JUNE 4, 2014


# State of Utah

# Utah LiDAR 2013/2014

## North Delivery

### Technical Data / Project History Report

Prepared For:

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WSI Applied Remote Sensing and Analysis

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# Overview

WSI is pleased to report that data collection, processing, and reporting is complete for the North Delivery of the Utah LiDAR 2013/2014 project. The total project area is 1,352 square miles along the Wasatch Front geographic area in the greater Salt Lake County, greater Utah County, and areas along the Wasatch Fault in Sanpete, Juab, Davis, Weber, Box Elder, and Oneida (Idaho) counties. Data acquisition, and all derivative products, met or exceeded all specifications outlined in the Scope of Work finalized on September 12, 2013.

The North Delivery area encompasses 988.84 square miles. 511.73 square miles of this delivery, in Salt Lake County, has not been delivered previously.

The provided Quality Level 1 LiDAR can be used in the detection of earthquake faults and related hazard modeling, to prepare for and mitigate flooding hazards through FEMA's Risk Map, and to delineate building and structure footprints for general purpose mapping.

See Table 1 (below) for a summary of data acquisition for data delivered to date.

PROJECTION
Universal Transverse Mercator, Zone 12N

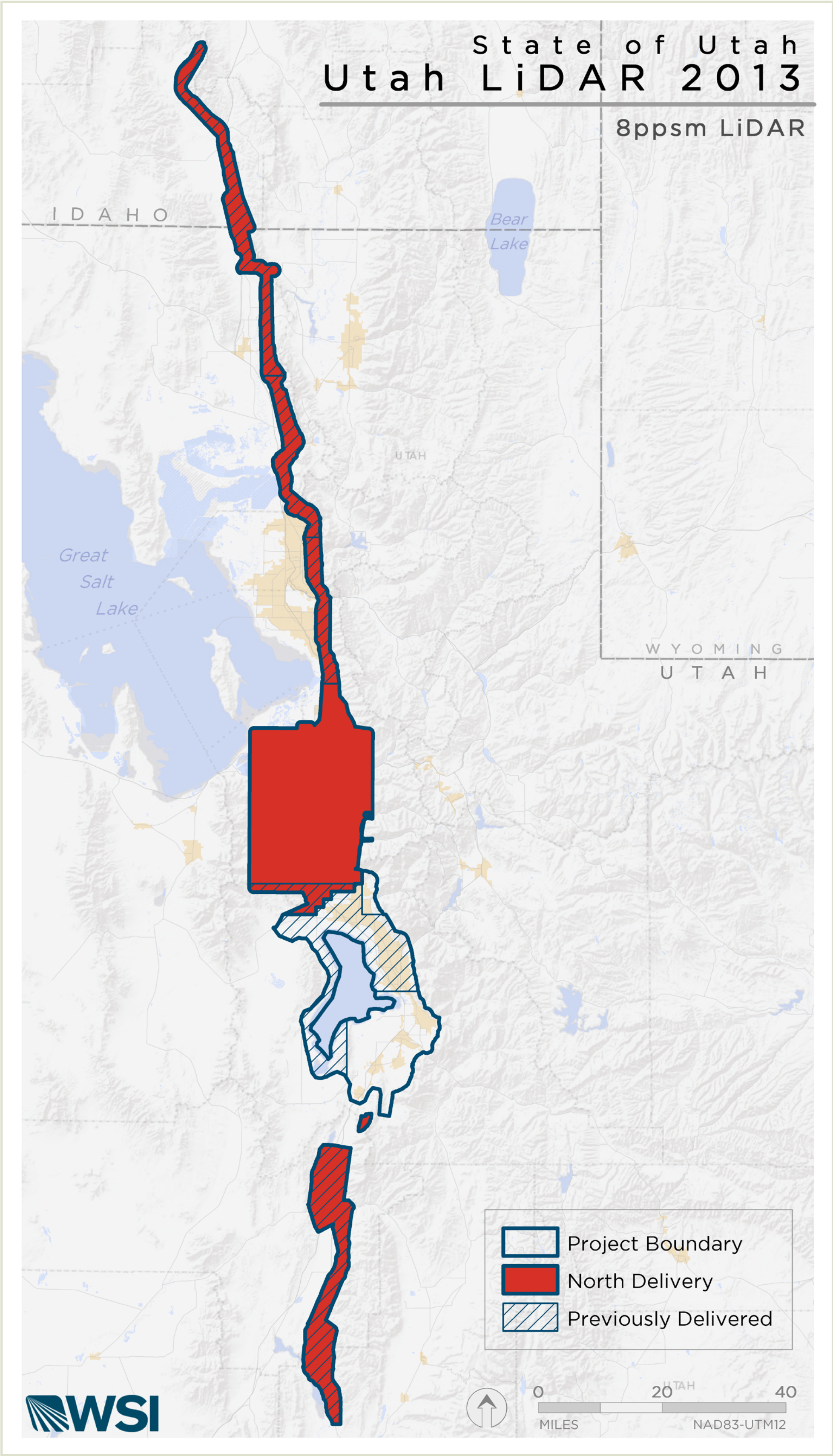
DATUM
Horizontal:
North American Datum of 1983 (NAD83) 2011
Vertical:
North American Vertical Datum 1988 (NAVD88), GEOID 12A

UNITS
Meters

Table 1 Acquisition dates

| Utah LiDAR 2013/2014 Summary | | | |
|---|---|---|---|
| Delivery | Area of Interest (AOI) | Acquisition Dates | Delivery Date |
| Delivery 1 | 190.6 square miles | 10/18 - 10/19, 10/22 - 10/23, 10/25 - 10/27/2013 | 11/22/2013 |
| Delivery 2 | 250.5 square miles | 10/21, 11/02, 11/06-11/11/2013 | 12/06/2013 |
| Delivery 3 | 265.8 square miles | 11/08, 11/11-11/14, 11/17-11/20, 11/26, 11/30, 12/01/2013 | 12/20/2013 |
| Combined Deliveries 1 and 2 | 441.1 square miles | 10/18-10/19, 10/21-10/23, 10/25-10/27, 11/02, 11/06-11/11/2013 | 2/17/2014 |
| North Delivery | 988.84 square miles<br><br>(477.11 sq mi previously delivered)<br>(511.73 sq mi new data) | 10/18-10/19, 10/21-10/23, 10/25-10/27, 11/02, 11/06-11/11, 11/26-11/27, 11/29/2013<br>3/12-3/13, 3/15-3/16, 3/19-3/22/2014 | 6/04/2014 |

Overview Map



# Deliverables

## LiDAR Data

- Raw Flightline LAS 1.2 files
- Fully classified LAS 1.2 files
  - RGB extraction
  - LAS Headers

## Vector Data

- Data extent (Area of Interest)
- USNG Tiling schemes
  - LAS: 1,000 x 1,000m
  - Rasters: 2,000 x 2,000m
- Hydro Breaklines

## Rasters (0.5 meter resolution)

- Hydro flattened bare earth DEM
- Highest hit DEM
- Intensity images
- Ground density images

## Acquisition Data

- Ground Control Check Points
- Withheld Hard Surface Check Points
- Withheld Land Class Check Points
- Survey Control Monuments
- Flightlines (SBET and *.trj)

## AGRC Control Procedures

Per control monument:

- 1 photo looking at the tripod over the point facing north
- 1 photo looking at the tripod over the point facing east
- 1 photo looking at the tripod over the point facing south
- 1 photo looking at the tripod over the point facing west
- 1 photo close-up of the point on the ground
- 1 Field Observation Sheet filled out completely
- 1 Raw GPS observation file for control point in RINEX format
- 1 National Geodetic Survey Online Positioning User Service (OPUS) Report

## Metadata

Metadata for all deliverable shapefiles and rasters meet or exceed National Spatial Data Infrastructure Content Standards for Digital Geospatial Metadata (FGDC, 1998) and LiDAR Base Specifications Version 1.0 (USGS, 2012).

| LiDAR Point Classifications | |
|---|---|
| 1 | Processed unclassified |
| 2 | Bare earth ground |
| 7 | Noise |
| 9 | Water |
| 10 | Ignored Ground |

# Acquisition

## Planning

After receiving the proposed study area from the State of Utah, WSI began the flight planning process.

Flightlines were developed using ALTM-NAV Planner (v.3.0) software. Careful planning of the pulse rate, flight altitude, and ground speed ensured that data quality and coverage conditions (8 pulses per square meter) were met while optimizing flight paths for minimal flight times.

The mission planning conducted at WSI was designed to optimize flight efficiency while meeting or exceeding project accuracy and resolution specifications. During this process, WSI prepared for known factors, such as GPS constellation availability, acquisition windows, and resource allocation. In addition, a variety of logistical barriers were anticipated, namely required permitting, air space restrictions, and acquisition personnel logistics.

While in the field, weather hazards and conditions affecting flight were continuously monitored due to their impact on the daily success of airborne and ground operations.

WHPacific provided oversight of the GPS ground operations and post-processing, including independently collected RTK check points, for evaluation of the WSI calibrated dataset.

## Ground Survey

### Monumentation

The ground survey conducted by WSI serves to establish GPS positions that are used in processing to ensure the accuracy of the data. The survey for Utah LiDAR 2013 included establishing and occupying survey control, collecting static positional data, and collecting ground check points (GCPs) using GPS real-time kinematic (RTK) survey with a roving radio relayed unit.

Using the High Accuracy Reference Network (HARN) and the Continuous Operation Reference System (CORS), WSI tied to a network of points with orthometric heights determined by differential leveling. Where available, First Order National Geodetic Survey (NGS) published monuments with NAVD88 were used. In the absence of NGS benchmarks, WSI produces our own monuments. Every effort is made to keep monuments established by WSI within the public right of way or on public lands. If monuments are necessary on private property, consent from the owner is required. All monumentation is done with 5/8" x 30" rebar topped with a two inch diameter aluminum cap stamped "Watershed Sciences, Inc."

WSI owns and operates multiple sets of Trimble Global Navigation Satellite System (GNSS) dual-frequency L1-L2 receivers, which were used in both static and RTK surveys (see table below).

During each LiDAR mission, a ground-based technician was deployed, outfitted with two Trimble Base Stations (R7) and one RTK Rover (R8).

| GPS Specifications | |
|---|---|
| GPS Satellite Constellation | ≥ 6 |
| GPS PDOP | ≤ 3.0 |
| GPS Baselines | ≤ 13 nm |

Receiver Equipment Specifications:

| Receiver Model | Antenna | OPUS Antenna ID | Use |
|---|---|---|---|
| Trimble R7 GNSS | Zephyr GNSS Geodetic Model 2 | TRM55972.00 | Static |
| Trimble R8 GNSS | Integrated Antenna R8 Model 2 | TRM_R8_Model 2 | Static & RTK |

# Final Monument Positions

All static control points were observed for a minimum of one two-hour session and one four-hour session. At the beginning of the session the tripod and antenna were reset, resulting in two independent instrument heights and data files. Data were collected at a recording frequency of one hertz using a 10-degree mask on the antenna. GPS data were uploaded to WSI servers for WSI PLS QA/QC and oversight. OPUS processing triangulated the monument position using three CORS stations resulting in a fully adjusted position. After multiple sessions of data collection at each monument, accuracy was calculated. Blue Marble Geographics Calculator 2013 SP1 software was used to convert the geodetic positions from the OPUS reports. A total of 28 control monuments were surveyed for the North Delivery.

Upon completion of the North Delivery, a total network adjustment was performed. All occupied monuments were certified by a Utah PLS (see page 16). The final monument positions are presented in the table below.

List of Monuments

| PID | Latitude | Longitude | Ellipsoid (m) |
|---|---|---|---|
| AB3820 | 42˚ 02' 09.31572" | -112˚ 12' 45.10531" | 1359.049 |
| AI5799 | 40˚ 40' 03.54453" | -112˚ 05' 29.48208" | 1461.294 |
| KN0448 | 39˚ 48' 23.56801" | -111˚ 51' 10.54938" | 1516.170 |
| MS0692 | 41˚ 32' 21.55182" | -112˚ 03' 50.72615" | 1272.437 |
| UT_01 | 41˚ 07' 52.89769" | -111˚ 55' 25.08496" | 1361.607 |
| UT_02 | 41˚ 03' 47.62117" | -111˚ 55' 49.98080" | 1367.053 |
| UT_03 | 40˚ 55' 58.89434" | -111˚ 53' 40.86218" | 1268.296 |
| UT_05 | 41˚ 19' 44.21083" | -111˚ 58' 12.75176" | 1515.098 |
| UT_06 | 41˚ 26' 06.59749" | -112˚ 02' 11.64677" | 1298.335 |
| UT_07 | 42˚ 00' 05.24641" | -112˚ 12' 04.87894" | 1336.072 |
| UT_08 | 41˚ 46' 51.96518" | -112˚ 05' 33.01212" | 1354.759 |
| UT_09 | 42˚ 14' 20.91409" | -112˚ 15' 21.00377" | 1474.520 |
| UT_10 | 42˚ 18' 57.41562" | -112˚ 24' 30.52343" | 1588.284 |
| UT_11 | 39˚ 20' 53.42216" | -111˚ 55' 38.00621" | 1527.435 |
| UT_12 | 39˚ 15' 40.45110" | -111˚ 51' 56.31627" | 1539.985 |
| UT_13 | 39˚ 32' 30.85603" | -111˚ 51' 49.75265" | 1596.037 |
| UT_15 | 40˚ 42' 35.47313" | -111˚ 56' 54.26924" | 1275.726 |
| UT_16 | 40˚ 45' 29.89132" | -111˚ 58' 05.07434" | 1272.895 |
| UT_17 | 39˚ 42' 36.38980" | -111˚ 51' 52.87726" | 1521.615 |
| UT_18 | 40˚ 28' 44.19303" | -111˚ 53' 38.61986" | 1438.122 |
| UT_19 | 40˚ 32' 38.48614" | -111˚ 54' 03.15291" | 1325.180 |
| UT_20 | 39˚ 39' 37.77907" | -111˚ 51' 15.83174" | 1576.521 |
| UT_31 | 40˚ 47' 02.27190" | -111˚ 53' 32.37442" | 1350.975 |
| UT_32 | 40˚ 40' 27.84309" | -111˚ 48' 01.51707" | 1495.983 |
| UT_33 | 40˚ 39' 19.30864" | -111˚ 59' 27.38919" | 1369.564 |
| UT_34 | 40˚ 41' 15.92294" | -112˚ 04' 21.51348" | 1342.980 |
| WP_HAL | 41˚ 44' 18.63469" | -112˚ 05' 55.73646" | 1351.310 |

Monument Accuracy

| FGDC-STD-007.2-1998 Rating | |
|---|---|
| Standard Deviation Northing, Easting | 0.050 m |
| Standard Deviation Z | 0.050 m |

DELIVERABLES FOR EACH CONTROL MONUMENT

- 1 photo looking at the tripod over the point facing north
- 1 photo looking at the tripod over the point facing east
- 1 photo looking at the tripod over the point facing south
- 1 photo looking at the tripod over the point facing west
- 1 photo close-up of the point on the ground
- 1 raw GPS observation file for control point in RINEX format
- 1 National Geodetic Survey Online Positioning User Service (OPUS) report

# Ground Control Check Points

RTK (Real Time Kinematic)

A Trimble R7 base unit was set up over an appropriate monument to broadcast a real-time correction to a roving R8 unit. This RTK rover survey allows for precise location measurement (1.5 centimeter RMSEz). All RTK measurements were made during periods with a Position Dilution of Precision (PDOP) of 3.0 and in view of at least six satellites by the stationary reference and roving receiver. For RTK data, the collector recorded at least a five-second stationary observation, and then calculated the pseudorange position from three one-second epochs with the relative error less than 1.5 centimeter horizontal and 2.0 centimeter vertical.

RTK positions were collected on bare earth locations such as paved, gravel or stable dirt roads, and other locations where the ground was clearly visible (and was likely to remain visible) from the sky during the data acquisition and RTK measurement periods. In order to facilitate comparisons with LiDAR data, RTK measurements were not taken on highly reflective surfaces such as center line stripes or lane markings on roads.

For each control monument, at least 25 RTK points were taken within five nautical miles of the base. The planned locations for these control points were determined prior to field deployment, and the suitability of these locations was verified on site. The distribution of RTK points depended on ground access constraints, and may not be equitably distributed throughout the survey area.

PPK (Post-Processed Kinematic)

Similar to an RTK survey, a roving GPS unit is paired with a static GPS base station and deployed to collect true ground points, but a radio connection to the base need not be established.  This potentially allows greater dispersion of ground data beyond the limit of radio communication, though no real-time correction is available.  All geometry is identical to that of a real-time survey, but baselines are post-processes and point values are determined afterward using applicable software.  Precision thresholds are equal to RTK thresholds and out-of-tolerance points are discarded.

Land Class Cover Checkpoints

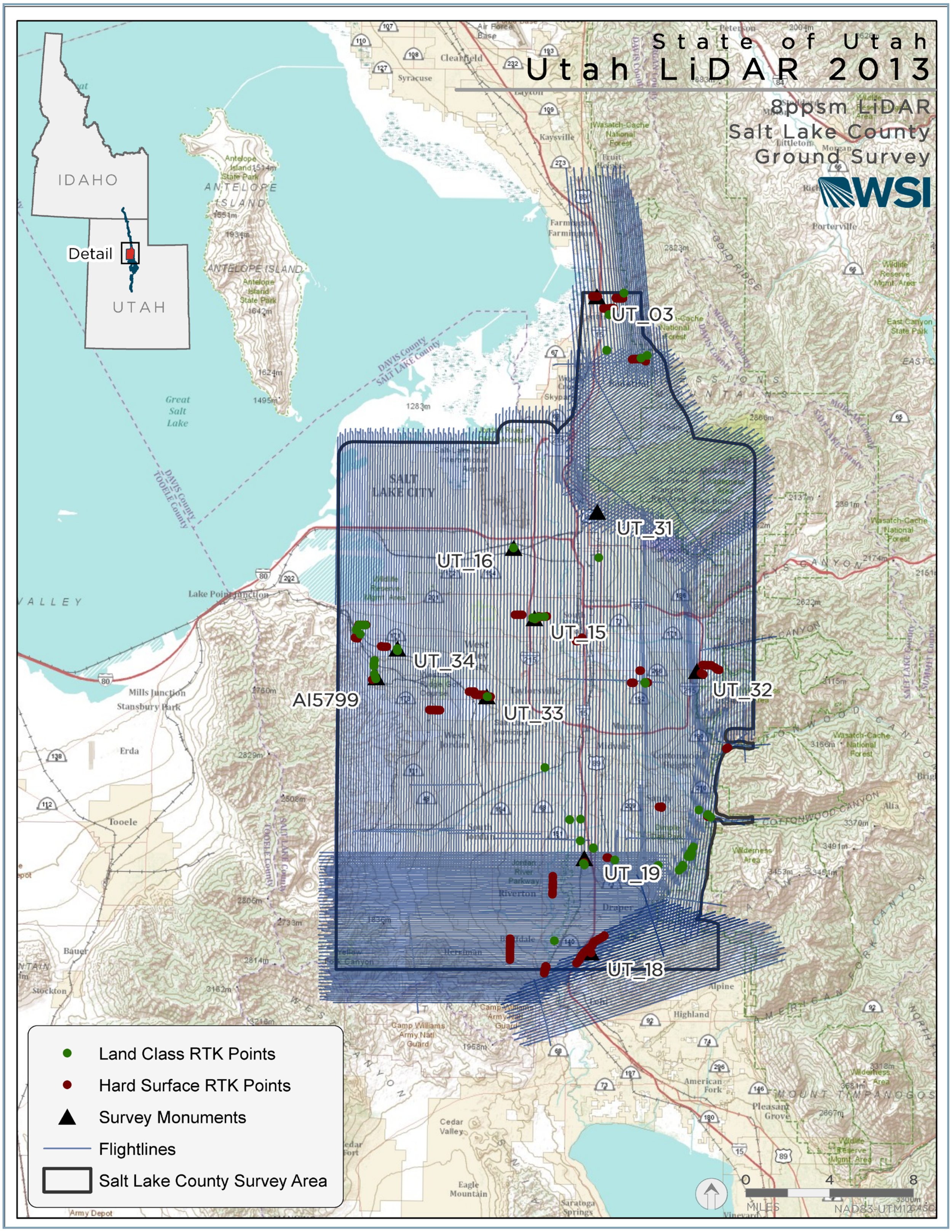
In addition to the hard-surface GCP data collection, check points were also collected across the delivery area on three different land class cover types to provide Supplemental Vertical Accuracy (SVA) statistics in accordance with National Standard for Spatial Data Accuracy (NSSDA) guidelines and used the U.S. Geological Survey's Land Cover Institute's land cover class definitions as a guideline (USGS LCI).

The dominant land cover classes within the project area are Urban, Shrub and Forest. A total of 227 individual land class checkpoints were collected for the North Delivery.

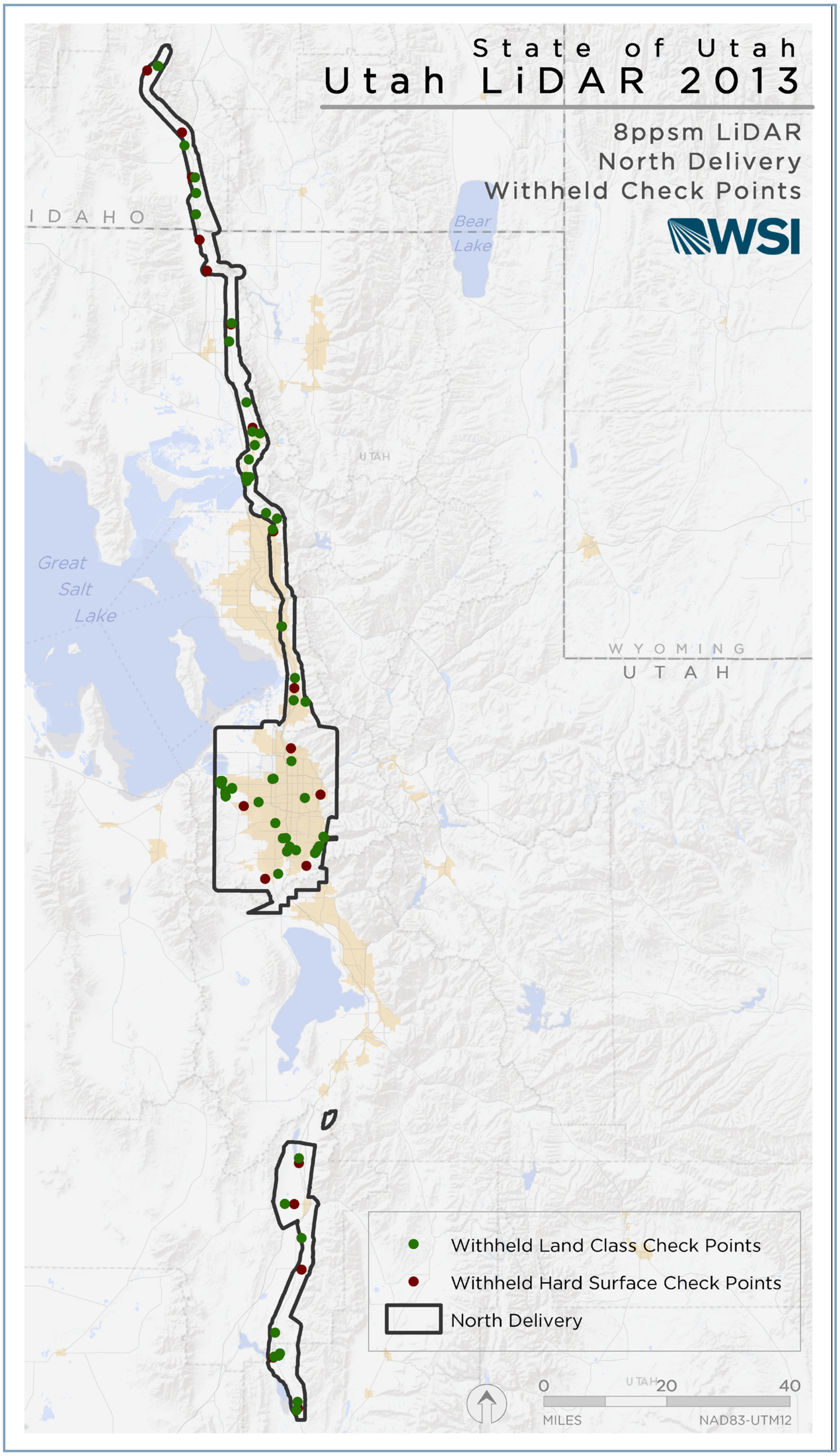
The accuracies reported in the table below describe the positional variability associated with geodetic control. Static monument positions are described in horizontal and vertical space, which can be summarized as RMSExyz.

| GPS Specifications | Survey Control Monuments | Ground Check Points (GCPs) |
|---|---|---|
| Accuracy | RMSExy ≤ 1.5 cm (0.6 in.) | RMSExy ≤ 1.5 cm (0.8 in.) |
| | RMSEz ≤ 1.5 cm (0.6 in.) | RMSEz ≤ 2.0 cm (0.8 in.) |
| Resolution | Minimum of one per 13 nautical mi. spacing | ≥ 25 per surveyed monument |
| | Minimum independent occupation of 4 hrs. & 2 hrs. | Techniques: RTK and PPK |
| Equipment | R7 GNSS | R7 GNSS |
| | R8 GNSS | R8 GNSS |

Ground Survey of Region Acquired in Spring 2014



Withheld Check Points in the North Delivery



# Airborne Survey

## LiDAR Survey

The LiDAR survey occurred between October 18th, 2013 and March 22, 2014, using a Leica ALS 70 sensor mounted in a Piper Navajo aircraft. The system was set to acquire a variable number of laser pulses per second and flown at a variable height above ground level (AGL). The laser captured a scan angle of 15 degrees from nadir (field of view equal to 30 degrees). The LiDAR system settings and flight parameters were designed to yield high-resolution data of >8 pulses per square meter over terrestrial surfaces.

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 was measured twice per second (two hertz) by an onboard differential GPS unit. Aircraft attitude is described as pitch, roll, and yaw (heading) and was measured 200 times per second (200 hertz) from an onboard inertial measurement unit (IMU).

The LiDAR sensor operators constantly monitored the data collection settings during acquisition of the data, including pulse rate, power setting, scan rate, gain, field of view, and pulse mode. For each flight, the crew performed airborne calibration maneuvers designed to improve the calibration results during the data processing stage. They were also in constant communication with the ground crew to ensureproper GPS coverage for data quality. The LiDAR coverage was completed with no data gaps or voids, barring non-reflective surfaces (e.g., open water, wet asphalt).

All necessary measures were taken to acquire data under conditions (e.g., minimum cloud decks) and in a manner (e.g., adherence to flight plans) that prevented the possibility of data gaps. All WSI LIDAR systems are calibrated per the manufacturer and our own specifications, and tested by WSI for internal consistency for every mission using proprietary methods.

The acquisition occurred under clear conditions with no cloud cover, and less than 10 percent cloud shadow. Weather conditions were constantly assessed in-flight, as adverse conditions not only affect data quality, but can prove unsafe for flying. The survey area was surveyed with opposing flight line side-lap of ≥50 percent to reduce laser shadowing and increase surface laser painting. The system allows up to four range measurements per pulse, and all discernible laser returns were processed for the output data set.

In the North Delivery area there was a change to the original AOI to exclude high elevation regions while still acquiring Big and Little Cottonwood Canyons. Due to the terrain and safety constraints, these canyons were acquired with at least double coverage (100% overlap) of full swaths, rather than the typical 50% overlap, in order to obtain a minimum of 8 pulses per square meter.

Above: Piper Navajo

# Processing

This section describes the processing methodologies for all data acquired by WSI for the Utah LiDAR 2013/2014 North Delivery. All of our methodologies and deliverables are compliant with federal and industry specifications and guidelines (USGS v.13, FGDC NSSDA, and ASPRS).

Below: Hillshade/intensity image of a portion of the Pilot Delivery area


## LiDAR Data Processing

### Calibration

Once the LiDAR data arrived at the Portland office, WSI employed a suite of techniques to calibrate it. Processing tasks included: GPS, kinematic corrections, calculation of laser point position, relative accuracy testing and calibrations, classification of ground and non-ground points, and assessments of statistical fundamental and supplemental vertical accuracy. The general workflow for calibration of the LiDAR data was as follows:

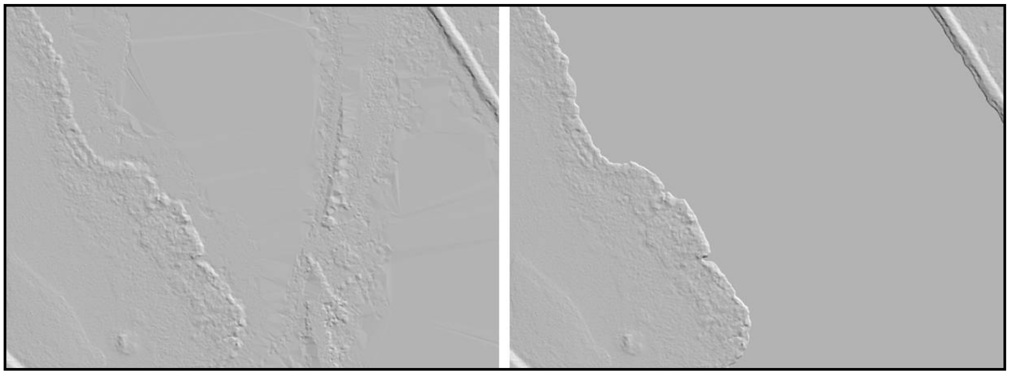
| LiDAR Processing Step | Software Used |
|---|---|
| Resolve GPS kinematic corrections for aircraft position data using kinematic aircraft GPS (collected at two hertz) and static ground GPS (one hertz) data collected over geodetic controls. | IPAS TC v. 3.2, Trimble Business Center v. 3.01 |
| Develop 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. | Inertial Explorer v. 8.50 |
| 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 v. 1.2) 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 12A correction. | Leica ALSPP 2.75 Build #9 |
| Import raw laser points into subset bins (less than 500 megabites, to accommodate file size constraints in processing software). Filter for noise and perform manual relative accuracy calibration. | TerraScan v. 14, Custom WSI software |
| Classify ground points and test relative accuracy using ground classified points per each flight line. Perform automated line-to-line calibrations for system attitude parameters (pitch, roll, heading), 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. 14, TerraScan v. 14, Custom WSI software |
| Assess fundamental and supplemental vertical accuracy via direct comparisons of ground classified points to ground RTK survey data. | TerraScan v. 14 |
| Assign headers (e.g., projection information, variable length record, project name, GEOTIFF tags) to *.las files. | Las Monkey v. 1.4.6 |

## Hydro Flattening

All bare-earth hydro flattened digital elevation models (DEMs) have been hydro flattened according to the U.S. Geological Survey's National Geospatial Program's "LiDAR Guidelines and Base Specification" Version 1, 2012 (USGS NGP). For all water bodies perceived to be "flat," LiDAR points were sampled to arrive at an elevation threshold defining the water surface at a uniform elevation where the water edge meets the surrounding terrain. 3-D breaklines were then created to encompass all areas considered to be water and were assigned the water surface elevation value determined previously. All "flat" water bodies greater than 2 acres were considered for hydro flattening. All "islands" greater than 100 square meters were retained in the DEMs.

The bare-earth DEMs were created by triangulating all ground classified points and inserting 3-D breaklines utilizing TerraSolid's TerraScan and TerraModeler software. Any ground points within 1 meter of the breaklines were reclassified to "ignored ground" (ASPRS code: 10) before triangulation. The highest-hit DEMs were generated from "ground" and "default" classified points. In instances where "water" classified points had the highest elevation value, the water surface elevation from the bare-earth raster was used.

Regular hillshade DEM



Hillshade DEM with hydro flattening

## *.las Files with RGB Extraction

Recently acquired AGRC aerial imagery with a 5 inch resolution was used to color LiDAR points. Where AGRC imagery was not available, USDA NAIP imagery was used.

LiDAR imagery with RGB extraction in the Pilot Delivery area, including Lagoon amusement park.

# Results

## Fundamental Vertical Accuracy

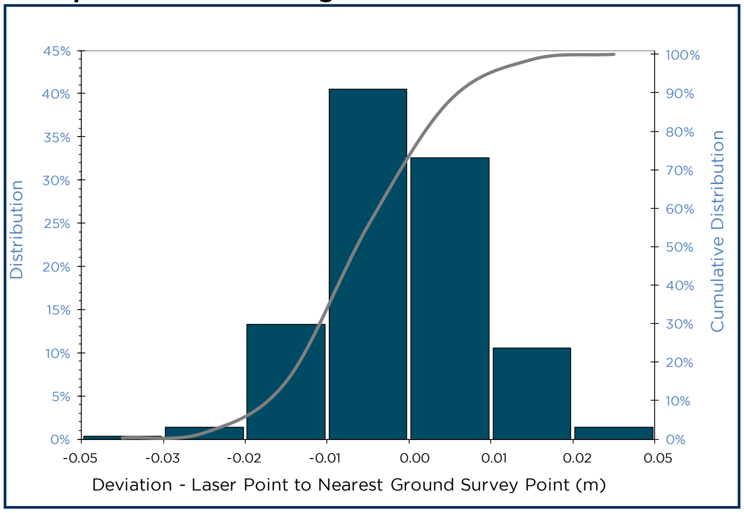
Fundamental Vertical Accuracy (FVA) reporting is designed to meet guidelines presented in the National Digital Elevation Program (NDEP), National Standard for Spatial Data Accuracy (NSSDA) (FGDC, 1998), and the ASPRS Guidelines for Vertical Accuracy Reporting for LiDAR Data V1.0 (ASPRS, 2004).

The statistical model compares known Ground Control Check Points (GCPs) to the closest laser point. FVA statistical analysis uses hard surface GCPs in open areas where the LiDAR system has a “very high probability” that the sensor will measure the ground surface and is evaluated at the 95% confidence level. For the Utah LiDAR 2013/2014 survey area, 6,444 GCPs were used to calibrate the North Delivery area.

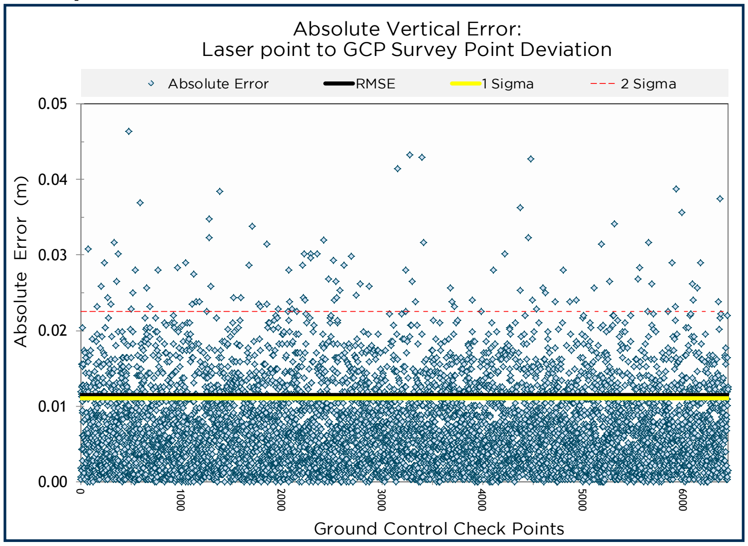
Vertical accuracy statistics are reported as “Compiled to Meet” and GCPs for hard surface and land classes were also withheld and will be delivered with the dataset for reporting accuracy as “Tested to Meet.”

Ground survey data to be delivered with this report includes all GCP’s, withheld checkpoints, and land class checkpoints.

**“Compiled to Meet” Histogram**




**“Compiled to Meet” Deviation Statistics**




**“Compiled to Meet” Accuracy Results**

| | LiDAR Swath | DEM | Spec |
|---|---|---|---|
| Sample Size (n) | 6,444 | 7,031 | N/A |
| 95% Confidence Level | 1.80 cm | 5.69 cm | 18.10 cm |
| Root Mean Square Error (RMSEz) | 0.92 cm | 2.90 cm | 9.25 cm |
| 1 Sigma | 0.88 cm | 2.70 cm | N/A |
| 2 Sigma | 1.80 cm | 5.90 cm | N/A |
| Minimum Deviation | -4.63 cm | -14.20 cm | N/A |
| Maximum Deviation | 4.30 cm | 14.91 cm | N/A |

## Supplemental & Consolidated Vertical Accuracy

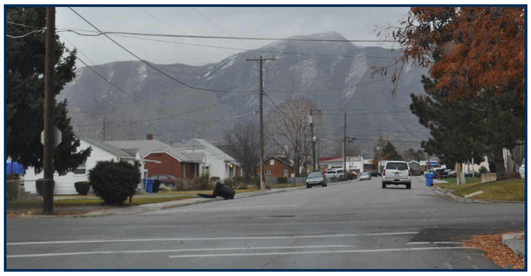
In addition to the hard surface land class, checkpoints were also collected across the project area for additional land cover classes to provide Supplemental Vertical Accuracy (SVA) statistics in accordance with NSSDA guidelines. All data collection was completed by WSI. As such, SVA statistics are reported as "Compiled to meet" in accordance with the ASPRS Guidelines Vertical Accuracy Reporting for LiDAR Data V1.0 (ASPRS, 2004).

The dominant land cover classes within the present project area are listed at right. This analysis demonstrates that the vertical accuracy of the interpolated ground surface, across all land cover classes, meets or exceeds vertical accuracy specifications.

Consolidated Vertical Accuracy (CVA) based on the DEM was compiled to meet at the 95th percentile based on both hard surface and land cover GCPs. The resulting CVA (sample size 7,258) is 6.04 cm.

Land Class Vertical Accuracy Results (DEM)

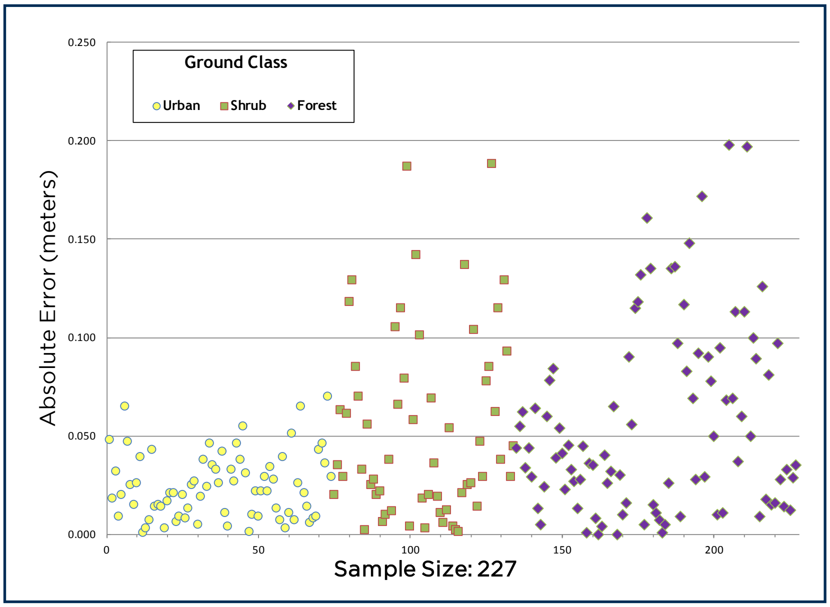
| | Hard Surface N = 7,031 | Urban N = 74 | Shrub N = 60 | Forest N = 93 | Spec |
|---|---|---|---|---|---|
| 95th Percentile | 5.90 cm | 5.24 cm | 13.72 cm | 14.08 cm | 26.90 cm |
| Bias (Average Dz) | -0.80 cm | 0.12 cm | 4.38 cm | 3.38 cm | N/A |
| Minimum | -14.20 cm | -7.00 cm | -9.30 cm | -9.70 cm | N/A |
| Maximum | 14.91 cm | 6.51 cm | 18.80 cm | 19.80 cm | N/A |
| Average Magnitude | 2.32 cm | 2.44 cm | 5.40 cm | 5.57 cm | N/A |
| 1 Sigma | 2.70 cm | 2.90 cm | 6.46 cm | 6.46 cm | N/A |
| 2 Sigma | 5.90 cm | 5.24 cm | 13.72 cm | 14.08 cm | 26.90 cm |



**Above: Urban**

**Below: Shrub**

Supplemental Vertical Accuracy



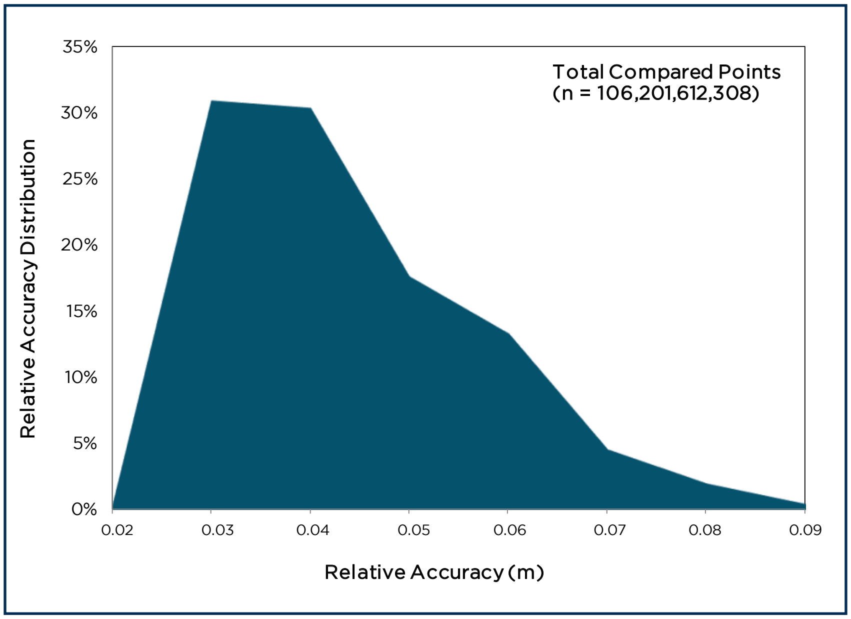
# Relative Accuracy

## Swath to Swath

Relative accuracy refers to the internal consistency of the data set and is measured as the divergence between points from different flightlines within an overlapping area. Divergence is most apparent when flightlines are opposing. When the LiDAR system is well calibrated the line-to-line divergence is low (<10 centimeters). Internal consistency is affected by system attitude offsets (pitch, roll, and heading), mirror flex (scale), and GPS/IMU drift.

Relative accuracy statistics for the North Delivery area are based on the comparison of 2,050 flightlines and over 106 billion points.

Swath to swath relative accuracy distribution results




| Swath to Swath Relative Accuracy | | Spec |
|---|---|---|
| Average | 3.91 cm | N/A |
| Median | 3.53 cm | N/A |
| 1 Sigma | 4.23 cm | N/A |
| 2 Sigma | 6.30 cm | N/A |
| RMSDz | 1.27 cm | 7.00 cm |
| 95% Confidence Level | 2.48 cm | N/A |

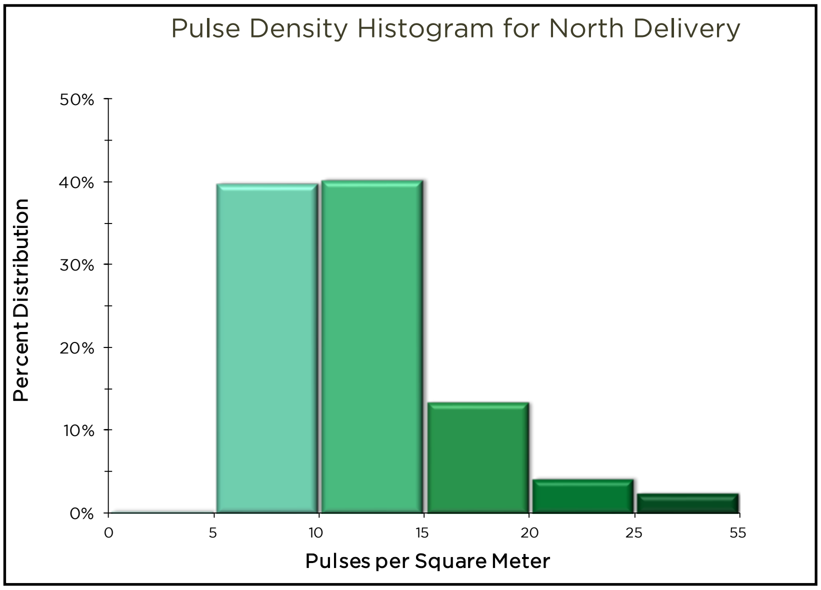
## Within Swath

WSI defines within swath relative accuracy as a measure of the point-to-point consistency across the width of a LiDAR swath. The statistic is derived through a GCP survey of flat pavement (typically airport tarmac) measured orthogonal to the direction of flight. The measure evaluates tilting or warping of the raw data, as well as "smiles" and "frowns" at the edge of scan. This test is performed with each system calibration upon installation of the sensor in the aircraft, as well as periodically during a sensor's residence within a specific aircraft.

| Within Swath Relative Accuracy | | Spec |
|---|---|---|
| RMSDz | 2 cm | 5 cm |
| 95% Confidence Level | 4 cm | N/A |

# LiDAR Density

| Pulse Density | Pulses per square meter: |
| --- | --- |
| | 12.20 |
| Ground Point Density | Ground points per square meter: |
| | 5.33 |



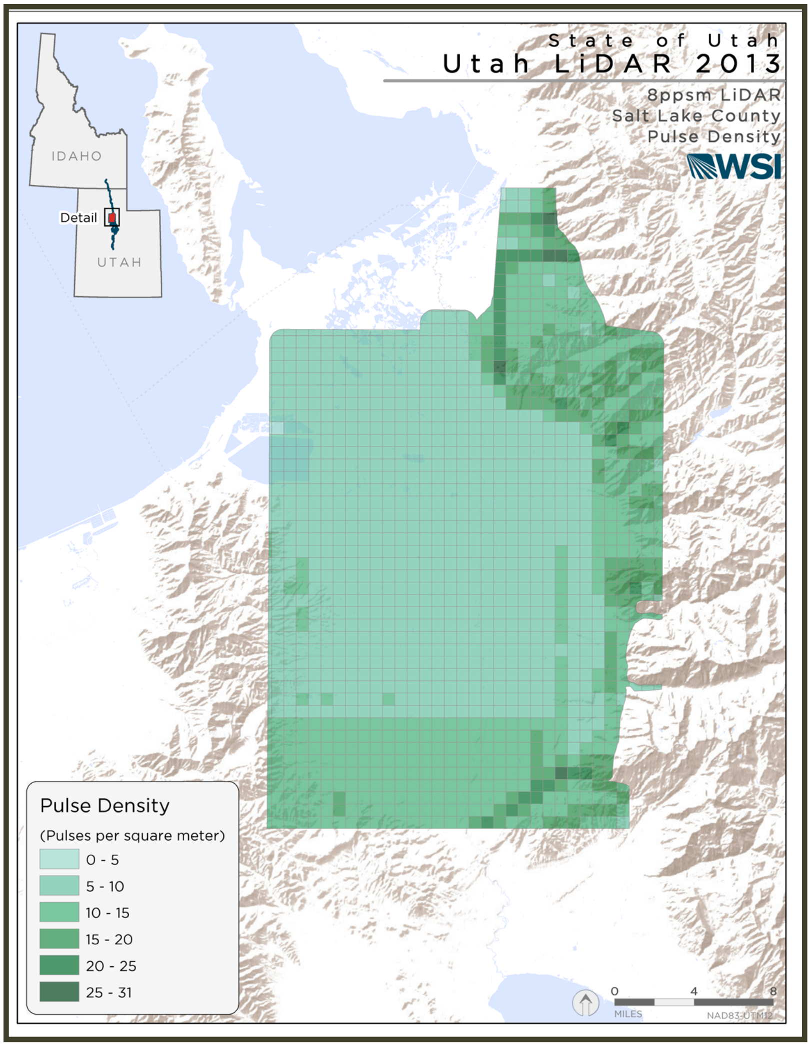

## Pulse Density

The native pulse density is the number of pulses emitted by the LiDAR system. Some types of surfaces (e.g. dense vegetation or water) may return fewer pulses than the laser originally emitted. Therefore, the delivered density can be less than the native density and lightly variable according to distributions of terrain, land cover, and water bodies.

The chart above at right shows pulse densities for the Utah LiDAR 2013/2014 North Delivery area and the map at right shows the Salt Lake County portion of this delivery. The density histogram was calculated based on first return laser point density.

Section 7.3 (Completeness) of the Scope of Work specifies that for the entire project area, ≥85% design aggregate pulse density, 8 ppsm, must be acheived. WSI surpassed this requirement with an aggregate pulse density of 12.20 ppsm.

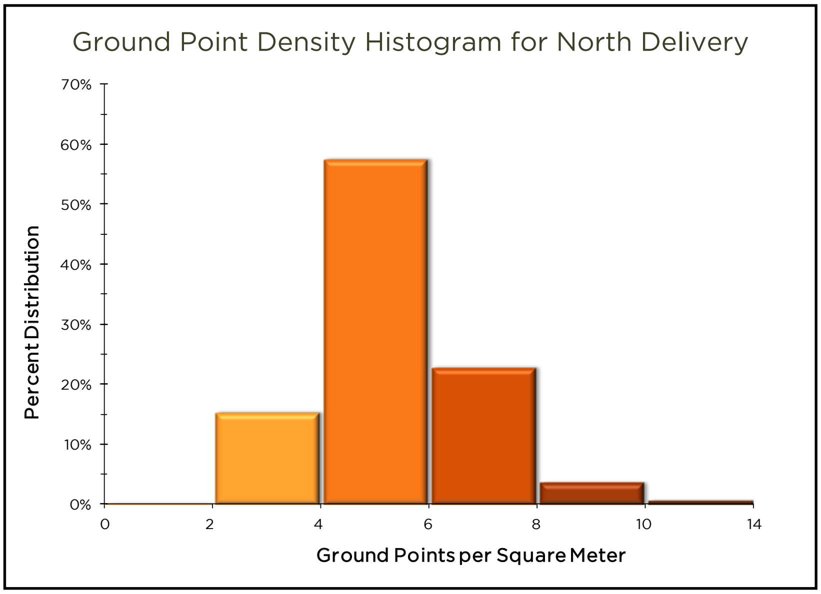
Pulse Density Map for Salt Lake County



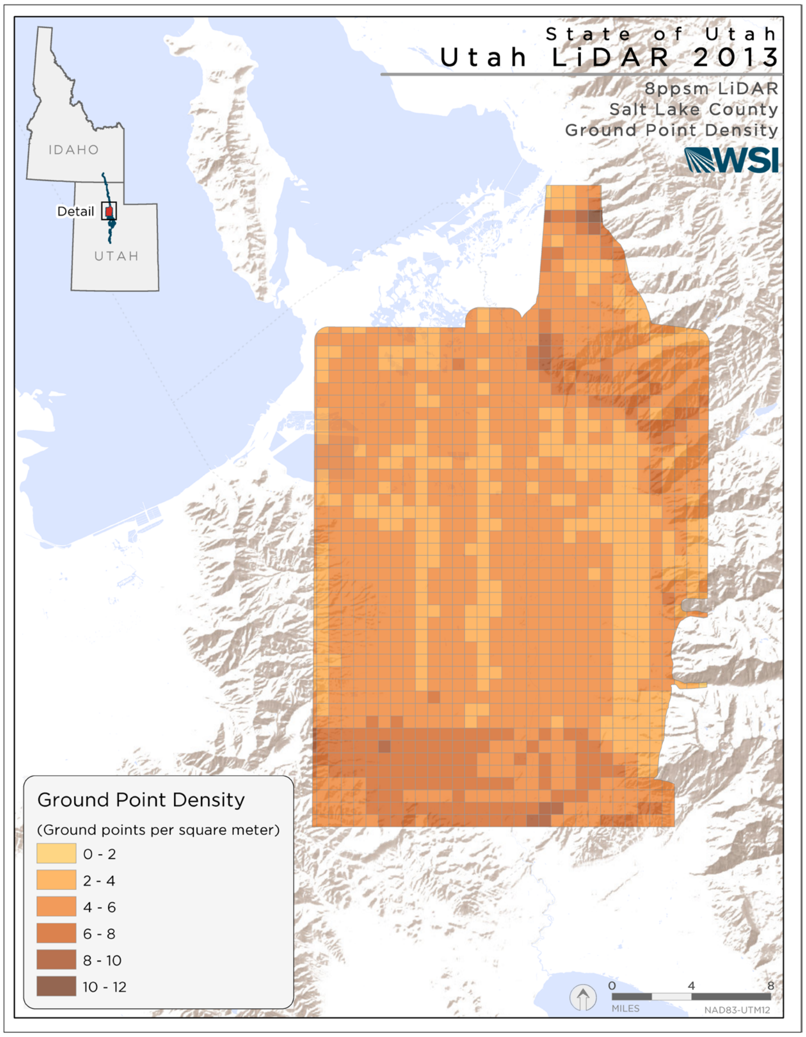
## Ground Point Density

WSI achieved an average of 5.33 ground density points per square meter.

The chart at right shows ground point densities for the Utah LiDAR 2013/2014 North Delivery area and the map below at right shows the Salt Lake County portion of this delivery. The density histogram was calculated based on ground classified point density.




Ground Point Density Map for Salt Lake County




Hillshade/intensity image of a portion of the Pilot Delivery area

# PLS Certificates

WHPacific

October 31, 2013

I, undersigned, being duly sworn, say that I have examined and checked all of the Survey Base Stations used during the "Acquisition" portion of this report for the Pilot Area that lies within a portion of Block 10, and which were surveyed using commonly accepted Standard Practices. The field work was conducted from October 17th through October 23rd, 2013.

Accuracy statistics shown in the Accuracy Section have been reviewed by me and found to meet the National Standard for Spatial Data Accuracy.

Mike Hart, PLS – Utah #8051637-2201
WHPacific, Inc
San Diego, CA 92123

PROFESSIONAL LAND SURVEYOR
8051637-2201
James Michael
Hart
STATE OF UTAH

WHPacific

November 21, 2013

I, undersigned, being duly sworn, say that I certify that the survey base stations used during the "Acquisition" portion of this report for Blocks 1, 2 and that portion of Block 3 that lie within the State of Idaho were surveyed under my supervision using commonly accepted Standard Practices. Field work was conducted from October 17 through October 23, 2013.

Accuracy statistics shown in the Accuracy Section have been reviewed by me and found to meet the National Standard for Spatial Data Accuracy.

Travis P. Foster, PLS – Idaho No. 10729
WHPacific, Inc
Boise, ID 83705

PROFESSIONAL LAND SURVEYOR
REGISTERED
10729
11/21/13
STATE OF IDAHO
TRAVIS P. FOSTER

WHPacific

November 21, 2013

I, undersigned, being duly sworn, say that I certify that the survey base stations used during the "Acquisition" portion of this report for that portion of Block 3 and all of Blocks 4, 5, 8, and 9 that lie within the State of Utah were surveyed under my supervision using commonly accepted Standard Practices. Field work was conducted from October 17 through October 23, 2013.

Accuracy statistics shown in the Accuracy Section have been reviewed by me and found to meet the National Standard for Spatial Data Accuracy.

Mike Hart, PLS – Utah #8051637-2201
WHPacific, Inc
San Diego, CA 92123

PROFESSIONAL LAND SURVEYOR
8051637-2201
James Michael
Hart
STATE OF UTAH

WHPacific

December 4, 2013

I, undersigned, being duly sworn, say that I certify that the survey base stations used during the "Acquisition" portion of this report for Blocks 6, 7, 12, 13, 14 and 21 that lie within the State of Utah were surveyed under my supervision using commonly accepted Standard Practices. Field work was conducted from November 11th through November 15th, 2013.

Accuracy statistics shown in the Accuracy Section have been reviewed by me and found to meet the National Standard for Spatial Data Accuracy.

Mike Hart, PLS – Utah #8051637-2201
WHPacific, Inc
San Diego, CA 92123

PROFESSIONAL LAND SURVEYOR
8051637-2201
James Michael
Hart
STATE OF UTAH

WHPacific

December 18, 2013

I, undersigned, being duly sworn, say that I certify that the survey base stations used during the "Acquisition" portion of this report for Blocks 18, 19, 22 and 23 that lie within the State of Utah were surveyed under my supervision using commonly accepted Standard Practices. Field work was conducted from November 11th through November 15th, 2013.

Accuracy statistics shown in the Accuracy Section have been reviewed by me and found to meet the National Standard for Spatial Data Accuracy.

Mike Hart, PLS – Utah #8051637-2201
WHPacific, Inc
San Diego, CA 92123

PROFESSIONAL LAND SURVEYOR
8051637-2201
James Michael
Hart
STATE OF UTAH

# Best Practices

WSI has high standards and adheres to best practices in all efforts. In the laboratory, quality checks are built in throughout processing steps, and automated methodology allows for rapid data processing. There is no off-shoring, which allows for in-house data collection and processing.

WSI's innovation and adaptive culture rises to technical challenges and the needs of clients like the state of Utah. Reporting and communication to our clients are prioritized through regular updates and meetings.

WSI appreciates the opportunity to assist the state of Utah and welcomes any future assignments.

## POINT OF CONTACT

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# Thank You

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