSI completes 100% of our data collection and processing in-house, only looking externally for independent verification of accuracy. Our Portland location provides 12,500 square feet of workspace, 56 workstations, 10 miles of high speed cable to support data transfer, and an environmentally controlled and secure data storage room.

At no time will the WSI team outsource or offshore any portion of the workflow.

The following PEP provides a detailed submittal of WSI's proposed approach to the Wasatch Front LiDAR project, which includes our industry leading methodologies for data collection and our uncompromising QA/QC procedures.

Initial Action Items

In compiling data for this PEP, several "action items" were identified as being critical next steps that required input of all stakeholders in order to mobilize to the area and begin acquisition of this project. The list below outlines these action items and recommended timelines.

1. **FLIGHT PLAN APPROVAL:**
   The first step toward beginning acquisition is flight plan approval by AGRC. Included with this PEP are flight plan files in *.dxf and *.kml formats. We request that AGRC review the coverage to ensure complete data coverage. WSI recommends verification of flight plans at least one week before acquisition begins.

2. **PILOT AREA DETERMINATION:**
   The 10 mi^2 pilot area for LiDAR data approval by AGRC and NGTOC has not yet been established. To allow for flexibility in the location of the starting location for acquisition, WSI includes four potential pilot area locations in Appendix A of this PEP and as a shapefile. WSI recommends determining pilot areas at least one week before acquisition begins.

3. **LAS VERSION AGREEMENT:**
   AGRC has requested *.las v1.3 as the LiDAR deliverable format. WSI would like to offer that instead, *.las v1.2 be utilized. WSI has found that *.las v1.3 has several processing, memory, and storage drawbacks when compared to *.las v1.2. WSI uses *.las v1.2 rather than v1.3 for the reasons outlined in the section titled "Comparing *.las v1.2 and *.las v1.3" of this PEP. We ask that AGRC consider the use of *.las v1.2, and that a consensus be reached by the time acquisition begins.

4. **DATUM AGREEMENT:**
   The most current vertical datum for use with NAD83 HARN is Geoid 09. Utilizing the most current geoid model available from the NGS (e.g. GEOID 12A), would require the use of NAD83 (2011) as the horizontal datum.

5. **KICK-OFF MEETING:**
   The kickoff meeting has been scheduled for Thursday, September 26th, 2013 at 1pm MDT. During the meeting WSI will present our approach and finalize details of the scope of work.

TASK 1: Project Management & Coordination

Project Initiation

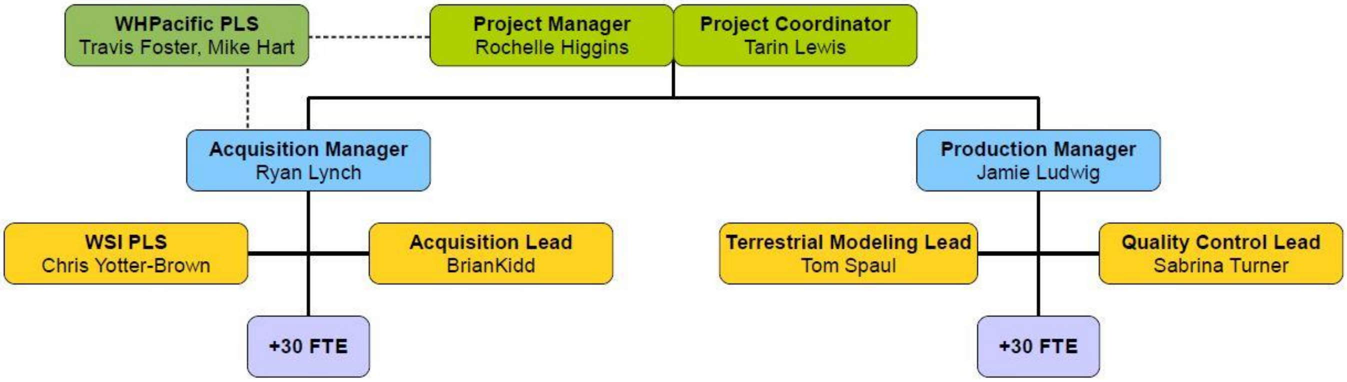
WSI and AGRC have completed the contracting phase, and have scheduled a kick-off meeting to introduce the team members, review this PEP, and discuss topics such as flight plan coverage, pilot area selection, schedule, and deliverables.

Project Management Roles and Responsibilities

Rochelle Higgins, a certified PMI Project Manager Professional, has been with WSI for twelve years and is overseeing this project. Tarin Lewis is the Project Coordinator and will be co-managing this project with Ms. Higgins. They both understand the value of stakeholder communication, and are available to the State of Utah at all times throughout completion of the project. The roles and responsibilities for this project are listed below.

Role	Responsibility	Team Member
Project Manager	Overall Project Management of scope, timeline, budget, Resolution of Technical Issues,	Rochelle Higgins 503-505-5104 rhiggins@wsidata.com
Project Coordinator	Allocate resources, WSI internal contact for project sponsors and contract employees, status reporting,	Tarin Lewis 503-505-5108 tlewis@wsidata.com
Acquisition Manager	Flight Planning, Acquisition Status Report/Review RTK Ground Check Point Coverage	Ryan Lynch 503-505-5320 rlynch@wsidata.com
Professional Land Surveyor (PLS)	Certification, Processing, Review of GPS Static Data and RTK Ground Check Point Data. Independent QC of calibrated dataset.	Travis Foster (Idaho) 208-275-8703 tfoster@whpacific.com Mike Hart (Utah) 858-715-1958 mhart@whpacific.com
Production Manager	Processing workflow resource allocation	Jamie Ludwig 503-505-5115 jludwig@wsidata.com
Terrestrial Modeling Lead	Data calibration, and relative accuracy checks, ground-model creation and supervision	Tom Spaul 503-505-5101 tspaul@wsidata.com
Quality Control Lead	Final quality assurance review of all data products.	Sabrina Turner 503-505-5305 sturner@wsidata.com

Project Staffing Plan



Communications Plan

Task	Frequency	Stakeholders	Content	Responsible Persons
Project Initiation	One-Time	WSI/AGRC & NGTOC	Review Project Scope/Schedule/ Critical Path	WSI Project Manager/ Coordinator, AGRC & NGTOC
Data Acquisition/Field Operations				
Field Crew Conference Call	Daily	WSI	Communicate Flight Plans & Report Issues	WSI Acquisition Manager, WSI Field Crew
Status Reports	Weekly, Emailed on Fridays	WSI/ AGRC & NGTOC	Graphic Showing Completed Data Acquisition with Statistics. See Status Reporting section below.	WSI Acquisition Manager & Project Manager/Coordinator
Conference Call	By AGRC & NGTOC Request	WSI/ AGRC & NGTOC	Discussion of progress and data collection plans	WSI Acquisition Manager & Project Manager/Coordinator
Data Processing/Deliverables				
Processing Team Meeting	Daily	WSI	Project Resources & Schedule	WSI Project Manager/ Coordinator & Production Manager
Status Reports	Weekly, Emailed on Fridays	WSI/ AGRC & NGTOC	Graphic report showing delivery status and schedule. See Status Reporting section below.	WSI Project Manager/ Coordinator & Production Manager
Conference Call	By AGRC & NGTOC Request	WSI/ AGRC & NGTOC	Discussion of progress/ Concerns	WSI Project Manager/ Coordinator
Project Debrief	As Needed	WSI/ AGRC & NGTOC	Relevant information on schedules & deliverables	Project Manager/ Coordinator

Performance Period & Delivery Schedule

WSI will acquire LiDAR data during fall for maximum coverage during the leaf-off/no-snow window. Should complications develop, such as early snow, WSI will work with AGRC to create an alternate schedule that may include acquisition of leaf-off data in the early spring.

Once AGRC has approved flight plan coverage, and environmental conditions allow, acquisition will begin. WSI will work with AGRC to create an agreeable schedule. WSI will take every possible step to ensure that the following proposed acquisition delivery schedule is adhered to. However, unforeseen circumstances as described in the Risk Management section of this PEP may lead to rescheduling flights or alterations in the number of square miles acquired in a given week. This may present deviations in the production schedule which will be well communicated to AGRC.

The current target start date for acquisition is October 15th, 2013. AGRC and WSI will be in communication on October 8th, 2013 to determine whether environmental conditions are such that acquisition can begin.

Proposed Pilot Project Area Schedule

Week	Acquisition Completed	Production & Delivery to AGRC & NGTOC	AGRC and NGTOC Feedback to WSI (15 days)
Week 1	10 mi^2		
Week 2			
Week 3		10 mi^2	
Week 4			
Week 5			10 mi^2

Proposed Full Project Area Schedule

Week	Acquisition Completed	Production & Delivery to AGRC & NGTOC	AGRC and NGTOC Feedback to WSI (60 days)	Re-delivery of Revised Data (10 working days)	NGTOC Review of Re-delivery Data (30 days)
Week 1	Area 1: 335 mi^2				
Week 2	Area 2: 335 mi^2				
Week 3	Area 3: 335 mi^2				
Week 4	Area 4: 345 mi^2				
Week 5					
Week 6		Area 1: 335 mi^2			
Week 8		Area 2: 335 mi^2			
Week 10		Area 3: 335 mi^2			
Week 12		Area 4: 345 mi^2			
Week 15			Area 1: 335 mi^2		
Week 17			Area 2: 335 mi^2	Area 1: 335 mi^2	
Week 19			Area 3: 335 mi^2	Area 2: 335 mi^2	
Week 21			Area 4: 345 mi^2	Area 3: 335 mi^2	Area 1: 335 mi^2
Week 23				Area 4: 345 mi^2	Area 2: 335 mi^2
Week 25					Area 3: 335 mi^2
Week 27					Area 4: 345 mi^2

Status Reporting

WSI is committed to weekly status updates with AGRC & NGTOC. WSI believes that frequent updates foster client confidence and ensure priority areas are being targeted. Depending on the status, weekly updates will include both a graphic and textual representation of:

Acquisition Update

- ✓ AOI mi^2 Acquired
- ✓ Total AOI mi^2
- ✓ Percent Acquired
- ✓ Days on Project
- ✓ Number of Days Flown
- ✓ Percent Flyable Conditions
- ✓ Average mi^2 per Day

Processing Update

- ✓ Contracted AOI mi^2
- ✓ Total Areas Flown (TAF) mi^2
- ✓ Delivery Number
- ✓ Delivery Date
- ✓ AOI Remaining

Please see Appendix B for the WSI Status Report template.

Safety

Safety is paramount during all WSI endeavors. At all times, safety in the field is ensured by strict adherence to the WSI Field Safety Plan. This plan addresses, among other topics, drug and alcohol policies, personal safety policies, communication, incident mitigation, emergency procedures, and vehicle safety. Safety pertaining to flight and ground procedures will be ensured by adherence to the WSI Flight Operations Manual and Ground Support Operating Procedures documents, which outline responsibilities, procedures and safety policies particular to each task.

Field Preparations

Successful data acquisition relies on a concerted planning effort between the flight and ground crews. Prior to each flight, the most suitable times to target for acquisition are determined by the field crews using all available methods.

WSI has maintained an impeccable safety record on past projects and we are committed to operating in a safe and responsible manner throughout the duration of the project. WSI will maintain all required permits for operation of field equipment and access to operating locations.

Risk Management

Risks are inherent to all project planning and execution. In the case of airborne remote sensing, the variability of weather always poses the greatest risk to the data acquisition schedule and is outside the control of the project team. Regardless, risk must be addressed with clear plans to mitigate the impact on the success of the project. The following provides an identification of risks, impacts, assessment, and steps to mitigate. The risks are separated into programmatic risks and general safety risks.

Risk	Impacts	Assessment	Mitigation Plan
Poor Weather	Schedule, Budget	Weather is a factor, inevitably affecting any airborne remote sensing project. Prolonged bad weather can result in inactive field crews (budget) and schedule delays.	• Monitor weather closely. • Relocate aircraft to areas with the highest probability of success. • Allocate additional resources during prolonged good weather.
Equipment Failure	Schedule	LiDAR systems are high-tech instruments that operate in harsh environments. System errors can be subtle and difficult to detect OR can be catastrophic. WSI cannot control when a system may/may not fail, but can take steps to maintain systems and minimize the impact on the project in the case of a failure.	• Reporting systems and quick-look analysis are based on experience and designed to catch system failures before they impact the project. • WSI owns 5 LiDAR systems. In the event of a failure we have enough resources to minimize the impact on acquisition schedule by deploying a different sensor. • If a system error causes the data to be out of specification, WSI will re-acquire the area or flight line
Operational Safety	Project Success	Airborne operations with ground support in remote areas have inherent risks. WSI maintains and operates reliable aircraft that are suitable for this project and provides the proper equipment to the ground crews.	• Minimize risks by providing the proper training and equipment to the field crews. • Field Crews follow established WSI Safety Protocols and Flight Operations Procedures. • Established communications protocols for reporting safety concerns.
Data Processing Anomalies	Delivery Schedule, Budget	WSI QA protocols are designed to ensure high quality data are received from the field. None-the-less data processing anomalies can still occur that can affect processing.	• Identify problem and assign technical resources. • Allocate additional processing staff or computational resources to offset any lost time due to delays in any step of the work-flow.

TASK 2: Acquisition

Flight Planning

WSI has retrieved the file "Utah_Lidar_2013.shp" downloaded from the "ftp.agrc.utah.gov" website. To coordinate and manage all field activities, plans are made in advance using National Agriculture Imagery Program (NAIP) imagery, while aerial survey flightlines are developed using Leica Geosystems Flight Planning and Evaluation Software (MissionPro v11.0.3.57909 SP3), and ALTM-NAV-Planner (v.2.6.30). This ensures that data quality and coverage conditions are met while optimizing flight paths for minimal flight times. Flight plans are created considering desired route, terrain relief, and the recommended sensor settings.

Please note that the actual location, direction and altitude of the flights paths may change, due to weather and sensor/aircraft configuration. Approval of the plans will consist of verification that the flight paths are over the desired area.

Above: A Partenavia P-68 is one platform for collecting LiDAR.
Below: A Cessna Grand Caravan (208B) to gather orthophotos

Aircraft

WSI owns and operates two Cessna 208B Caravans and will have at minimum one aircraft dedicated to the project for its entirety. WSI can immediately deploy one additional Cessna 208B caravan and/ or two additional P-68 aircraft should weather or other logistical concerns develop during acquisition. WSI targets 6 hours of aerial acquisition per day, with the Caravan capable of 7+ hours of endurance with maximum fuel load.

Above: The Leica ALS70
Below: The Leica ALS60

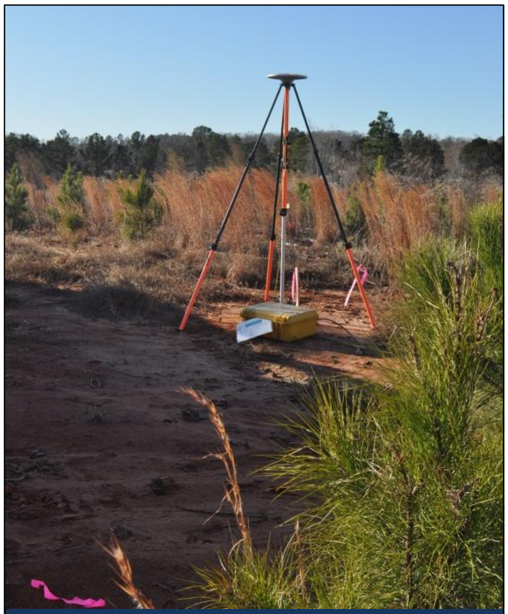
Sensors

This LiDAR survey will utilize both a Leica ALS60 and an ALS70 sensor. The LiDAR systems will be set to acquire ≥150,000 laser pulses per second (i.e., 150 kHz pulse rate) while being flown at 1,400 meters above ground level (AGL), capturing a scan angle of 28° from nadir[1]. The survey implemented opposing flight lines with side-lap of ≥50% (≥100% overlap) to reduce laser shadowing and increase surface laser painting. To solve for laser point position, an accurate description of aircraft position and attitude is vital. Aircraft position is described as x, y, and z and is measured twice per second (2 Hz) by an onboard differential GPS unit. Aircraft attitude is described as pitch, roll, and yaw (heading) and is measured 200 times per second (200 Hz) from an onboard inertial measurement unit (IMU).

LiDAR Acquisition Characteristics	
Pulse Frequency	Up to 200kHZ
Pulse Density	>8/m2
Scan Frequency	50 Hz
Scan Width FOV	28°
Planned envelope Minimum	780 m AGL
Planned Envelope Maximum	1280 m AGL
Intensity/ Range Capture	3
Position / Orientation System	Honeywell uIRS 200 Hz-IMU NoaATEL-OEMV GPS/SNDD/L-Band receiver
Manufacturer Model / Type	Leica ALS60

Ground Survey

WSI stands apart from other LiDAR vendors because we incorporate a rigorous ground survey component. Because we deploy an extensive network of WSI-owned ground survey equipment during each LiDAR flight, we are able to provide survey and engineering grade LiDAR data that are accurate to within centimeters. As described in this section, we will have a full ground survey crew and equipment dedicated to the Wasatch project at all times.

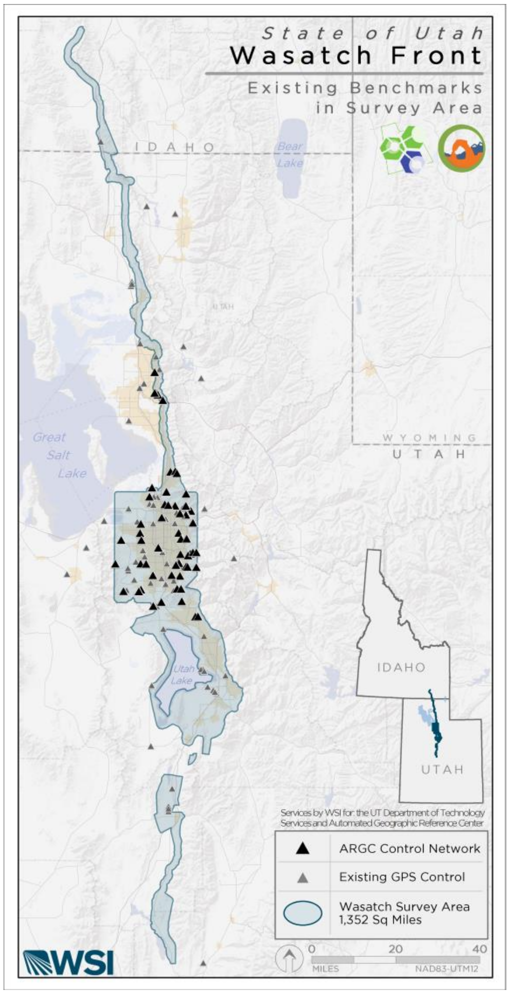


Trimble Base Station collecting static data.

Simultaneous to the airborne data collection missions, our team will collect static (1 Hz recording frequency) positional data across a network of dual-frequency DGPS base stations. Time-indexed GPS data are used to correct the continuous onboard measurements of aircraft position recorded throughout the mission. WSI and WHPacific will ensure quality GPS data are acquired for this project. Potential survey monument locations have been identified. Where possible, WSI will occupy first order National Geodetic Survey (NGS) Continuously Operating Reference Stations (CORS) published monuments with NAVD88, and update published coordinates based on our occupation results.

All established monuments will be tied to first order NGS published monuments with NGS CORS. In areas where existing control monuments do not meet the minimum criteria of currency, reasonable access, and proximity to the mission area, we will establish and certify new monuments.

Our project team will occupy each monument for a minimum of two independent sessions (4+ hours, 2+ hours) to verify and update control coordinates. Each new monument will be located by tying to one or more NGS CORS by static GPS. Maximum baseline lengths between control points and the aircraft GPS will not exceed our standard of 24 kilometers (13 nautical miles). We have found that both absolute and relative accuracy degrade quickly when baseline lengths exceed 13 nautical miles.



LiDAR point calibration QA/QC will use ground check points (GCPs) using GPS-based real-time kinematic (RTK) survey techniques. For an RTK survey, the ground crew uses a roving unit to receive radio-relayed corrected positional coordinates for all ground points from a GPS base unit set up over a survey control monument. The roving unit records precise location measurements with a standard deviation error (σ) at $\leq$ 1.5 cm relative to the base control. All acquisition will occur during optimal GNSS conditions (e.g., 6 or more satellites and a Position Dilution of Precision [PDOP] below 3.0). Daily forecasts from Trimble Planning software ensure that these conditions are met.

For the Wasatch Project, a variety of GPS control points will be collected, as provided below:

1. **Control Points:** WSI will collect >100 points in each of the following land cover classes:
    a. Brush lands and low trees (predominant land cover class in the project area; we will not be focusing on medium vegetation)
    b. Forested areas fully covered by trees
    c. Urban areas with dense man-made structures

2. **Checkpoints:** WSI will collect >20 hard surface checkpoints for verification of the data; these points will not be incorporated into the vertical solution of the LiDAR data.

3. **Ground Control Points (RTK):** WSI will collect at least 4,500 hard surface RTK points in the study area, which will be used to calibrate the LiDAR data and assist in QC procedures.

WSI will collect at least 500 hard surface RTK points per150 square miles of the study area, for a total of >4,500 RTK points for the Wasatch project

All acquired LiDAR data, base station and GCP data will be "quick-looked" in the field and sent daily to our Portland, Oregon processing center for next-day processing. At the conclusion of each week and the entire survey, a project report of the acquisition status will be generated and sent to the State of Utah.

Relationship with WHPacific

WHPacific will be responsible for oversight of the GPS ground operations and post-processing, PLS certification for Utah and Idaho, as well as providing independent GCPs for a "blind" evaluation of the calibrated dataset created by WSI. Mike Hart, a Utah PLS, and Travis Foster, and Idaho PLS will be working together to oversee these operations and assist in statistical reporting.

Example of a Trimble R7 GNSS base station and radio antenna set up over a survey monument.

WSI and WHPacific are committed to providing a quality combined product and as such, have built an interactive schedule and workplan designed to create a high-resolution, high-accuracy dataset in a timely fashion.

WHPacific will act as an independent party to assess, report, and attest to the quality of the acquired data. WHPacific will verify all WSI observation files as they are collected in the field during our survey to develop final coordinates. Each static file will be processed by the following methods:

1. Utilize OPUS to derive N, E, Z values
2. Process against the CORS network using Trimble Business Center, independent of the OPUS solution
3. Integrate data into a network solution and adjust using the traditional minimal constraint, H constraint, V constraint, and then fully constrained adjustment to arrive at the final control point value.

Files will be delivered in clusters as they are observed, assessed, and returned to WSI within 5 days for comparison of final coordinates as well as calibration of LiDAR data.

WHPacific is responsible for conducting independent ground truthing and QC work in the project area for all three types of GCPs. They will incorporate use of the Utah RTN where accessible. WHPacific and WSI will work in an iterative QC process delivering N, E positions without Z, followed by a WHPacific comparison and statistical assessment, and exchanging results.

As a final stage, WHPacific will provide comprehensive reporting, and stamped certification for the states of Utah and Idaho upon completion and approval of the calibrated data.

TASK 3: Data Processing

LiDAR Data

Once the LiDAR data arrive on site, WSI employs a suite of automated and manual techniques for processing. The overall goal of LiDAR point processing is to rapidly create highly accurate data. Processing tasks include: GPS post processing, kinematic corrections, calculation of laser point position, relative accuracy testing and calibrations, classification of ground and non-ground points, assessments of statistical absolute accuracy (i.e. fundamental vertical accuracy), and creation of ground and highest hit surface models. Absolute accuracy will be assessed by comparing laser points to ground level survey data (i.e., GCPs). The general workflow for LiDAR deliverables processing will include:

LiDAR Processing Step	Software Used
Resolve GPS kinematic corrections for aircraft position data using kinematic aircraft GPS (collected at 2 Hz) and static ground GPS (1 Hz) data collected over geodetic controls.	POSGNSS v. 5.3, Trimble Business Center v. 2.30, PosPacMMS v 5.4
Develop a smoothed best estimate of trajectory (SBET) file that blends post-processed aircraft position with attitude data. Sensor heading, position, and attitude are calculated throughout the survey.	POSGNSS v. 5.3, PosPacMMS v5.4 IPAS Pro v.1.35
Calculate laser point position by associating SBET information to each laser point return time, with offsets relative to scan angle, intensity, etc. included. This process creates the raw laser point cloud data for the entire survey in *.las (ASPRS v1.2) format, in which each point maintains the corresponding scan angle, return number (echo), intensity, and x, y, z information. These data are converted to orthometric elevation (NAVD88) by applying a Geoid 12 correction.	ALS Post Processing Software v. 2.74
Import raw laser points into subset processing tiles (less than 500 MB, to accommodate file size constraints in processing software). Filter for noise and perform manual relative accuracy calibration. Ground points are then classified for individual flight lines to be used for relative accuracy testing and calibration.	TerraScan v.12, Custom Watershed Sciences software
Test relative accuracy using ground classified points per each flight line. Perform automated line-to-line calibrations for system attitude parameters (pitch, roll, yaw), mirror flex (scale) and GPS/IMU drift. Calibrations are performed on ground classified points from paired flight lines. Every flight line is used for relative accuracy calibration.	TerraMatch v.12, TerraScan v.12, Custom Watershed Sciences software
Classify using custom methodologies	TerraScan v.12

Each LiDAR sensor is tuned and calibrated at its respective factory prior to delivery. A calibration test flight is also performed every time a sensor is installed (or re-installed) in an aircraft or in the case of any in-field maintenance. The calibration test flight verifies computation of lever arms and ultimately the relative and absolute accuracy of the system. The calibration test flights are documented electronically for each flight. Further, each mission is calibrated to remove IMU initialization bias.

WSI collects a suitable sample size of GCP measurements to compare to laser points collected on bare earth surfaces for a robust absolute accuracy assessment. This accuracy assessment serves also as a verification of the calibration of the sensor. Absolute accuracy assessments compare known ground survey points to derived LiDAR points. Accuracies will be described as the mean and standard deviation (sigma~σ) of divergence from ground survey point coordinates. These statistics assume the error for x, y, and z is normally distributed, and therefore we also considered the skew and kurtosis of distributions when evaluating error statistics. All accuracy statistics ($RMSE_z$, $Accuracy_z$ - 1.96 σ (standard deviation), skewness/distribution, and percentile deviations) will be reported. In flights involving LiDAR acquisition over mountainous areas, **we have consistently achieved absolute accuracy values less than RMSE 9 cm.**

Within-Swath Reproducibility

Whenever possible, WSI will take steps to maximize within-swath reproducibility by flying low, employing terrain following, increasing laser power, targeting optimal GPS windows, and reducing scan angles. Departures from planarity should not exceed 10 cm for the project as a whole, and the RMSE within any 10m x 10m area will be less than 9 cm. Typical laser noise evaluated over multiple projects completed by WSI has been approximately 2 cm.

Swath-to-Swath Reproducibility

We address swath-to-swath reproducibility by comparing overlap between flight lines, and by conducting orthogonal flight lines over study areas (to detect slight system misalignments). Relative accuracy will be assessed and slight system pitch, roll, and yaw misalignments were corrected through automated sampling and calibration routines comparing elevation, slope and intensity values for the within two or more overlapping flight lines. Relative accuracy will be calculated by averaging reproducibility determined from near-planar areas across an entire survey area.

The LiDAR coverage will be completed with no data gaps or voids, barring non-reflective surfaces (e.g., open water, wet asphalt, etc.). We will take all necessary measures to acquire data under conditions (e.g., minimum cloud decks) and in a manner (i.e., adherence to flight plans) that prevent the occurrence of data gaps. Moreover, terrain following to maintain consistent aircraft altitudes will eliminate the potential for data gaps related to both acquisition and laser shadowing of targets.

Comparing *.las v1.2 and *.las v1.3

AGRC has requested a LiDAR deliverable format of *.las v1.3. WSI would like to recommend that *.las v1.2 be implemented and delivered instead. Though the capability for waveform data was included in the ASPRS *.las file definition with the introduction of version 1.3, WSI has found that v1.3 has several processing, memory, and storage drawbacks when compared to v1.2. File sizes greatly increase with v1.3 as do record sizes; returns that are typically limited to first, second, third, and last with v1.2 become dependent on user settings for v1.3. In addition, large amounts of returns that are solely noise and of no value relevant to analysis are retained in the dataset. Additionally, due to the high amount of these false returns in v1.3, processing is extremely labor intensive and not streamlined for commercial usability. Even without waveform data, v1.3 *.las files are as cumbersome as they would be with waveform data, due to the fact that specific waveform fields are still present, storing null values, and requiring just as many bytes. Proprietary software packages by sensor vendors only take advantage of raw time-of-flight data for waveforms, while very few off-the-shelf software products take advantage of waveform data. Almost no automated approaches to these data exist outside of academia.

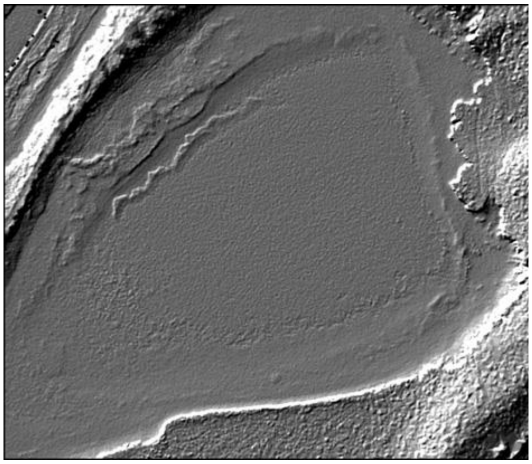
WSI uses *.las v1.2 because it is our belief that increasing the acquisition pulse density of a dataset is the key to generating richer, more revealing analysis. Increasing the pulse density of a dataset requires more individual measurements to any given target—allowing for more perspectives of each ranging event. This practice has the benefit of simultaneously improving the likelihood of illuminating more targets while minimizing the risk of noise, potentially degrading analysis. WSI requests that AGRC consider accepting *.las v1.2 and provide a decision to WSI by the time acquisition begins.

Hydro-Flattening

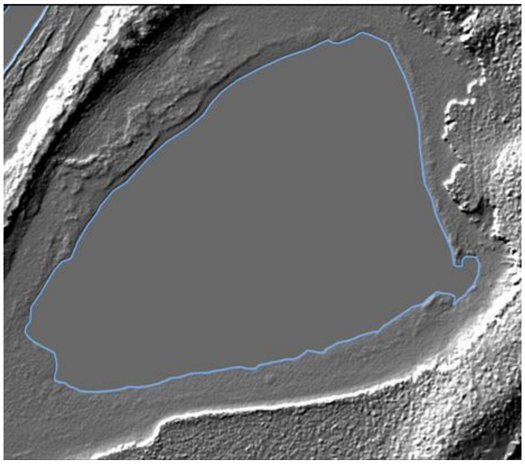
The bare-earth hydro-flattened digital DEMs will be hydro-flattened according to the USGS's National Geospatial Program's "LiDAR Guidelines and Base Specification" Version 13 (USGS NGP). For all water bodies perceived to be "flat," LiDAR points will be sampled to arrive at an elevation threshold defining the water surface at a uniform elevation where the water edge meets the surrounding terrain. Three-dimensional breaklines will be created to encompass all areas considered to be water and will be assigned the determined water surface elevation value. All "flat" water bodies greater than two acres will be considered for hydro-flattening. All "islands" greater than 100 square meters will be retained in the DEMs. All "streams" greater than 100 meters across will be considered for hydro-flattening.

Centerlines will be digitized for all water surfaces not perceived as "flat." The three-dimensional Z value will be generated from the LiDAR points collected. A smoothing algorithm will be applied to ensure centerlines consistently run downstream. LiDAR points will be classified as water using the Z threshold values of the appropriate centerlines. A breakline polygon will be created around the water points with all discontinuities such as bridges and overhanging vegetation removed. These Z values will be applied to the breakline polygons based on the elevation values of the closes, associated centerline vertex.

The bare-earth DEMs will be created by triangulating all ground classified points and inserting 3-D breaklines by utilizing Terra-Solid's TerraScan and TerraModeler software. Any ground points within one meter of the breaklines will be reclassified to "ignored-ground" (ASPRS code: 10) before triangulation. The highest-hit DEMs will be generated from "ground" and "default" classified points. In instances where "water" classified points have the highest elevation value, the water surface elevation from the bare-earth raster will be used.



Hillshade of non-hydro-flattened raster



Hillshade of hydro-flattened raster with corresponding breaklines

Data Delivery and Acceptance

All delivery products will be at a minimum compatible with USB 2.0 drives. Deliveries will be made according to the delivery schedule agreed upon by AGRC & NGTOC.

WSI understands the importance of a thorough and independent inspection on a dataset before the release of those data to the public. WSI is prepared to accommodate the following procedure for interaction with AGRC and NGTOC for preliminary and final deliveries of processed data.

1. Prior to data acquisition, WSI and AGRC will select a pilot area, encompassing a 10 square mile block area, to be delivered ahead of the remainder of the project area, to ensure WSI's ability to provide data meeting the specifications of this RFP. Acquisition would begin with this area, and upon receipt of data to the office in Portland, would enter into the processing workflow, as acquisition continues. All products would be developed, a data report produced, and all specifications, methodologies and accuracies presented to Both AGRC and NGTOC. AGRC and NGTOC will have 15 calendar days to respond to WSI with feedback, which will ensure all issues regarding the acquisition and delivery of data are clearly communicated and remedied before the remainder of the study area is provided.
2. WSI will continue to acquire the remainder of the study area, process the data in blocks, and provide it to AGRC for review and initial quality control assessment.
3. AGRC will then provide the data to NGTOC for preliminary review (60 days).
4. NGTOC will then provide QC requests to AGRC who will then submit requests for edits to WSI.
5. Upon review and submission of any QC items, WSI will then proceed, integrating those amendments, to produce the final dataset within 10 working days.
6. NGTOC and AGRC will then have 30 days to do a thorough review of the final deliverable, as is required for final acceptance of the data.

WSI agrees not to release data produced as part of this project to any other party or entity prior to the geodatabase processing, loading, incorporation, and USGS acceptance procedure. After final acceptance, all deliverable data and documentation will be free from restriction regarding use and distribution. Data produced and provided during this project effort will be in the public domain and freely distributed by Federal, state, and local government agencies. It is WSI's policy, even on publicly-available datasets, to secure the permission of the funding partners prior to distribution of any product to any third party.

WSI agrees to all proposed invoicing terms and expects that all data will be delivered well before the May 31, 2014 deadline.

Quality Assurance and Quality Control Procedures

To ensure the LiDAR data and corresponding deliverables meet the required specifications, rigorous QA/QC is performed throughout the acquisition, processing and finalization stages of the survey.

Data Collection

Flight Plans - Shapefiles provided by the client have been overlaid on available aerial imagery and verified to completely and correctly capture the targeted area. These files have been submitted to AGRC for approval.

Airborne - On the same day as acquisition, all LAS files will be verified (with redundancy) to contain complete and correct header information, variable length records, geo-encoding, adjusted GPS time stamps, point record families and complete study area coverage.

Ground Survey

- Static – Static data collected over either pre-existing NGS monuments or newly set WSI monuments will be adjusted using the Online Positioning User Service (OPUS[1]) to quantify daily variance. After multiple sessions of data collection at each monument, accuracy will be calculated. All static survey data, including base station coordinate finalization, will be conducted under the supervision of WHPacific.
- GCPs – The positions and quality of these data will be verified internally by WSI prior to their use in LiDAR processing.

Data Processing

LiDAR Data - In order to proceed with deliverables, initial calibration and LiDAR processing results must meet internal WSI standards.

- Relative Accuracy - Relative accuracy will be calculated by comparing hard surface returns between adjacent or overlapping swaths. Cross-hatch patterns flown outside the study area, both before and after data collection, will be used for data calibration and relative accuracy calculation. **Data will be analyzed to ensure swath-to-swath relative accuracy ≤5cm RMSE.**
- Vertical Accuracy - Vertical accuracy will be calculated by comparing known GCPs collected using a real-time kinematic (RTK) survey to a TIN created from ground classified points. **Data will be analyzed to ensure vertical accuracy ≤9cm RMSE.**

LiDAR Data Processing

- Completeness - Immediately post-acquisition, all LiDAR data will be verified for completeness.
- Tile Naming and Georeferencing - All file naming conventions and georeferencing will be verified in comparison to the desired tiling scheme and deliverable coordinate system.
- Correctness - The point cloud classification will be reviewed using customized noise detection routines, identifying anomalies caused by sensor malfunction, artifacts caused by processing, and incorrect point classifications. Supervised review of point classifications will be conducted and areas with obvious misclassification will be addressed.
- Resolution - A quantitative analysis for resolution will be conducted. Density of first return laser pulses and ground-classified laser points will be computed. Statistical summaries for each class per tile will allow for a review of the distribution of points.

Deliverables

All deliverables will be inspected for correct formatting, scaling, units and completeness.

[1] OPUS is run by the National Geodetic Survey to process corrected monument positions.

Deliverables

Ground Survey Data Deliverables

Survey Monuments	
Accuracy	$RMSE_{XY} \leq$ 1.5 cm & $RMSE_{Z} \leq$ 3.0 cm
Resolution	One per 13 nautical miles
Occupation	Minimum independent occupation of 4 hrs & 2 hrs
Equipment	Trimble R7/R8 GNSS/GLONASS
Projection	Universal Transverse Mercator (UTM) Zone 12
Horizontal Datum	NAD83 HARN
Vertical Datum	NAVD88 GEOID 09
Units	Meters

Ground Check Points	
Accuracy	$RMSE_{XYZ} \leq$ 1.5 cm (*Deviation from monument coordinates)*
Resolution	≥100 per surveyed monument & ≥ 500 total per field day expected
Equipment	Trimble R7/R8 GNSS/GLONASS
All ground survey data will be certified by WHPacific.	

Project Deliverables

WSI will work with AGRC to ensure high-quality deliverables, listed below. As applicable, WSI will deliver data using the USNG and 1000 m^2 tiles as specified in the contract.

Calibrated LiDAR Point Data (1000m x 1000m tiles) *.las v1.2 or v1.3	
Sensor	Leica ALS 60 or 70
Aircraft	Cessna Caravan 208B and Partenavia P-68
Accuracy	FVA RMSE $_{Z} \leq$ 9 cm, Relative Accuracy RMSDz ≤ 5 cm
Resolution/Density	≥8 pulses per square meter
Maximum Returns	4
Intensity	12-bit
GPS Baselines	≤13 nm

GPS PDOP	≤3.0
GPS Satellite Constellation	≥6
Planned Height	1,500 m (above ground level)

LiDAR Data	
*.las v1.2 or v1.3	Raw point cloud
Classified *.las	1. Processed unclassified; 2. Bare earth ground; 7. Noise; 9. Water; 10. Ignored ground; 11. Withheld
RGB *.las	RGB values applied to .las based on existing NAIP imagery or other orthophotography as specified by client.

Raster Data	
Bare Earth	0.5m, .img, hydro-flattened (all water bodies >2 acres, streams >100m wide)
Highest Hit	0.5m, .img
Intensity Images	0.5m, GeoTIFF
Ground Density Images	0.5m ground and first return (ESRI grid format)

Vector Data	
Tile Delineations	.shp, US National Grid
Area of Interest	.shp, Project area and delivery area
Total Area Flown	.shp
Ground Control	.shp
Flight trajectories	.trj, SBET, by mission in single folder
Real Time Kinematic points	.shp, control points with land cover classes
Breaklines	.shp

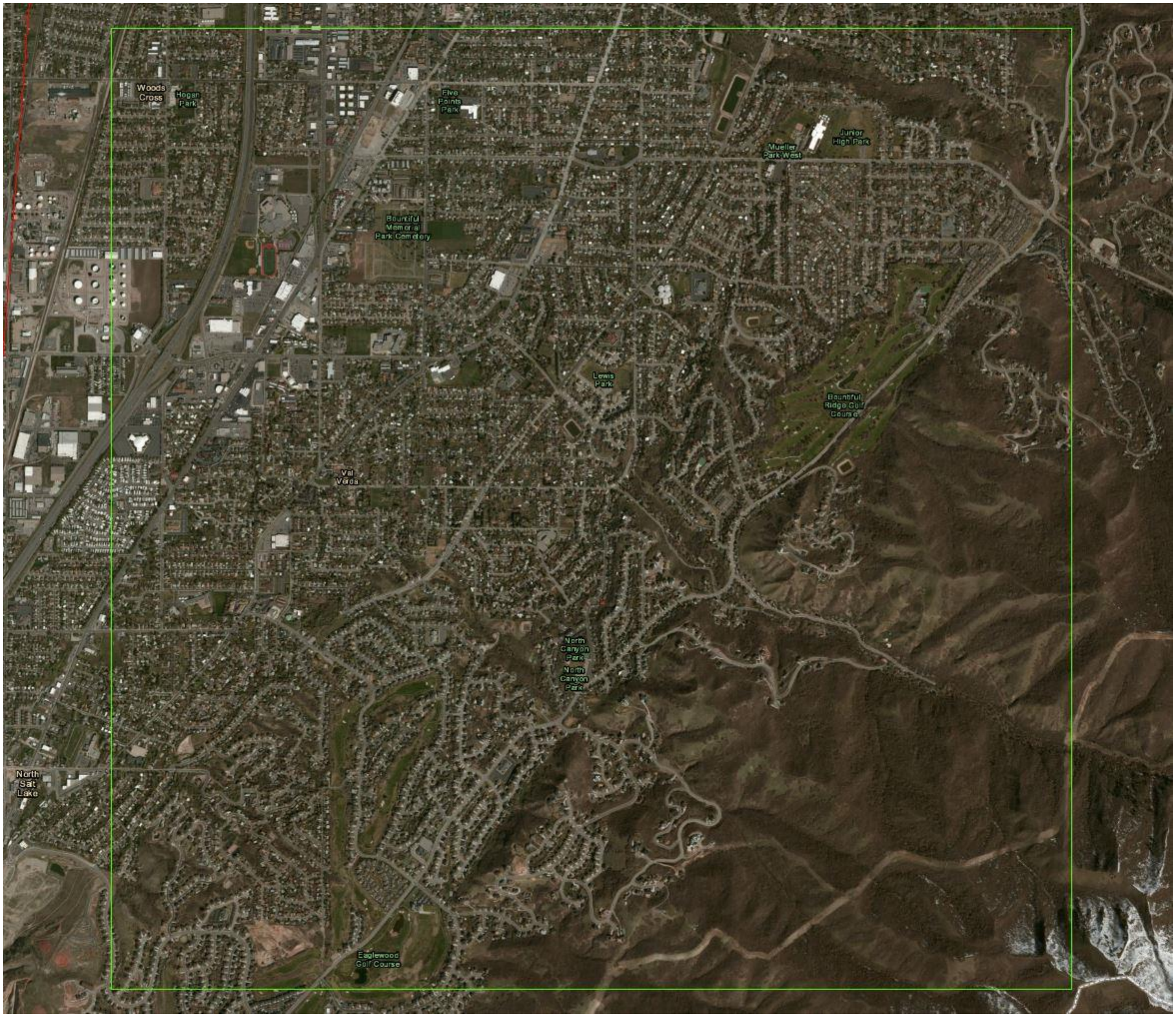
Other Deliverables	
Metadata*	WSI standard and as detailed in section 5.2 of contract
Data Report	WSI standard plus Project History Report as detailed in section 5.3 of contract

*All metadata shall meet or exceed National Spatial Data Infrastructure Content Standards for Digital Geospatial Metadata (FGDC, 1998) and LiDAR Base Specifications Version 1.0 (USGS, 2012)

Appendix A: Pilot Area Options

Pilot Area Options Overview

Pilot Area Option 1



Pilot Area Option 2

Pilot Area Option 3

Pilot Area Option 4

Appendix B: Project Status Update Template

Applied
Remote Sensing
and Analysis

[DATE]

Project Status Update:

Wasatch Front LiDAR Elevation Data Survey 2013 – 2014

Prepared for:
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UTAH AGRC
Automated Geographic Reference Center

Applied Remote Sensing and Analysis

Project Overview

The Wasatch Front LiDAR Elevation Survey study area covers approximately 1352 mi^2 in the greater Salt Lake County, greater Utah County, and areas along the Wasatch Fault in Sanpete, Juab, Davis, Weber, and Box Elder Counties in Utah as well as Oneida County in Southern Idaho. The objective of this project is to acquire LiDAR elevation data and LiDAR derivatives thereof for geological analysis.

[Additional information including a map of areas which have been acquired and/or delivered.]

Project Area Status Map

Current Project Status

[Acquisition or processing status, updates on action items, etc.]

Timeline

[Acquisition or processing status, updates on action items, etc.]

Schedule Item	Start Date (Estimated)	Completion (Estimated)	Reported Percent Complete
Acquisition	(date)	(date)	(%)
Calibration	-	-	-
Processing	-	-	-
Finalization & QA/QC	-	-	-
Delivery	(date)		

Details per Planned Delivery Area

- **[Area 1 Delivery]**
  Size: [sq mi.]
    - [Details for each processing stage]
    - [Initial delivery status]
    - [Final delivery status]
    - [Other]
- **[Area 2 Delivery]**
  Size: [sq mi.]
    - [Details for each processing stage]
    - [Initial delivery status]
    - [Final delivery status]
    - [Other]
- **[Area 3 Delivery]**
  Size: [sq mi.]
    - [Details for each processing stage]
    - [Initial delivery status]
    - [Final delivery status]
    - [Other]
- **[Area 4 Delivery]**
  Size: [sq mi.]
    - [Details for each processing stage]
    - [Initial delivery status]
    - [Final delivery status]
    - [Other]