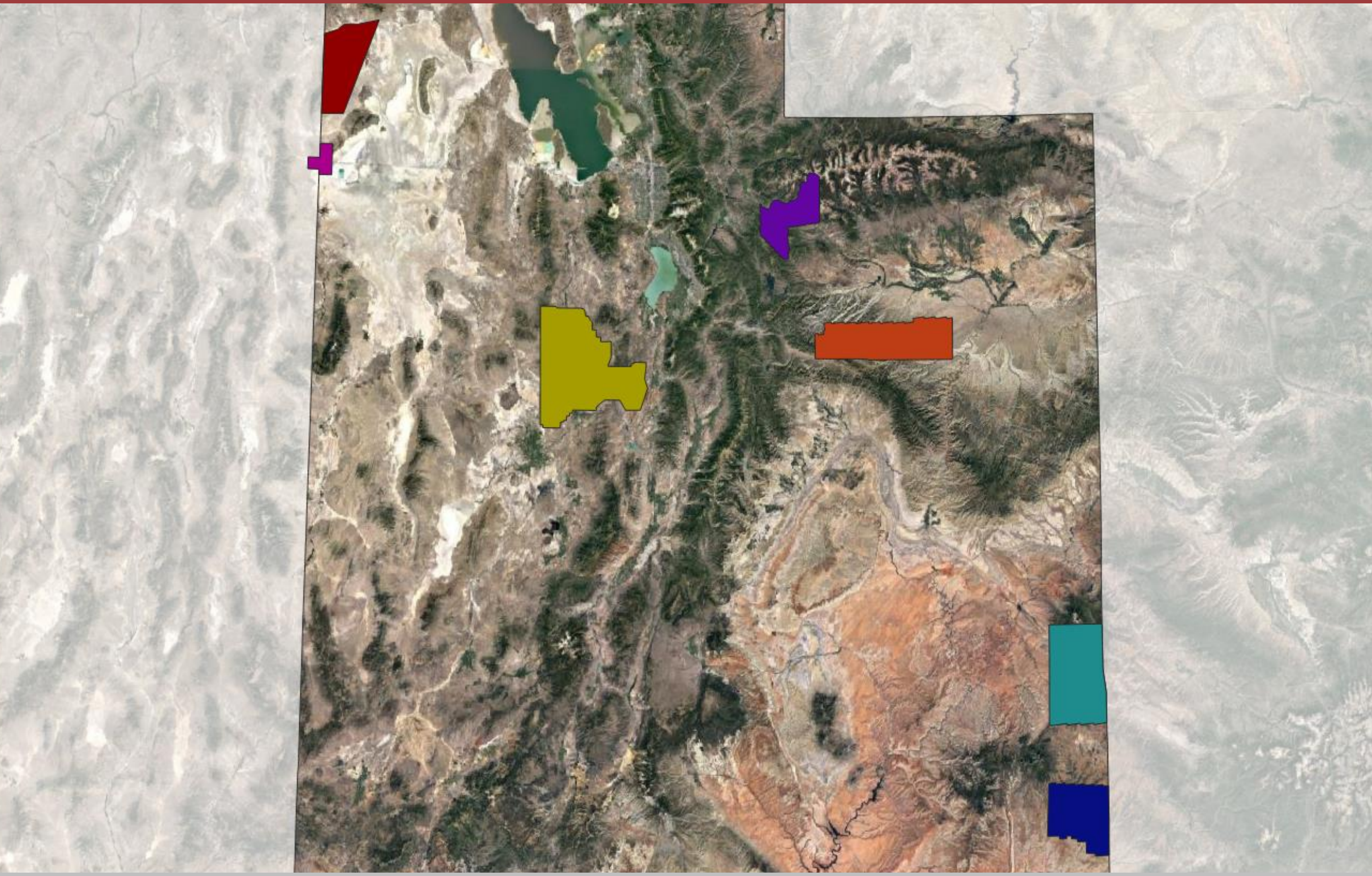
TECHNICAL PROJECT REPORT

UTAH AGRC FALL ADDITIONS AERIAL SURVEY

Project Name: UT_StatewideCenSouth_2020_A20
Work Package ID: 207269
PTS Work Unit Numbers:
QL2 UTM 11N: 213807
QL2 UTM 12N: 207266

Submitted: May 7, 2021



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Technical Project Report
Utah AGRC Fall Additions – QL2 UTM11 & UTM12

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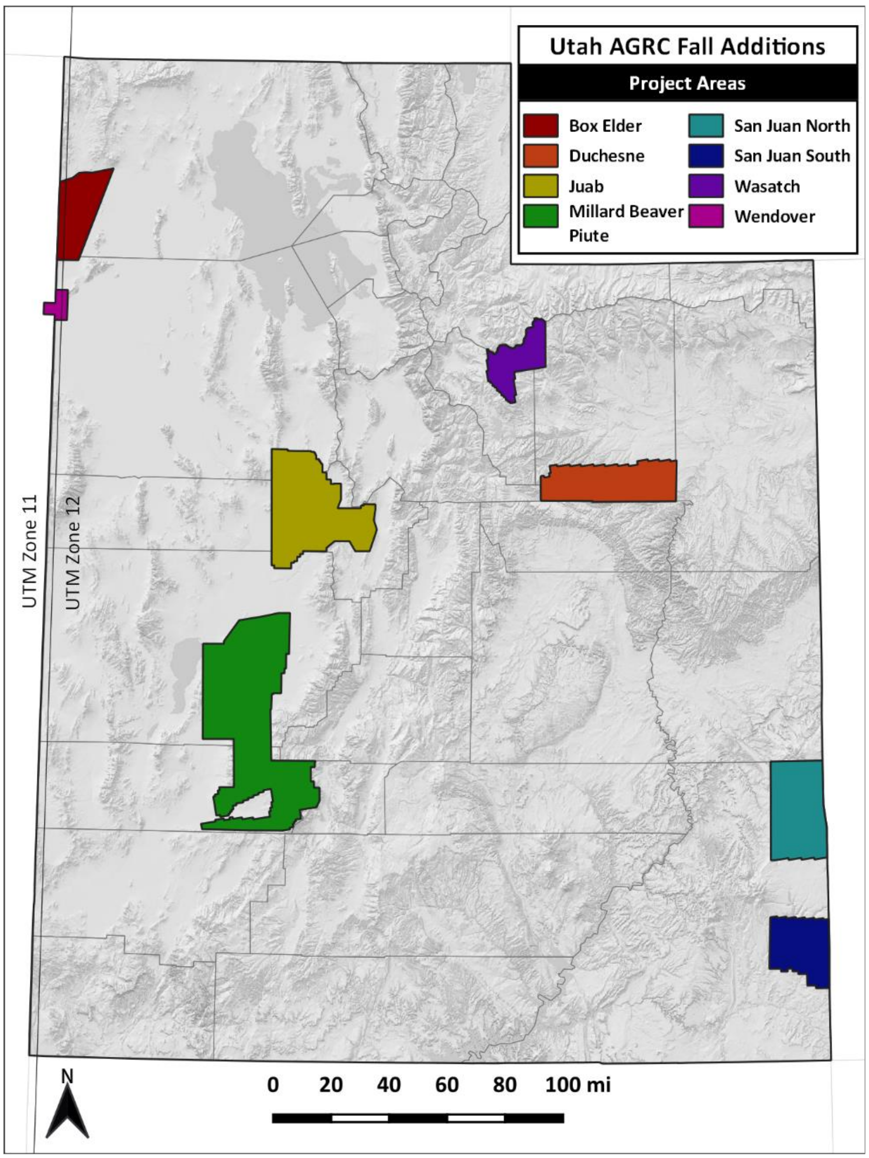
1. Overview

1.1 Project Overview

Aero-Graphics, Inc. (AGI), a full-service geospatial firm located in Salt Lake City, Utah, was contracted by the State of Utah, Department of Technology Services, Division of Integrated Technology, Automated Geographic Reference Center (AGRC) and partners to acquire, process, and deliver aerial lidar data and derivative products that adhere to U.S. Geological Survey (USGS) National Geospatial Program (NGP) Lidar Base Specification Version 2.1 (2019). The assigned project areas cover portions of Utah totaling approximately 5,078 mi^2.

Exhibit 1: Overview of the Utah AGRC Fall Additions project by delivery areas.



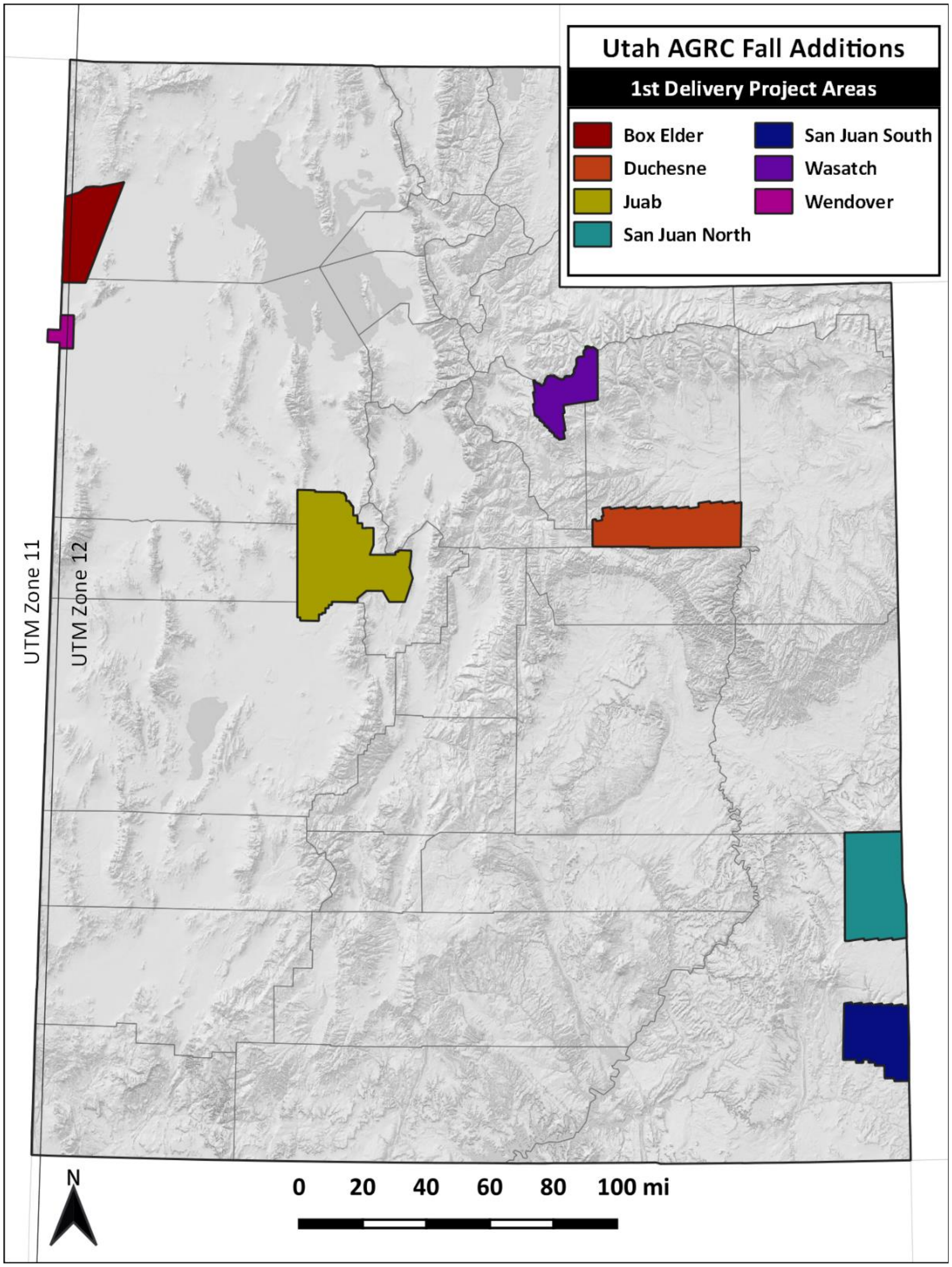
1.2 Project Area Description

The Utah AGRC Fall Additions project was separated into two (2) delivery areas: Millard Beaver Piute as one delivery, and all the remaining areas as the other delivery. This report is the first of two deliveries and focuses on all the areas of interest (AOIs) besides Millard Beaver Piute. These seven AOIs cover a total of 3,312 mi² (**Exhibit 2**).

Exhibit 2: First delivery AOIs and their sizes

First Delivery Project Areas	
AOI Name	**Area (mi²)**
Box Elder	373
Wendover	59.5
Wasatch	288
Juab	955
Duchesne	591
San Juan North	628
San Juan South	417

Exhibit 3: Overview of the first delivery project areas.



1.3 Project Deliverables

LiDAR Data	▪ Raw and classified point cloud data in LAS v1.4 format
Raster Data	▪ Bare-earth and first return DEMs with a cell size of 1 meter in .TIF format ▪ Intensity images at a 1-meter resolution in GeoTIFF format
Vector Data	▪ Breaklines in SHP format
Report of Survey	▪ Reports and metadata as described in SOW

**Tiling for the LiDAR deliverables is based on the U.S. National Grid System. Tile names are based on the SW corner of the tile. All .LAS and raster tiles are 1,000 meters x 1,000 meters.*

1.4 Projection, Datum, Units

Projection		UTM Zone 11N & UTM Zone 12N
EPSG		6340 & 6341
Datum	Vertical	NAVD88 (Geoid18)
	Horizontal	NAD83 (2011) / HARN
Units		Meters

2. LiDAR Acquisition

2.1 Flight Planning

Aero-Graphics' Aerial Department created a unique flight plan for this project using Optech's Airborne Mission Manager (AMM) flight planning software. AMM simulates flight plans based on a project area's terrain, as well as the sensor's model, mount, and settings. These features helped ensure all contract specifications were met in the most efficient way possible. Prior to mobilizing to the acquisition sites, Aero-Graphics' staff monitored all site conditions and potential weather hazards including wind, rain, snow, and blowing dust. Additionally, Aero-Graphics ensured all airspace clearances were secured by the proper officials before acquisition occurred. A summary of the flight parameters and sensor settings for the seven areas are outlined in **Exhibit 4**.

Exhibit 4: Summary of planned flight parameters and sensor settings

Planned Specifications		Box Elder	Duchesne, Juab, Wendover	San Juan North	San Juan South	Wasatch
		Optech Galaxy T2000	Optech Galaxy Prime	Leica Terrain Mapper	Leica Terrain Mapper	Optech Galaxy Prime
Aircraft		Cessna 206	Cessna 206	Piper Navajo	Piper Navajo	Cessna 206
Altitude (ft above ground level)		8,202	5,249	10,997	9,842	5,249
Speed (kts)		120	120	160	160	120
PRF (kHz)		500	300	700	668.1	350
Scan frequency (Hz)		57.2	55.6	86.4	89	59.8
Scan Angle	From nadir	± 23°	± 20°	± 20°	± 23°	± 23°
	Full	46°	40°	40°	46°	46°
Planned Average Point Density (p/m^2)		3.44	3.24	2.22	2.38	3.74
Post Spacing at Nadir	Cross Track (m)	0.56	0.70	0.60	0.52	0.52
	Down Track (m)	0.56	0.70	0.60	0.52	0.52
Swath Width (m)		2122	1358	2440	2184	1358
NPS (m)		0.5	0.5	0.7	0.6	0.5
Sidelap (%)		20	20	20	20	20

2.2 Data Acquisition

AGI's acquisition platform was our turbocharged Cessna 206 (**Exhibit 5**). The stability of this platform is ideal for efficient data collection at high and low altitudes and at a variety of airspeeds. Additionally, our Cessna 206 has been customized to house a variety of airborne sensors, and the power systems and avionics have been upgraded specifically to meet aerial survey needs.

Exhibit 5: AGI used their Cessna 206s as their acquisition platforms for this project

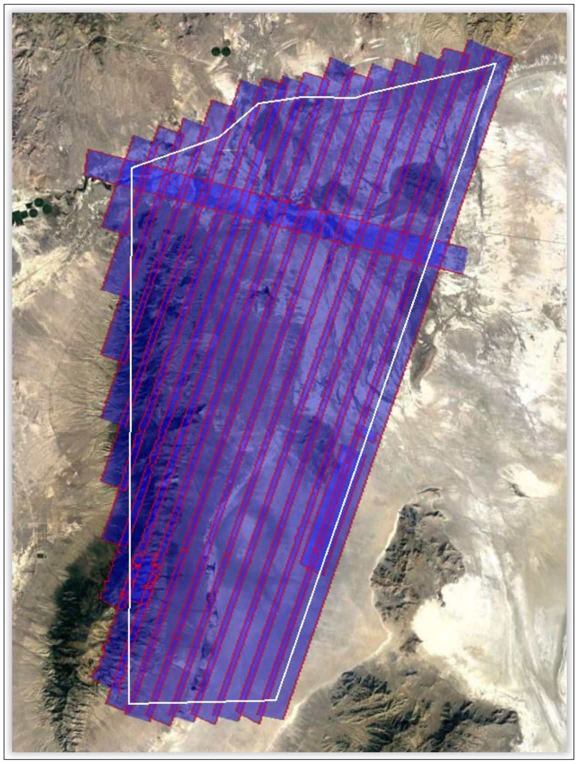
The Optech Galaxy Prime and T2000 were selected for this project on account of their high accuracy and efficiency (**Exhibit 6**). These sensors use SwathTrak technology, which dynamically adjusts the scan field of view in real time to maintain a constant swath width over a variety of terrains. They also feature up to 8 returns per pulse, which increase the vertical resolution of complex terrains. The sensors are complemented with the use of FMS Nav, which allowed the system operators to monitor the point density and swath attributes of this project in real time, ensuring quality data and full coverage for each AOI, portions of which are shown in **Exhibit 7**. Optech serviced and updated the Galaxy Prime and Galaxy T2000 in December 2019 and June 2020, respectively. More information about point density can be found in Section 5.7.

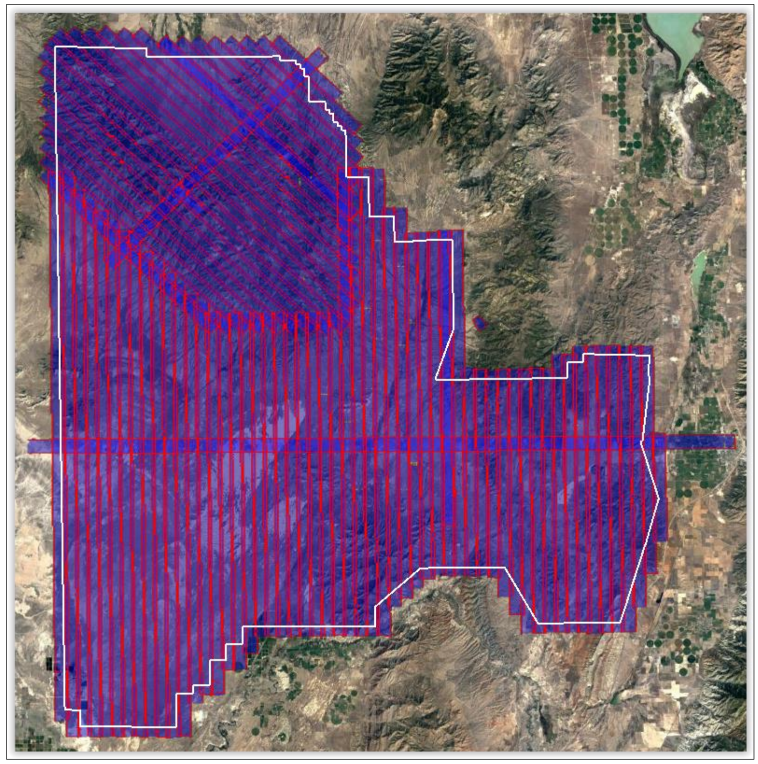
Exhibit 6: The Optech Galaxy Prime and T2000 were used for data acquisition

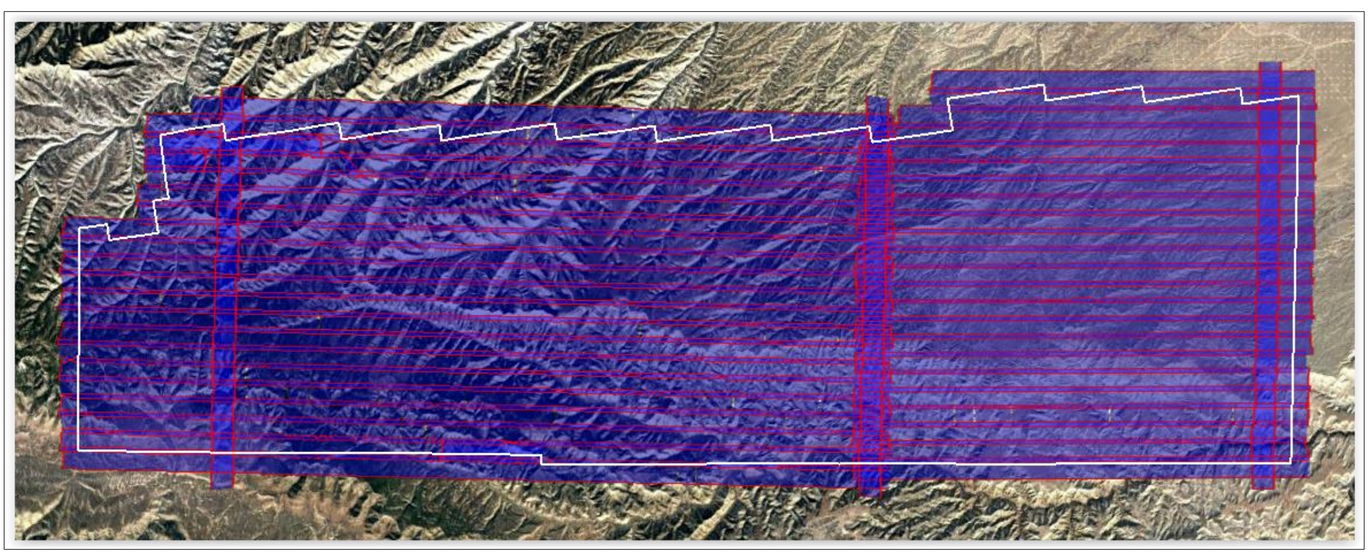
<u>Exhibit 7:</u> Swath data for the project was recorded and viewed real-time by the sensor operator.

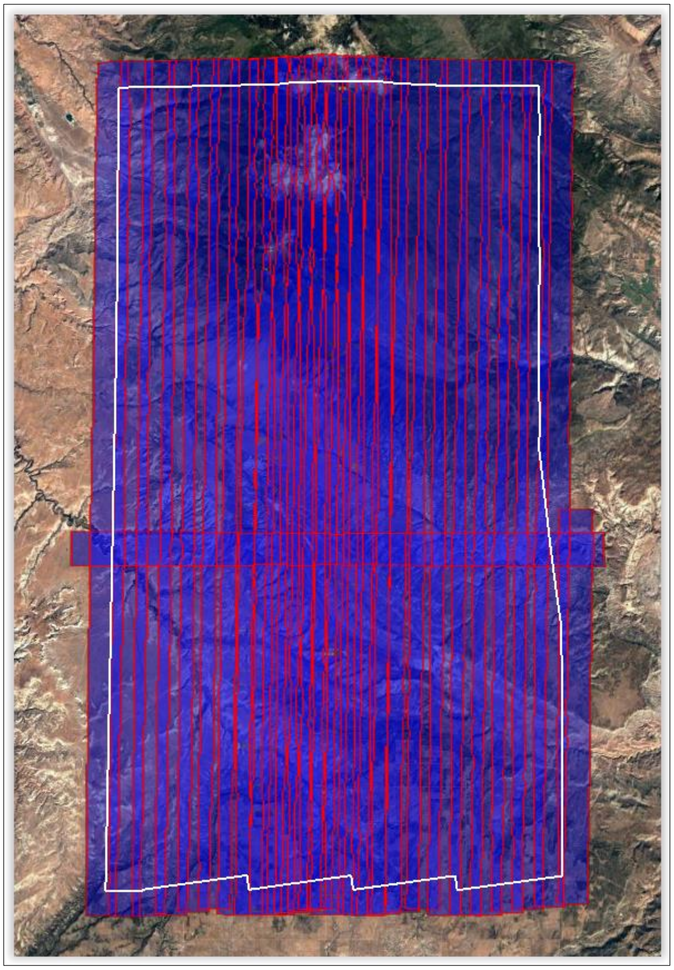
Top left: Box Elder. Top right: Juab. Bottom: Duchesne.

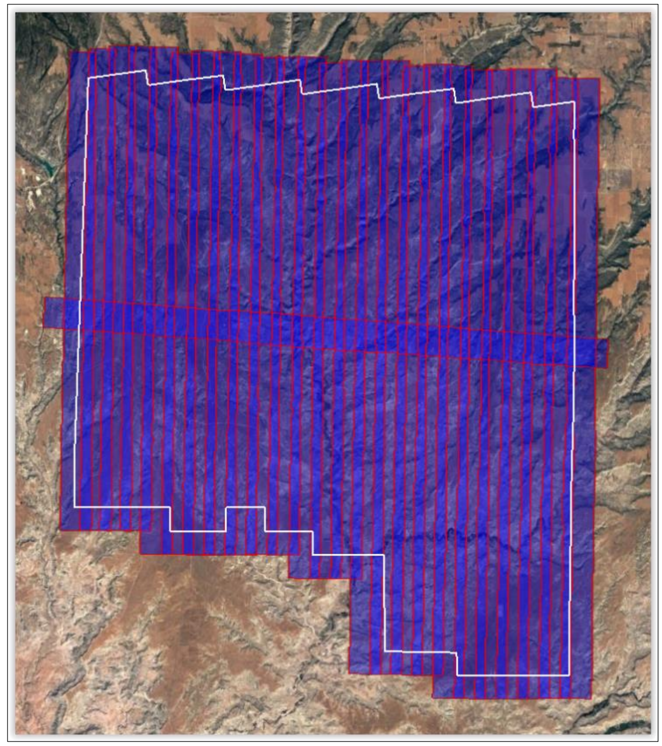
Next page: Top left: San Juan N. Top right: San Juan S. Bottom left: Wendover. Bottom right: Wasatch.

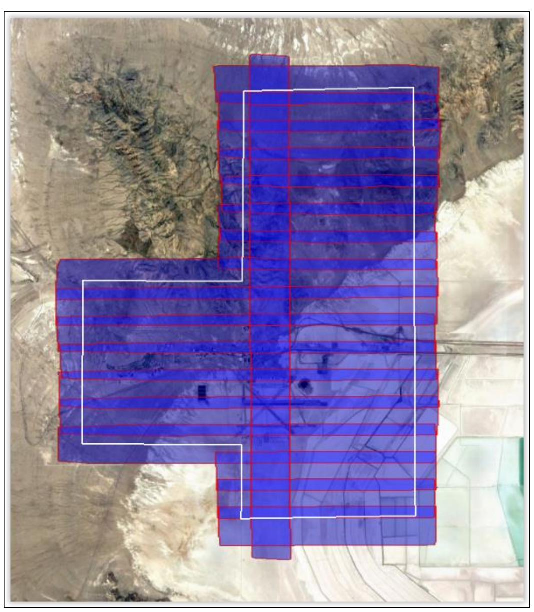


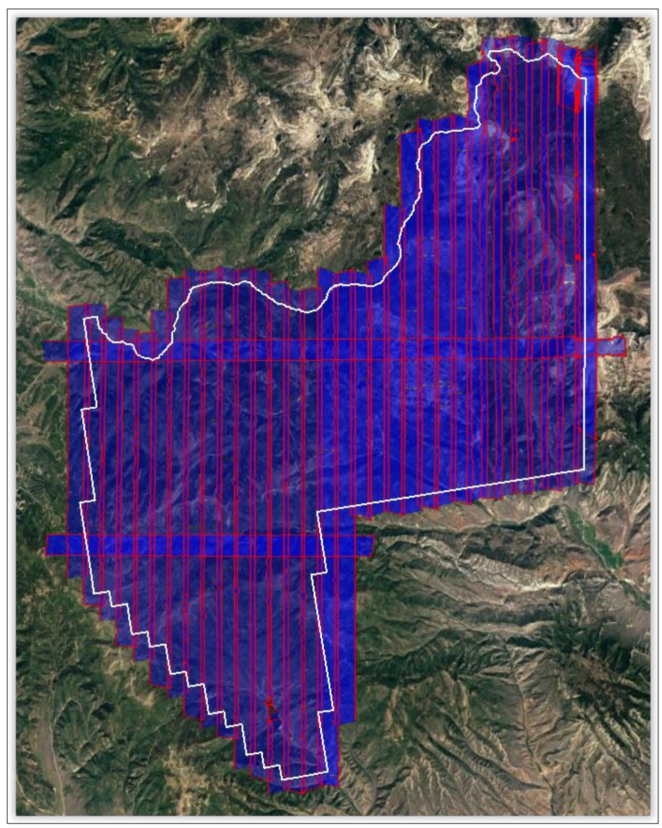








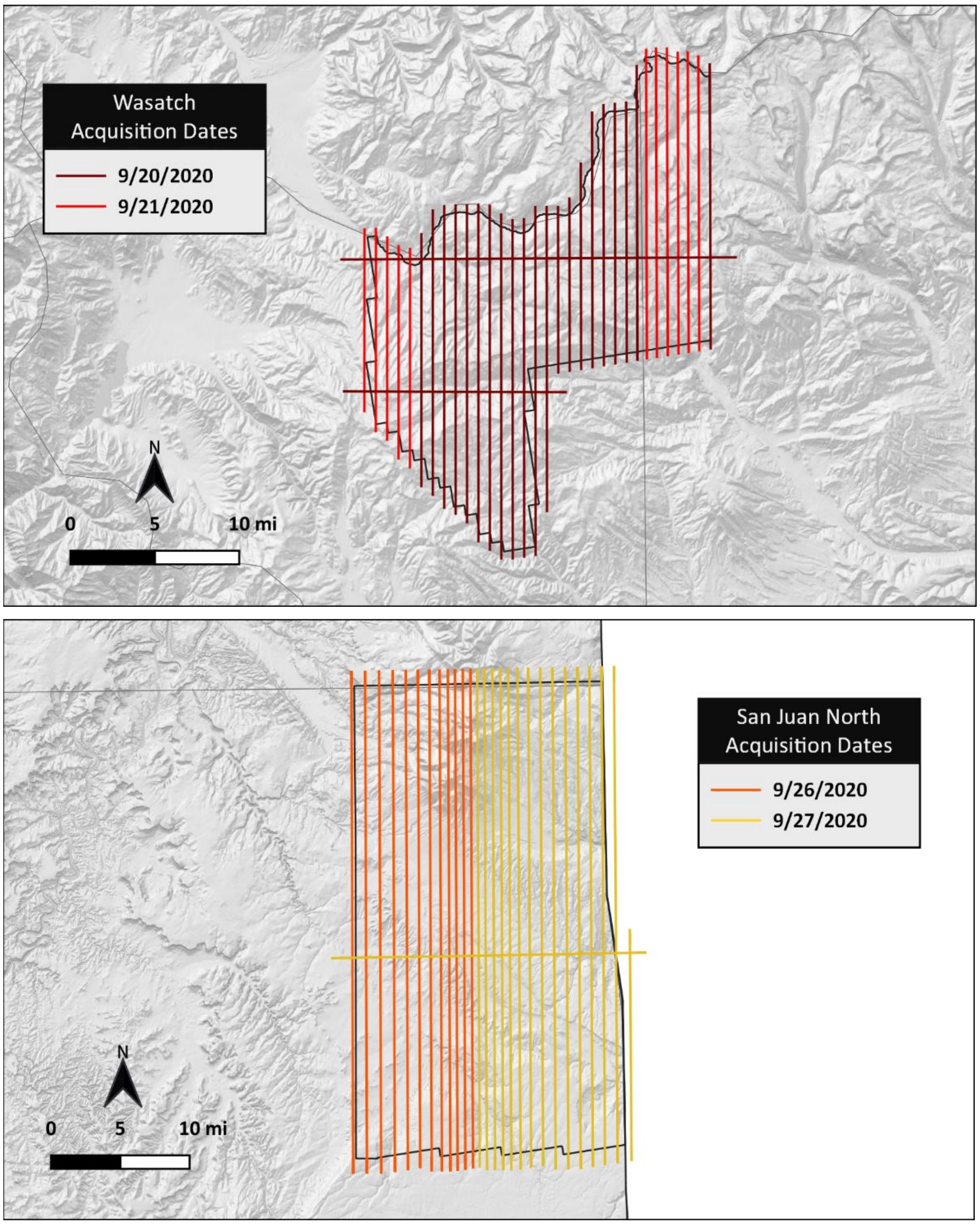


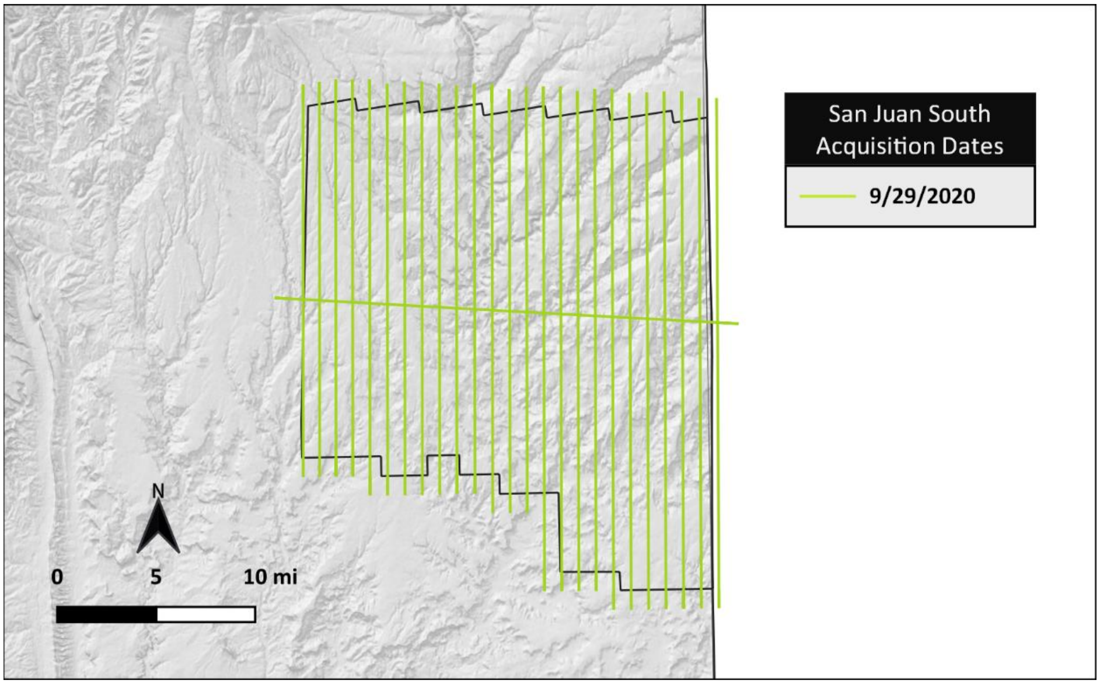


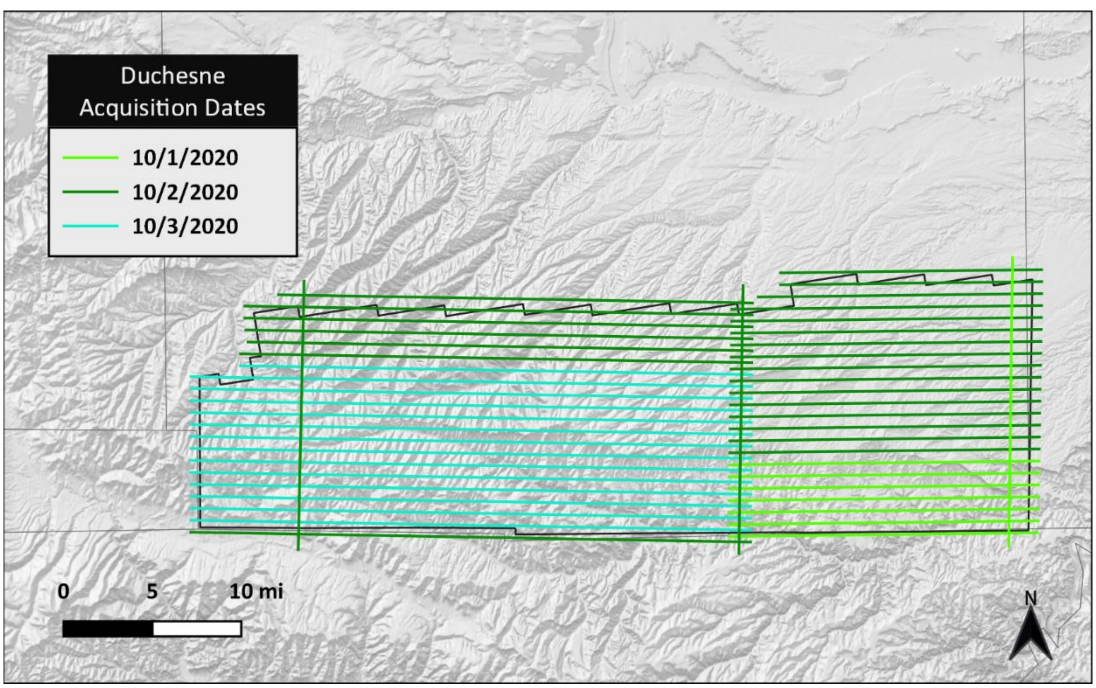
2.3 Acquisition Summary

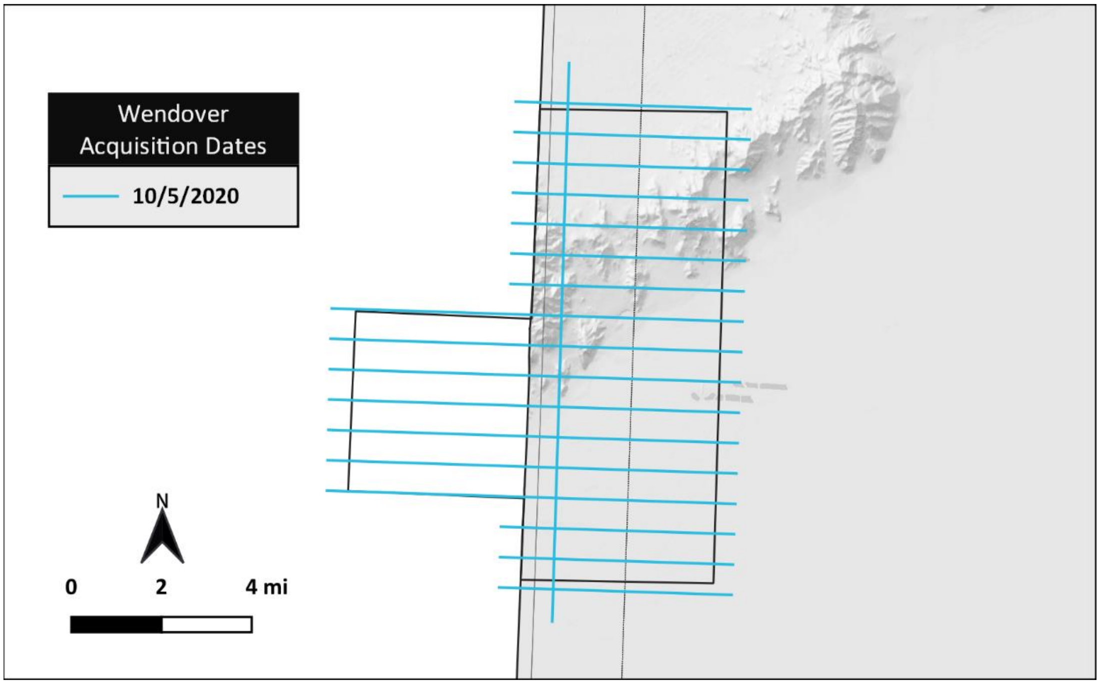
Acquisition for the first delivery AOIs occurred between September 20 and October 10, 2020, and reflights were performed throughout acquisition as needed. These flights took place when ground conditions were free of snow, ice, and standing water. A total of 19 lifts were required to complete lidar acquisition for the assigned Box Elder, Duchesne, Juab, San Juan North, San Juan South, Wasatch, and Wendover AOIs.

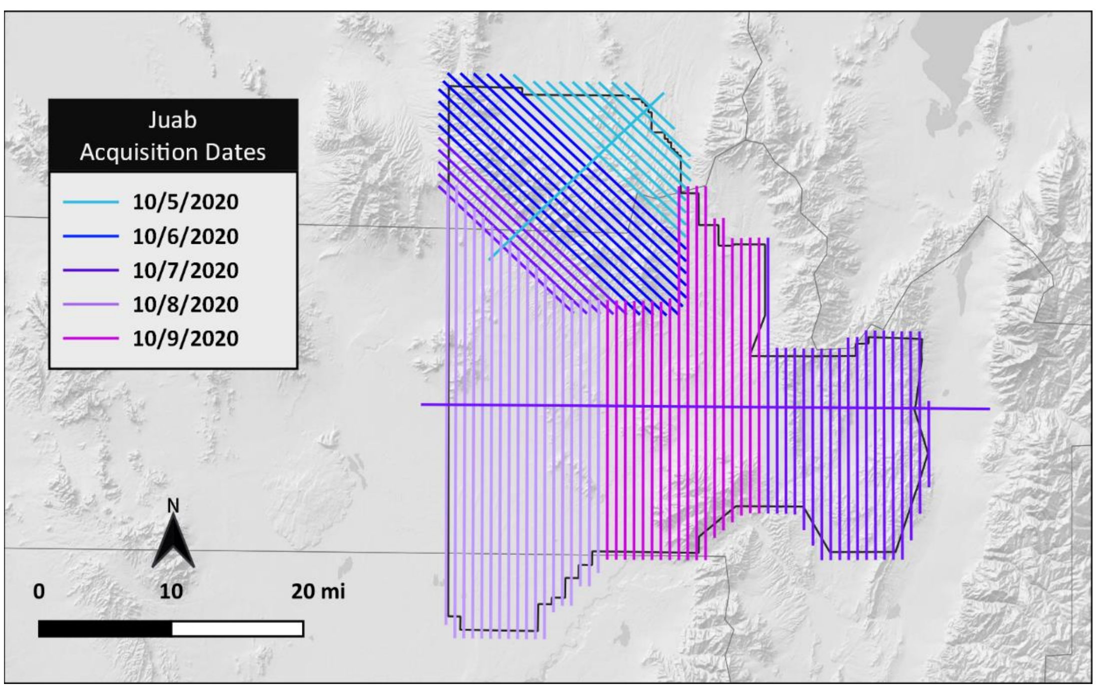
Exhibit 8: Flightlines by day of acquisition

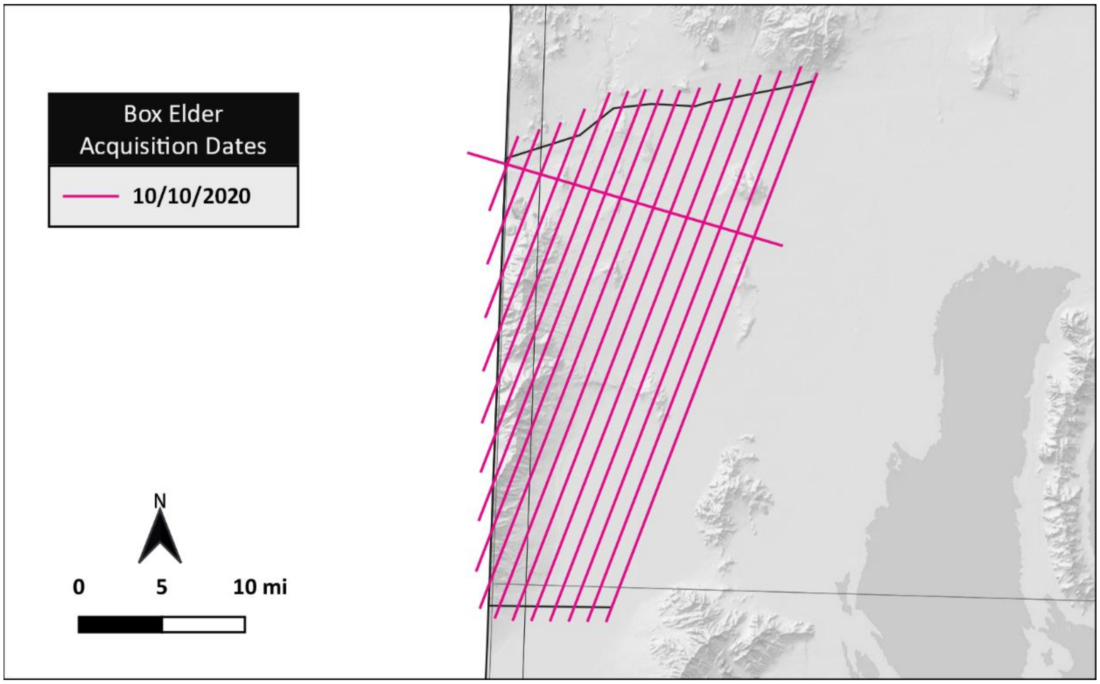



San Juan South
Acquisition Dates
9/29/2020
N
0
5
10 mi


Duchesne
Acquisition Dates
10/1/2020
10/2/2020
10/3/2020
0
5
10 mi
N


Wendover
Acquisition Dates
10/5/2020
N
0
2
4 mi


Juab
Acquisition Dates
10/5/2020
10/6/2020
10/7/2020
10/8/2020
10/9/2020
N
0
10
20 mi



2.4 Flight Logs

Flight dates are listed in the table on the following page, showing the lift ID, the AOI flown, take-off and landing times (in Mountain Daylight Time), the weather and ground conditions, the sensor name and serial number, the aircraft's tail number, and any in-flight disturbances and instrument anomalies. As mentioned in Section 2.2, Optech serviced and updated the Galaxy Prime and Galaxy T2000 in December 2019 and June 2020, respectively. Reflights are sometimes necessary to fill gaps in the LiDAR coverage due to clouds, extreme terrain, sensor malfunctions, or other issues that cannot be resolved during the flight.

Flight Logs												
Flight Date	**Lift ID**	**AOI Covered**	**Take-off Time (MT)**	**Landing Time (MT)**	**Weather Conditions**	**Ground Conditions**	**Sensor Name**	**Sensor Number**	**Aircraft Make & Model**	**Aircraft Tail Number**	**In-flight Disturbances**	**Instrumental Anomalies**
9/20/2020	Was_0920_1	Wasatch	06:55	09:20	Clear	Clear	Optech Galaxy Prime	5060410	Cessna 206	N7269T	None reported	None reported
	Was_0920_2	Wasatch	09:50	12:50	Clouds	Clear	Optech Galaxy Prime	5060410	Cessna 206	N7269T	None reported	None reported
9/21/2020	Was_0921_1	Wasatch	08:40	10:45	Clear	Clear	Optech Galaxy Prime	5060410	Cessna 206	N7269T	None reported	None reported
9/26/2020*	Was_0926_1	Wasatch	10:10	11:00	Clear	Clear	Optech Galaxy Prime	5060410	Cessna 206	N7269T	None reported	None reported
	SJN_0926_1	San Juan North	08:50	13:30	Clear	Clear	Leica TerrainMapper	91555	Piper Navajo	N278RC	None reported	None reported
9/27/2020	SJN_0927_1	San Juan North	08:25	11:00	Clear	Clear	Leica TerrainMapper	91555	Piper Navajo	N278RC	None reported	None reported
	SJN_0927_2	San Juan North	12:20	14:35	Clear	Clear	Leica TerrainMapper	91555	Piper Navajo	N278RC	None reported	None reported
9/29/2020	SJS_0929_1	San Juan South	10:05	13:25	Clear	Clear	Leica TerrainMapper	91555	Piper Navajo	N278RC	None reported	None reported
	SJS_0929_2	San Juan South	14:20	16:10	Clear	Clear	Leica TerrainMapper	91555	Piper Navajo	N278RC	None reported	None reported
10/1/2020	D_1001_1	Duchesne	14:45	18:00	Clear	Clear	Optech Galaxy Prime	5060410	Cessna 206	N7269T	None reported	Restarted system
10/2/2020*	D_1002_1	Duchesne	08:00	13:30	Clear	Clear	Optech Galaxy Prime	5060410	Cessna 206	N7269T	None reported	None reported
10/3/2020	D_1003_1	Duchesne	07:45	12:20	Clear	Clear	Optech Galaxy Prime	5060410	Cessna 206	N7269T	None reported	None reported
10/5/2020	Wen_1005_1	Wendover	11:45	13:00	Clear	Clear	Optech Galaxy Prime	5060410	Cessna 206	N7269T	None reported	None reported
	J_1005_1	Juab	13:30	16:30	Clear	Clear	Optech Galaxy Prime	5060410	Cessna 206	N7269T	None reported	None reported
10/6/2020*	J_1006_1	Juab	12:00	15:00	Hazy	Clear	Optech Galaxy Prime	5060410	Cessna 206	N7269T	None reported	None reported
10/7/2020	J_1007_1	Juab	08:30	14:05	Clear	Clear	Optech Galaxy Prime	5060410	Cessna 206	N7269T	None reported	None reported
10/8/2020	J_1008_1	Juab	08:30	15:45	Some light rain	Clear	Optech Galaxy Prime	5060410	Cessna 206	N7269T	None reported	None reported
10/9/2020	J_1009_1	Juab	08:45	13:55	Scattered clouds	Clear	Optech Galaxy Prime	5060410	Cessna 206	N7269T	None reported	None reported
10/10/2020*	BE_1010_1	Box Elder	08:00	13:10	Clear	Clear	Optech Galaxy T2000	5060452	Cessna 206	N27DV	None reported	Restarted sensor

3. LiDAR Processing Workflow

1. **Absolute Sensor Calibration.** Following acquisition, the raw laser point cloud was adjusted for the difference in roll, pitch, heading, and scale through a comparison to the surveyed ground control points.
2. **Kinematic Air Point Processing.** The airborne GPS positions (collected at 1-second intervals) were post-processed using Applanix's POSPac MMS GNSS Inertial software (PP-RTX). A smoothed best estimate of trajectory (SBET) was developed by combining the corrected GPS positions with 1/200-second inertial measurement unit (IMU) data, which tracked the plane's roll, pitch, and yaw throughout the flight.
3. **Raw LiDAR Point Processing (Calibration).** The SBET and LiDAR range data were combined to solve for the real-world positions of each laser point. Point cloud data was produced by flight strip in ASPRS v1.4 LAS format. Flight strips were output in the project's coordinate system.
4. **Relative Calibration.** Discrepancies between adjacent flightlines were corrected for roll, pitch, heading, and scale, and were tested for relative accuracy. These results are presented in Section 5.1.
5. **Vertical Accuracy Assessment.** Height differences between each static survey point and the laser point surface were identified through comparative tests. Results are presented in Section 5.2.
6. **Tiling & Long/Short Filtering.** Data was clipped to match the project specified tiles. Extremely long and short returns were also filtered out as outliers.
7. **Classified LAS Processing.** The point classification was performed with the ASPRS classes described in **Exhibit 9**. After the bare earth surface was generated, it was manually reviewed to ensure correct classification on the ground (Class 2) points. Once the bare-earth surface was finalized, it was used to generate all hydro-breaklines through heads-up digitization.

   All ground LiDAR data within the lake, pond, and double line drain hydro-flattened breaklines were classified to water (Class 9) using TerraScan macro functionality. A buffer of 1 meter was also used around each hydro-flattened feature to classify these ground points to ignored ground (Class 20). Bridge decks were classified to Class 17. The overlapping data was processed using TerraScan macro functionality to set the overlap bit flag on overlapping flight line data.

   The data was manually reviewed, and any remaining artifacts were removed using TerraScan functionality. A final check of the bare earth dataset was completed and the deliverable LAS files were created in LP360. A final statistical analysis of the classes was performed on a per-tile level to verify classification metrics and LAS header information using Aero-Graphics, Inc. proprietary software.

Exhibit 9: The ASPRS classes used in lidar point classification

USGS Version 2.1 minimum point cloud classification scheme		
CLASS #	**CLASS NAME**	**DESCRIPTION**
1	Processed, but unclassified	Points that do not fit any other classes
2	Bare earth	Bare earth surface
7	Low noise	Low points identified below surface
9	Water	Points inside of lakes/ponds
17	Bridge decks	Points on bridge decks
18	High noise	High points identified above surface
20	Ignored ground	Points near breakline features; ignored in DEM creation process

8. **Hydro-Flattened Breakline Collection.** Ground LiDAR points were used to create a bare earth surface model, which was used to heads-up digitize 2D breaklines of inland streams and rivers with a 100-foot nominal width, and inland ponds and lakes of 2 acres or greater surface area. Elevation values were assigned to all inland ponds and lakes, inland pond and lake islands, and inland stream and river islands, using LP360 functionality. Elevation values were assigned to all inland streams and rivers using Aero-Graphics, Inc. proprietary software. All ground LiDAR data inside of the collected inland breaklines were then classified to water using TerraScan macro functionality.

   Breaklines were collected at bridges but not culverts. The distinction between bridges and culverts was based on the following guidelines: Bridges are structures carrying a road, path, railroad, canal, aircraft taxiway, or any other transit between two locations of higher elevation over an area of lower elevation. A bridge may traverse a river, ravine, road, railroad, or other obstacle. "Bridge" also includes but is not limited to aqueduct, drawbridge, flyover, footbridge, overpass, span, trestle, and viaduct. In mapping, the term "bridge" is distinguished from a roadway over a culvert in that a bridge is an elevated deck that is not underlain with earth or soil. Culverts are a tunnel carrying a stream or open drainage under a road or railroad or through another type of obstruction to natural drainage.

   The breakline files were translated to ESRI shapefile format using were reviewed against LiDAR intensity imagery to verify completeness of capture. All breaklines were compared to triangular irregular networks (TINs) created from ground-only points prior to water classification. To ensure the breaklines matched the LiDAR within accepted tolerances, the horizontal placement of breaklines was compared to terrain features, and the breakline elevations were compared to LiDAR elevations. Some deviation is expected between breakline and LiDAR elevations due to monotonicity, connectivity, and flattening rules that are enforced on the breaklines. Once horizontal placement and vertical variance was reviewed, all breaklines were checked for topological consistency and data integrity using a combination of ESRI ArcMap tools and proprietary tools.

9. **Hydro-Flattened Raster DEM Creation.** A hydro-flattened raster digital elevation model (DEM) was created using the ground classified LiDAR points and the hydro breaklines, and the DEM was then tiled in the GeoTIFF format using LP360 and automated scripting routines within ArcMap. Each surface was reviewed in ESRI ArcMap and ArcScene to check for any surface anomalies or incorrect elevations found within the surface.

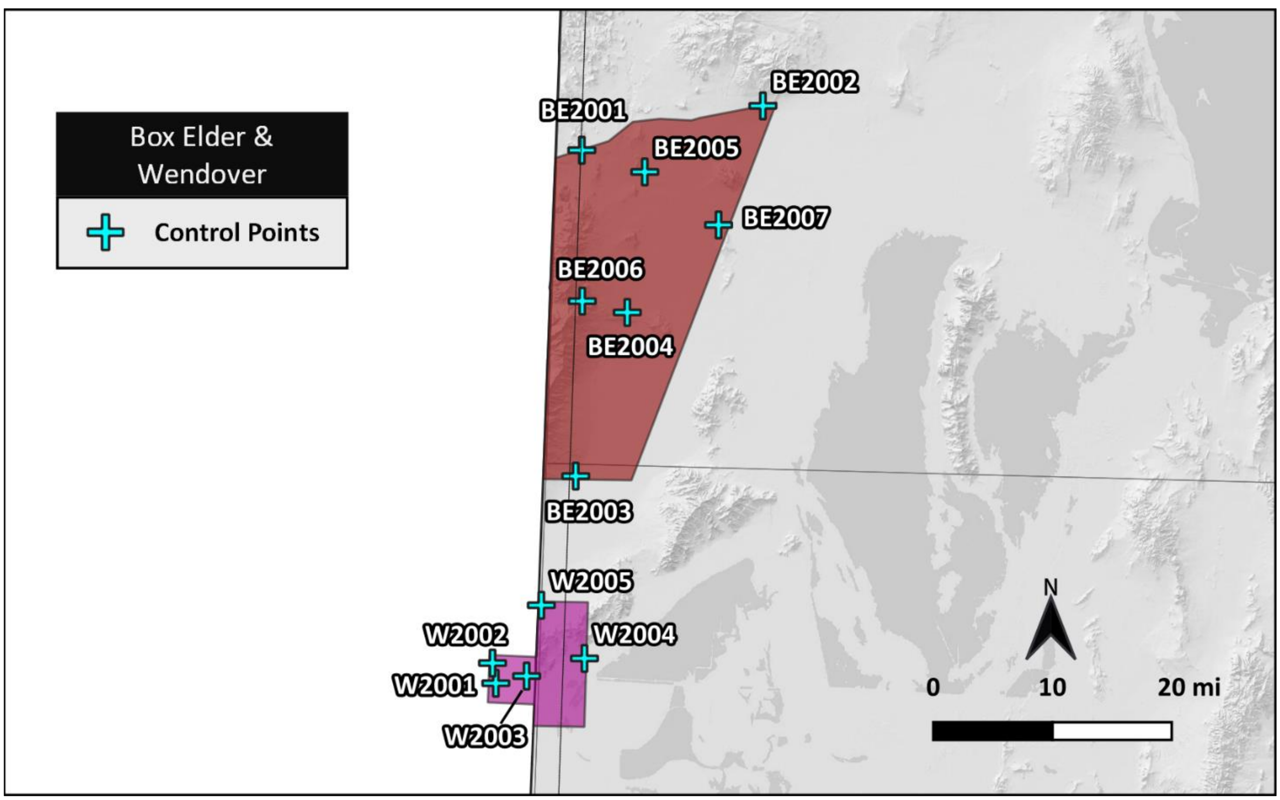
10. **First Return Raster DSM Creation.** A first-return raster digital surface model (DSM) was created using the first-return LiDAR points, which was then tiled in the GeoTIFF format using LP360 and automated scripting routines within ArcMap. Each surface was reviewed in ESRI ArcMap and ArcScene to check for any surface anomalies or incorrect elevations found within the surface.

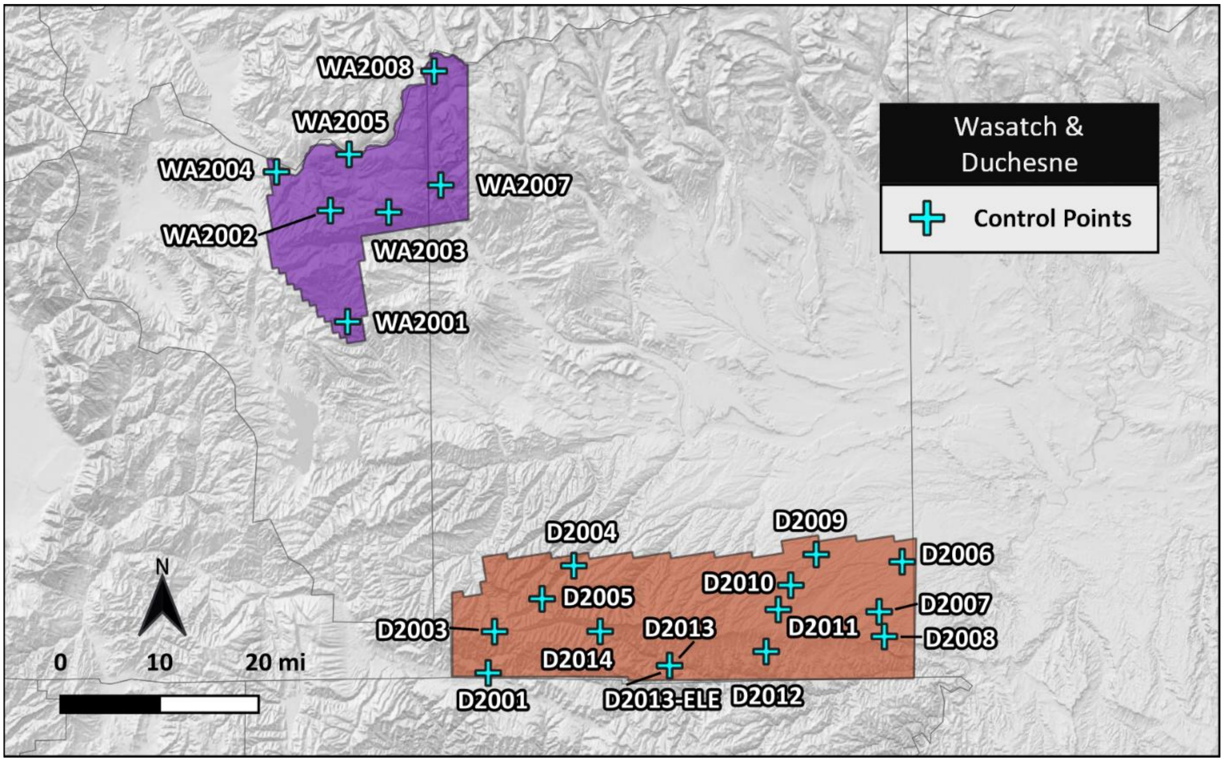
11. **Intensity Image Creation.** The intensity imagery was created in TerraScan software. All overlap classes were ignored during this process to create a more aesthetically pleasing image. Full project coverage was verified in ESRI ArcMap software.

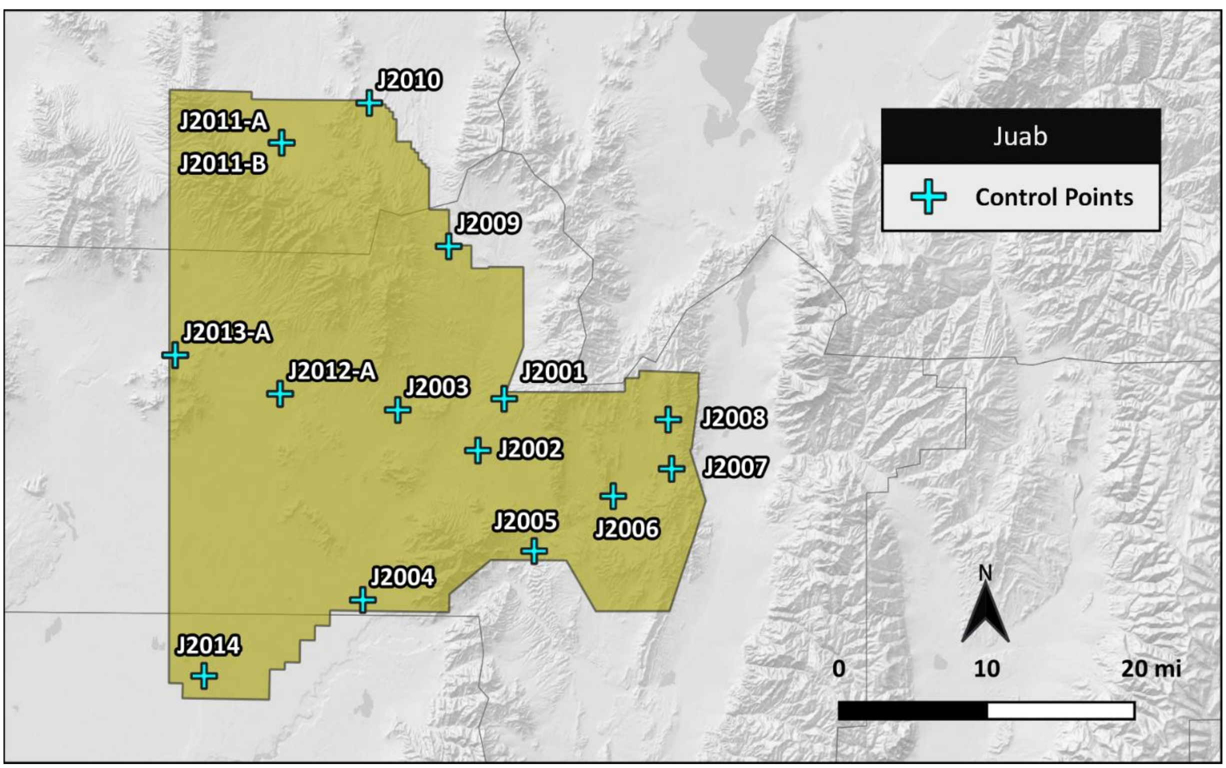
4. Ground Control and Check Point Survey

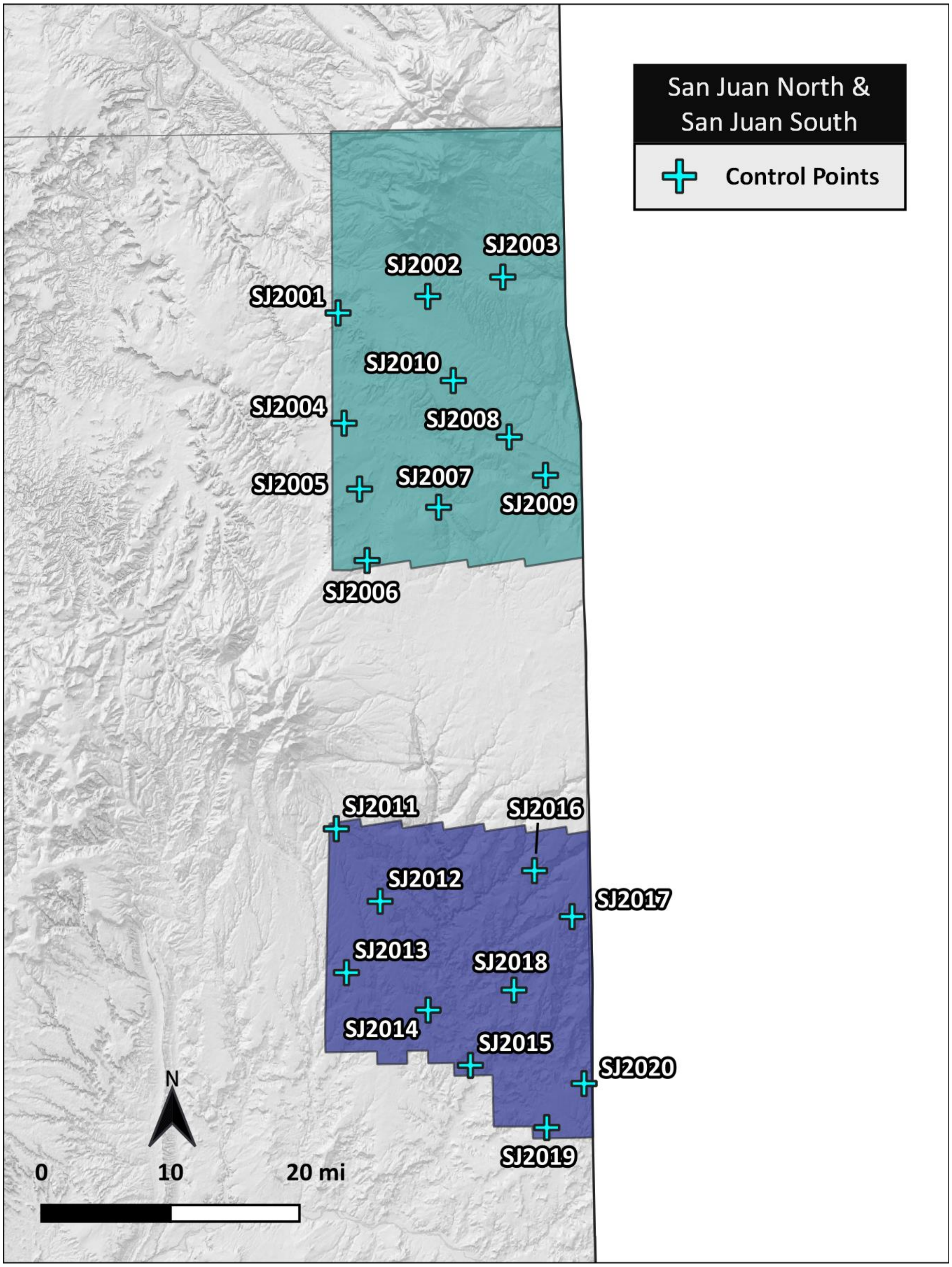
Aero-Graphics' professional land surveyor identified, targeted, and surveyed 70 ground control points for use in data calibration as well as 309 QC check points in vegetated and non-vegetated land cover classifications as an independent test of accuracy for this project. Their locations are shown in **Exhibits 10-12.** A combination of precise GPS surveying methods, including static and RTK observations, were used to establish the 3D position of ground calibration points and QC check points. Calibration control point and QC check point coordinates are included in the deliverable ESRI shapefiles.

Exhibit 10: Locations and names for each ground control point throughout the project areas



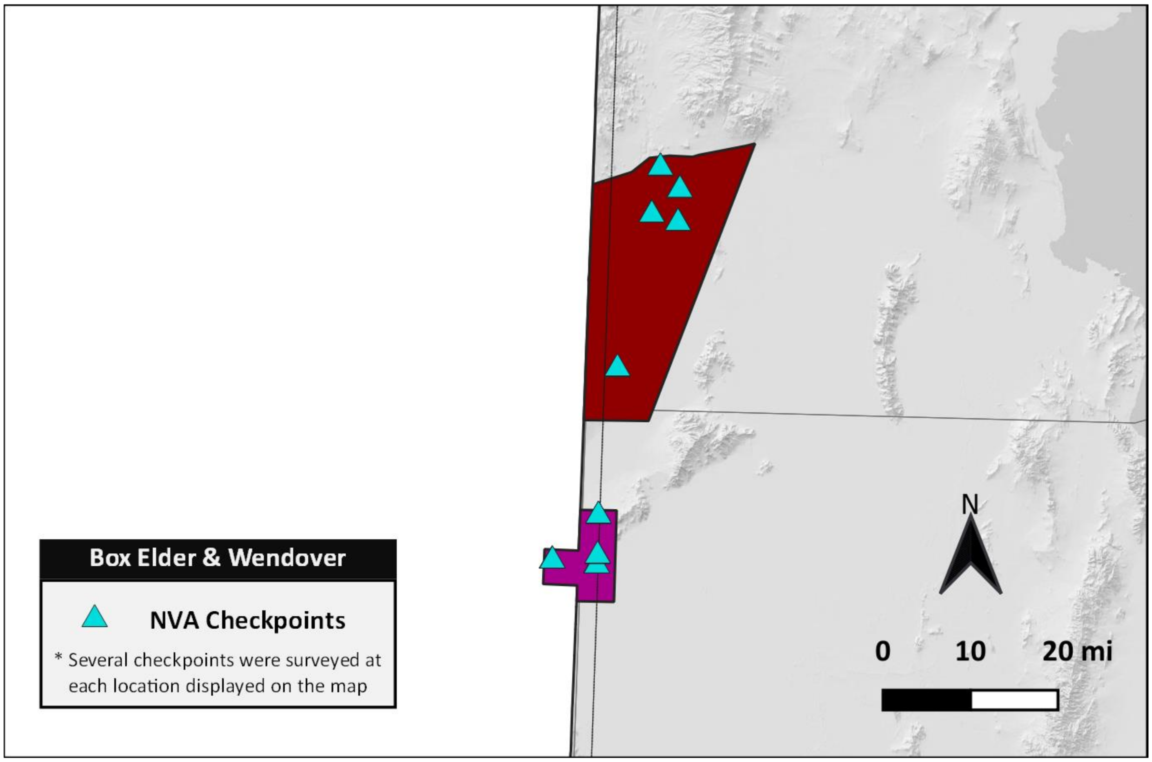

Wasatch & Duchesne
Control Points
WA2008
WA2005
WA2004
WA2007
WA2002
WA2003
WA2001
D2004
D2009
D2006
D2010
D2005
D2007
D2003
D2013
D2011
D2008
D2014
D2001
D2013-ELE
D2012
N
0
10
20 mi

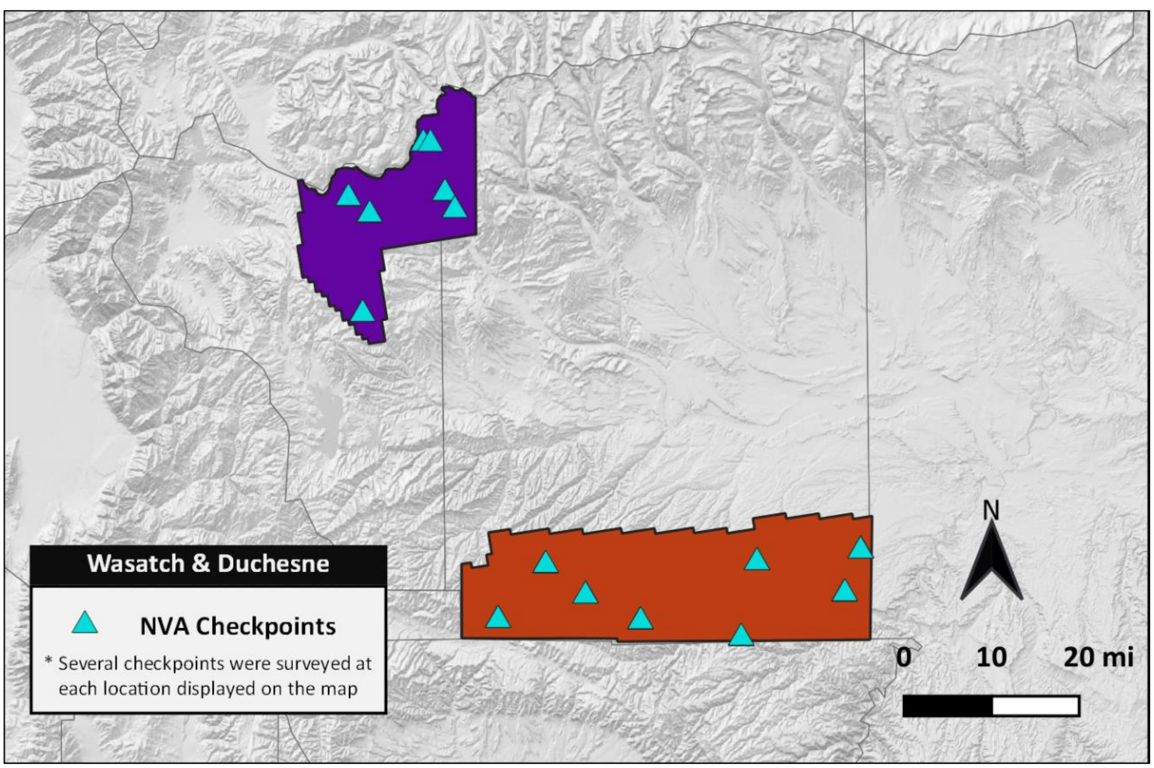

Juab
Control Points
J2010
J2011-A
J2011-B
J2009
J2013-A
J2012-A
J2003
J2001
J2008
J2002
J2007
J2005
J2006
J2004
J2014
N
0
10
20 mi

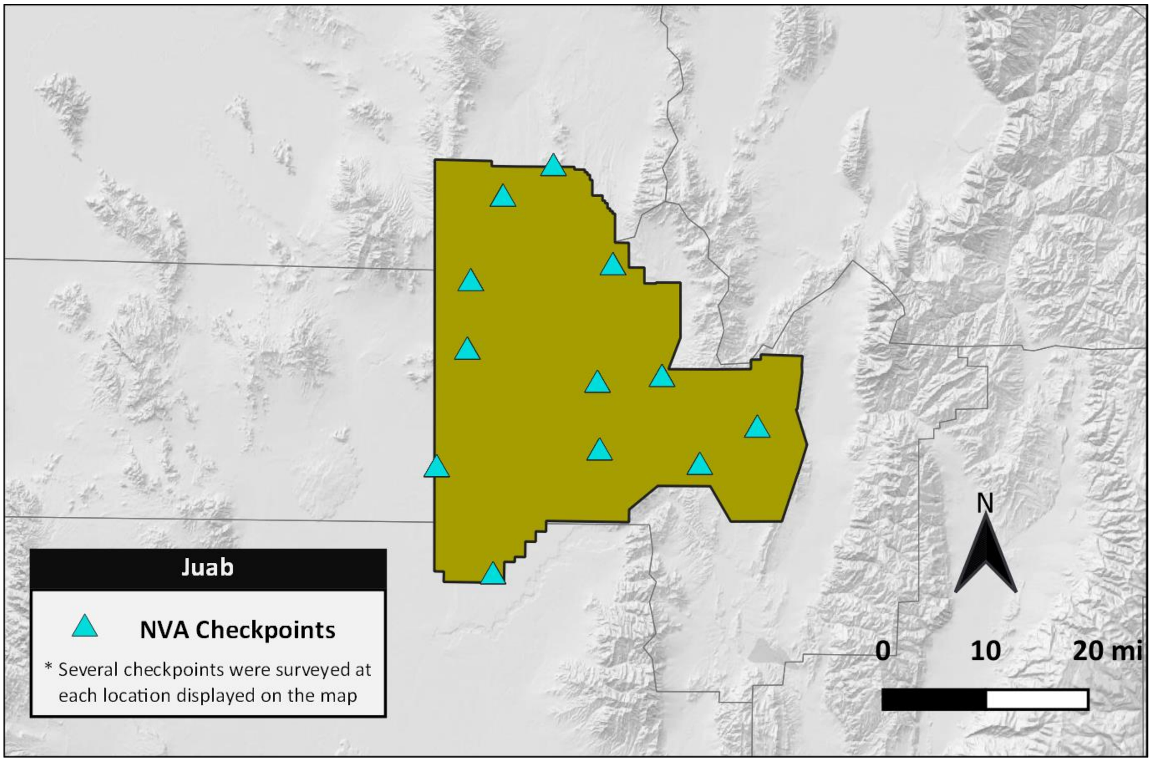


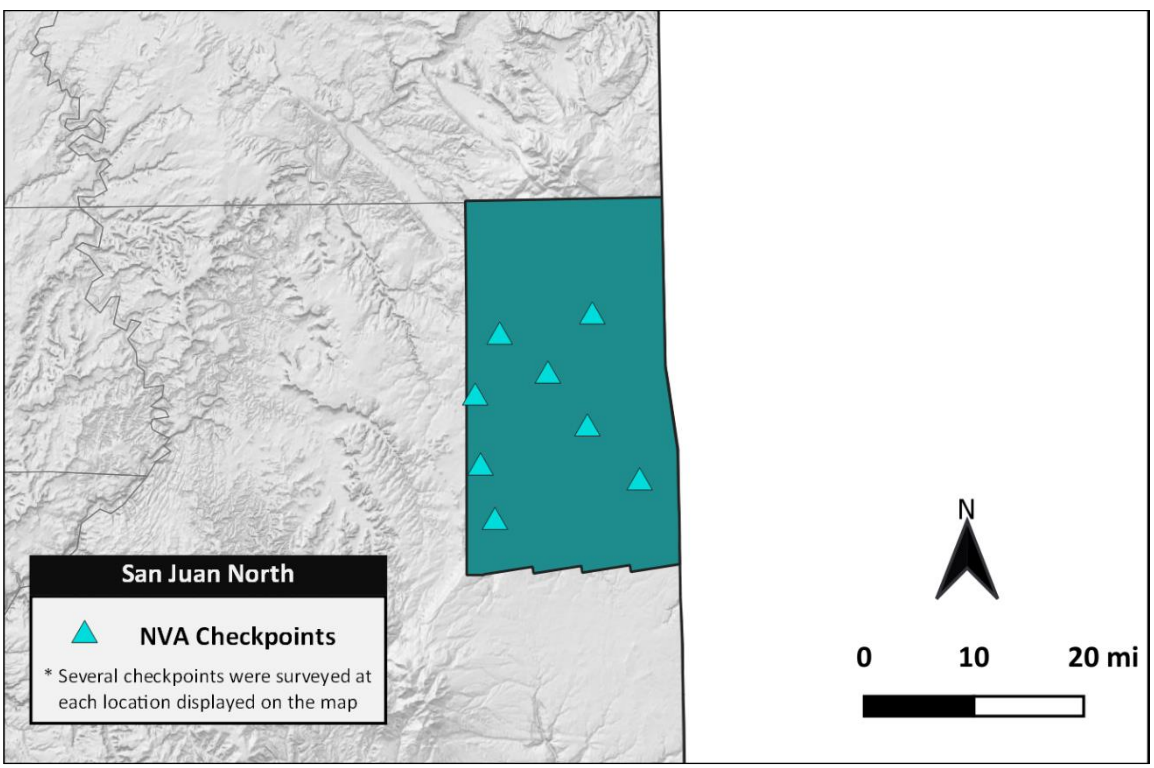
San Juan North &
San Juan South
Control Points
SJ2001
SJ2002
SJ2003
SJ2004
SJ2005
SJ2006
SJ2007
SJ2008
SJ2009
SJ2010
SJ2011
SJ2012
SJ2013
SJ2014
SJ2015
SJ2016
SJ2017
SJ2018
SJ2019
SJ2020
N
0
10
20 mi

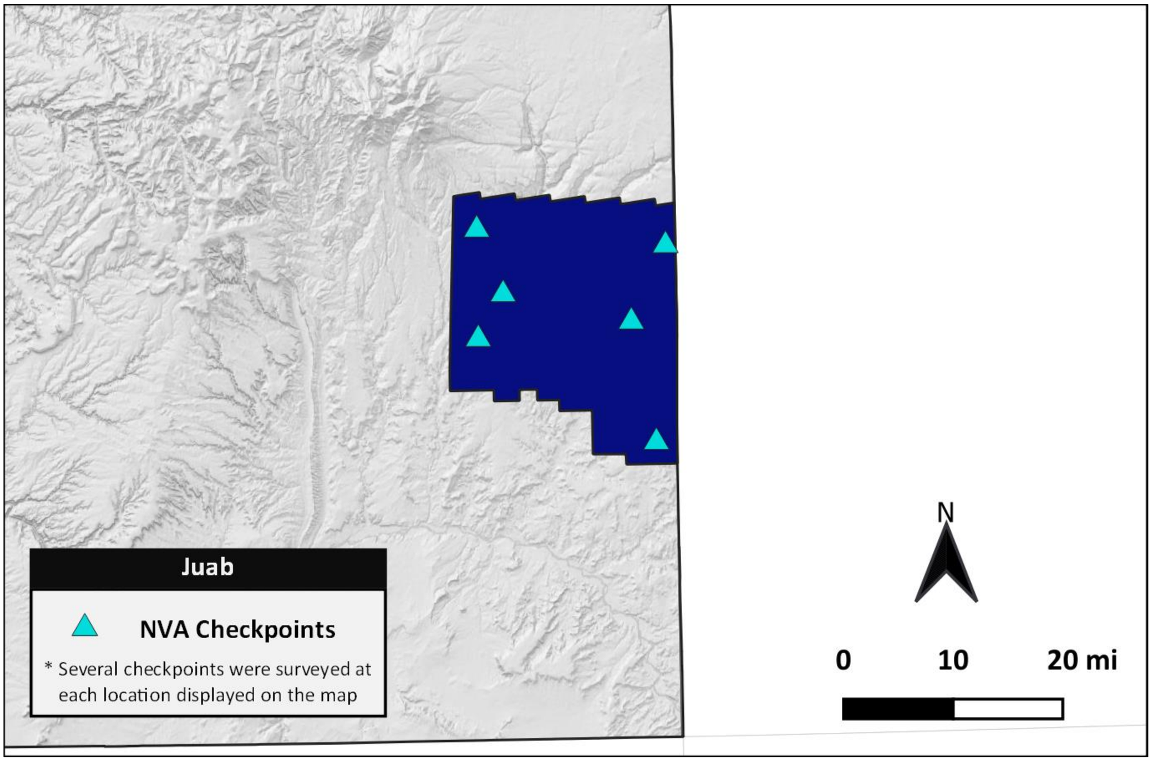
Exhibit 11: Locations of NVA checkpoints throughout the project areas



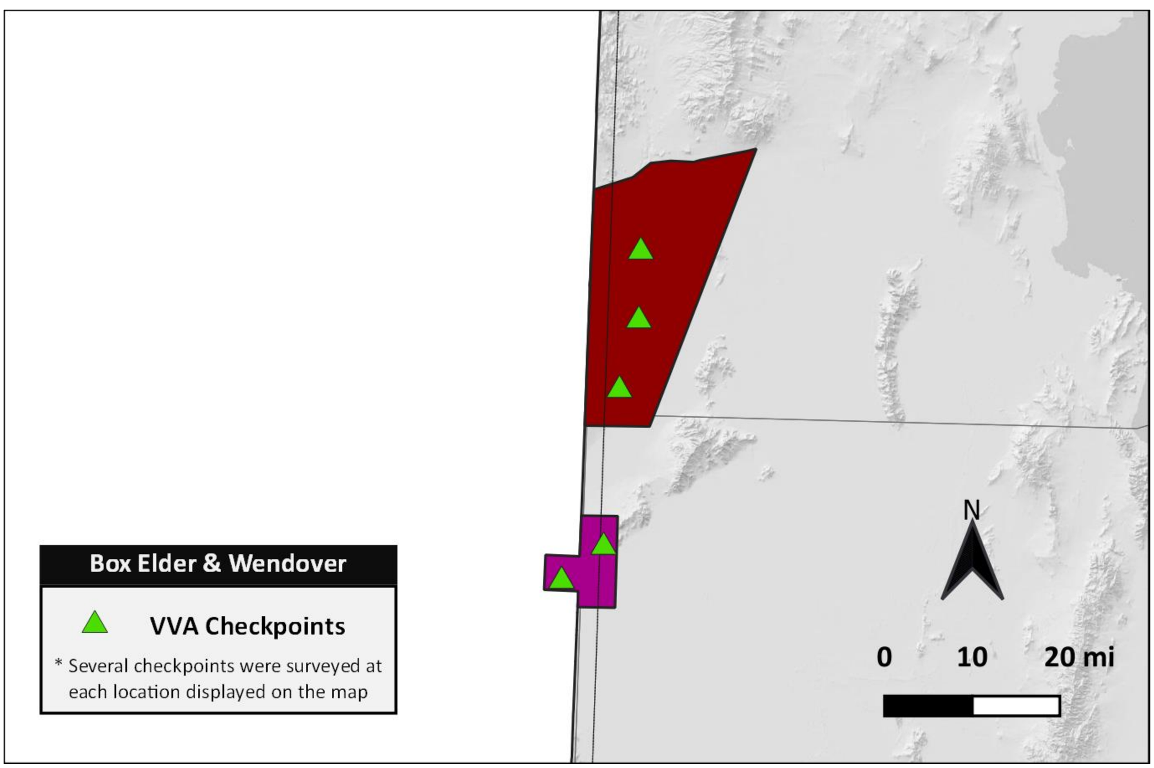


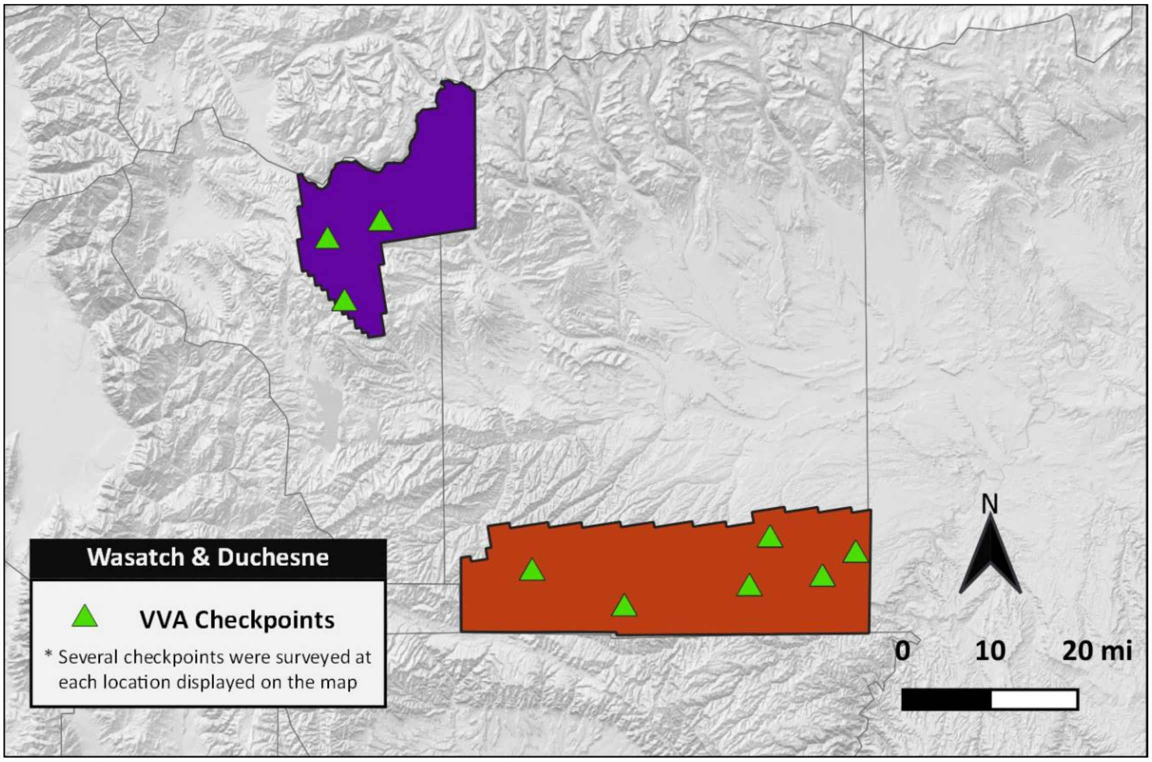

Juab
NVA Checkpoints
* Several checkpoints were surveyed at each location displayed on the map
N
0
10
20 mi

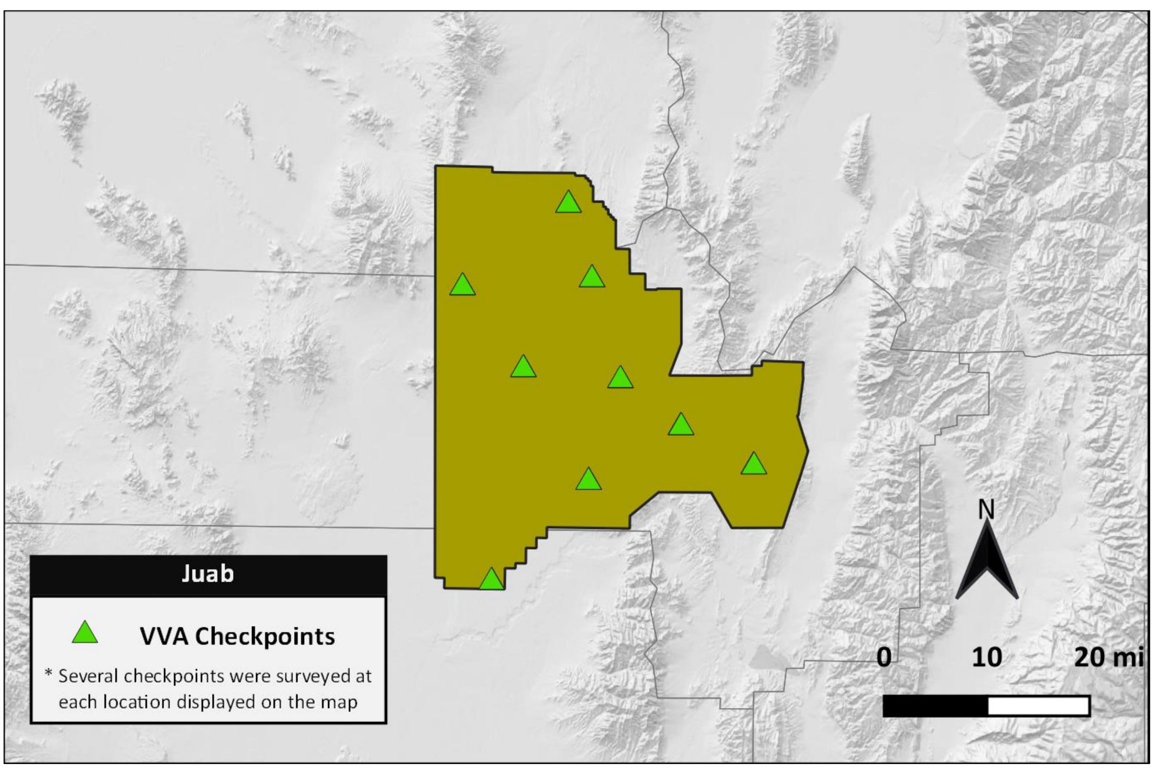

San Juan North
NVA Checkpoints
* Several checkpoints were surveyed at each location displayed on the map
N
0
10
20 mi

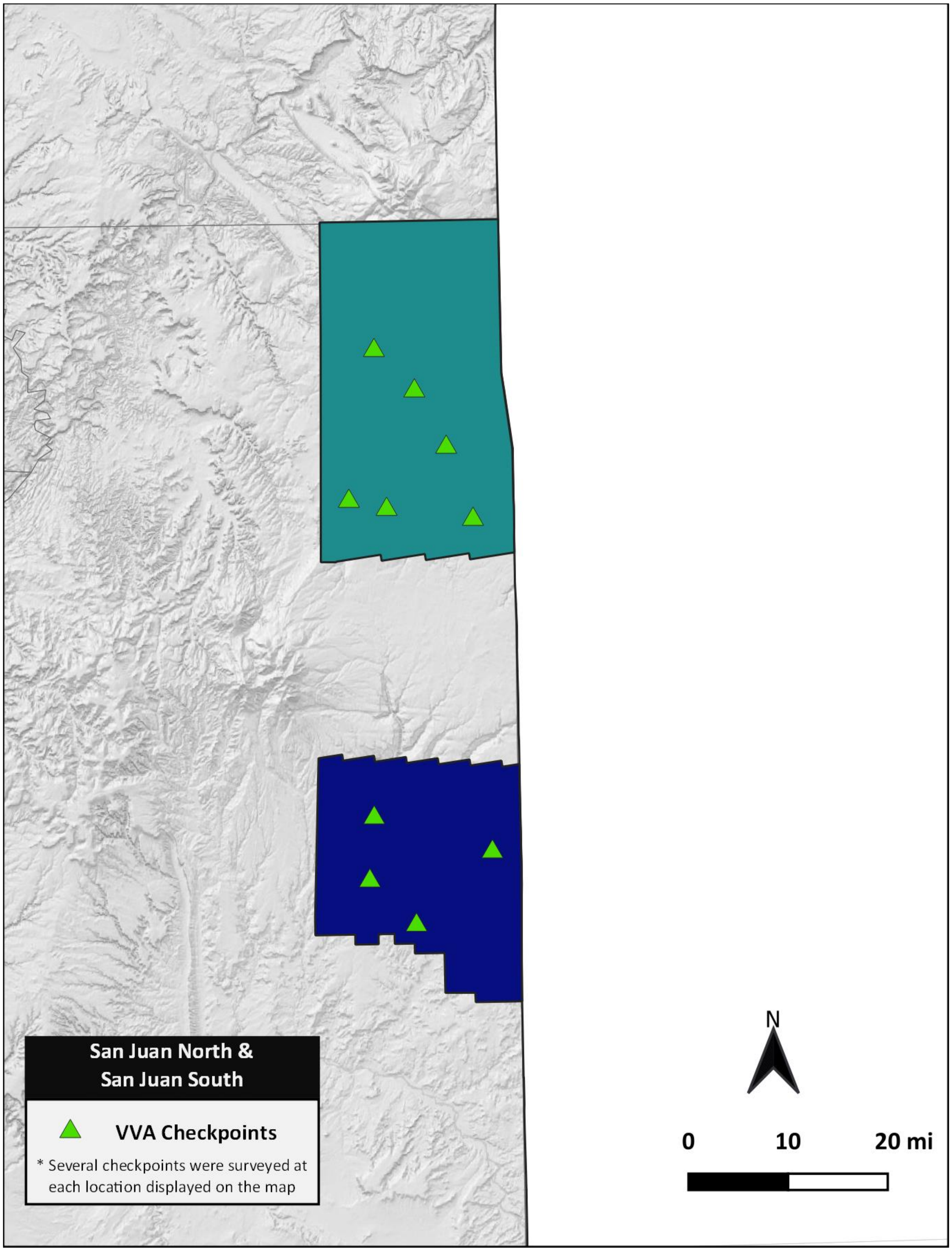


<u>Exhibit 12:</u> Locations of VVA checkpoints throughout the project areas




Wasatch & Duchesne
VVA Checkpoints
* Several checkpoints were surveyed at each location displayed on the map
N
0
10
20 mi


Juab
VVA Checkpoints
* Several checkpoints were surveyed at each location displayed on the map
N
0
10
20 mi


San Juan North &
San Juan South
VVA Checkpoints
* Several checkpoints were surveyed at each location displayed on the map
N
0
10
20 mi

5. Accuracy Testing and Results

5.1 Relative Calibration Accuracy Results

Inter-swath relative accuracy is defined as the elevation difference in the overlapping area of parallel swaths. During the calibration process, coincident tie-lines are created in the overlapping regions of each swath. The elevation difference between these tie lines was used to measure the between-swath relative accuracy of the dataset. During calibration, this process is carried out to verify consistency from swath to swath, but as a quality assurance measure it can also point toward the internal consistency of the overall dataset. The results are based on the comparison of the flightlines and points for each area. The results below include any reflights that were completed over each area, increasing the number of flightlines from what was originally planned.

Utah AGRC Fall Additions First Delivery project areas: (257 flightlines, > 16 billion points)

- Inter-swath relative accuracy **average** of 0.046 m

5.2 Calibration Control Vertical Accuracy

Calibration control point reports were generated as a quality assurance check. These results are shown below in **Exhibit 13**, and the location of each control point is displayed throughout Exhibit 10.

Exhibit 13: Calibration control vertical accuracy results summary

Calibration Control Accuracy$_Z$: Utah AGRC Fall Additions Project Area	
Average Error = +0.008 m	Average Magnitude = 0.045 m
Minimum Error = -0.210 m	RMSE = 0.058 m
Maximum Error = +0.120 m	σ = 0.058 m
Survey Sample Size: n = 70	

5.3 Absolute Horizontal Accuracy

The data set collected at 1,600m AGL was produced to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 26.0 cm RMSEx / RMSEy Horizontal Accuracy Class which equates to Positional Horizontal Accuracy = +/- 45cm at a 95% confidence level. The data set collected at 2,500m AGL was produced to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 35.0 cm RMSEx / RMSEy Horizontal Accuracy Class which equates to Positional Horizontal Accuracy = +/- 60.6 cm at a 95% confidence level.

5.4 Point Cloud Testing

The project specifications require that only Non-Vegetated Vertical Accuracy (NVA) be computed for raw LiDAR point cloud swath files. NVA is defined as the elevation difference between the LiDAR surface and ground surveyed static points collected in open terrain (bare soil, sand, rocks, and short grass) as well as urban terrain (asphalt and concrete surfaces). The NVA for this project was tested with 198 check points (20 in UTMz11 and 178 in UTMz12). These check points were not used in the calibration or post processing of the LiDAR point cloud data. Elevations from the unclassified LiDAR surface were measured for the xy location of each check point. Elevations interpolated from the LiDAR surface were then compared to the elevation values of the surveyed control points.

Raw Non-vegetated Vertical Accuracy (Raw NVA): The tested Raw NVA for this dataset was found to be 0.017 meters in UTMz11 and 0.042 meters in UTMz12, in terms of the RMSEz. The resulting NVA stated as the 95% confidence level (RMSEz x 1.96) is 0.033 meters in UTMz11 and 0.082 meters in UTMz12. Therefore, this dataset meets the required NVA of 0.196 meters at the 95% confidence level as defined by the National Standards for Spatial Data Accuracy (NSSDA).

5.5 Digital Elevation Model Testing

The project specifications require the accuracy of the derived DEM be calculated and reported in two ways: (1) Non-Vegetated Vertical Accuracy (NVA) calculated at a 95% confidence level in "bare earth" and "urban" land cover classes and (2) Vegetated Vertical Accuracy (VVA) in all vegetated land cover classes combined calculated based on the 95th percentile error. The NVA for this project was tested with 198 check points (20 in UTMz11 and 178 in UTMz12). The VVA was tested with 129 check points (5 in UTMz11 and 124 in UTMz12).

The tested Non-Vegetated Vertical Accuracy (NVA) for this dataset captured from the DEM using bi-linear interpolation to derive the DEM elevations was found to be 0.016 meters in UTMz11 and 0.041 meters in UTMz12, in terms of the RMSEz. The resulting accuracy stated as the 95% confidence level (RMSEz x 1.96) is 0.032 meters in UTMz11 and 0.081 meters in UTMz12. Therefore, this dataset meets the required NVA of 0.196 meters at the 95% confidence level.

The tested Vegetated Vertical Accuracy (VVA) for this dataset captured from the DEM using bi-linear interpolation for all classes was found to be 0.026 meters in UTMz11 and 0.147 meters in UTMz12. Therefore, this dataset meets the required VVA of 0.294 meters based on the 95th percentile error.

5.6 Data Accuracy Summary

Accuracy has been tested to meet 19.6 cm or better Non-Vegetated Vertical Accuracy at 95% confidence level using RMSEz x 1.96 as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation (NDEP)/ASPRS Guidelines. The results are summarized below in **Exhibit 14.**

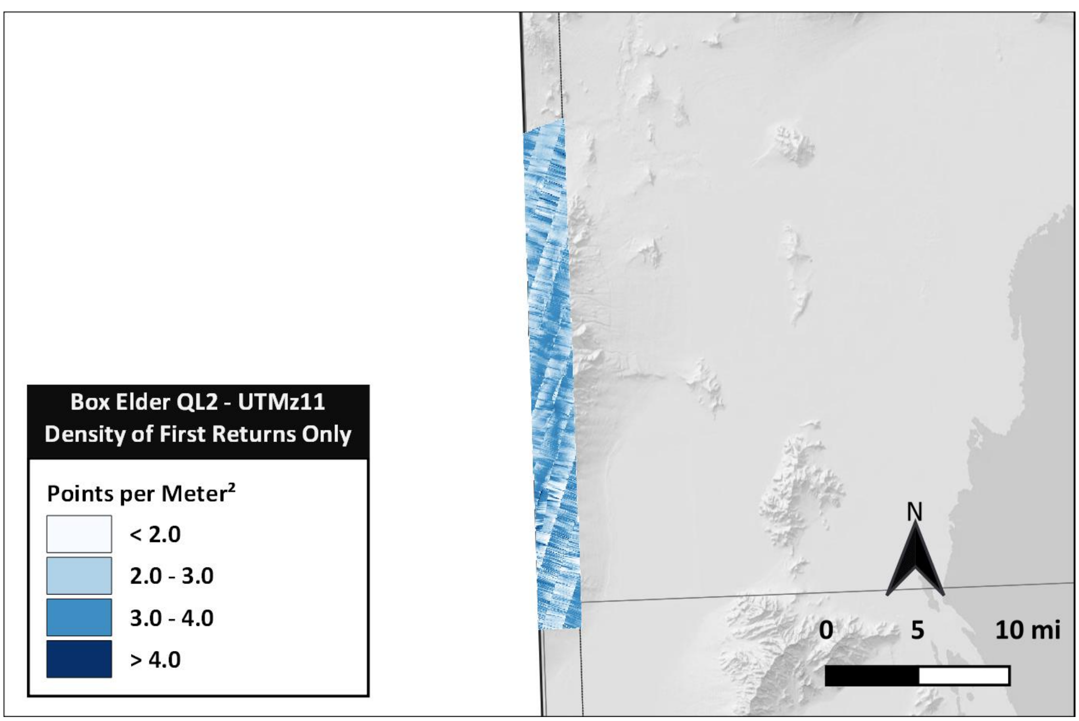
Exhibit 14: Summary of the data accuracy tests

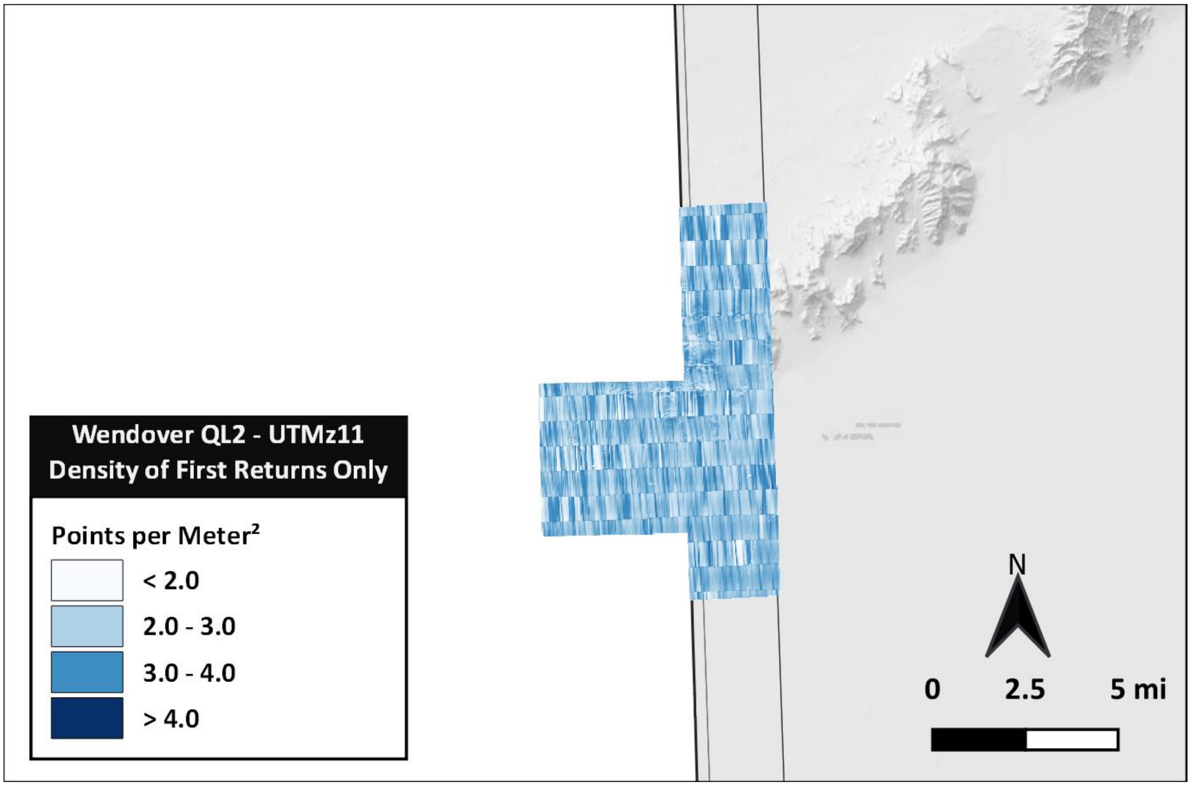
Area	Raw Point Cloud NVA (m)	DEM NVA (m)	DEM VVA (m)	Points Tested NVA	Points Tested VVA
UTMz11	0.017	0.032	0.013	20	5
UTMz12	0.082	0.081	0.147	178	124

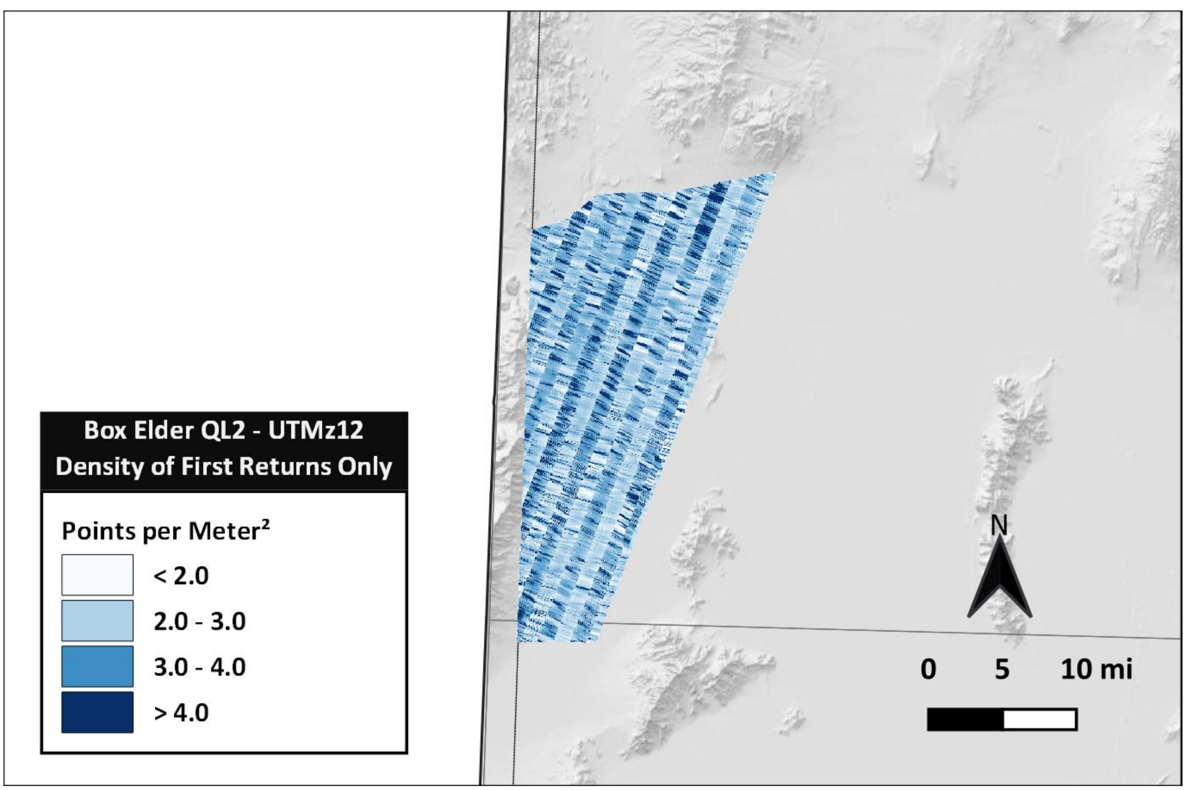
5.7 Data Density

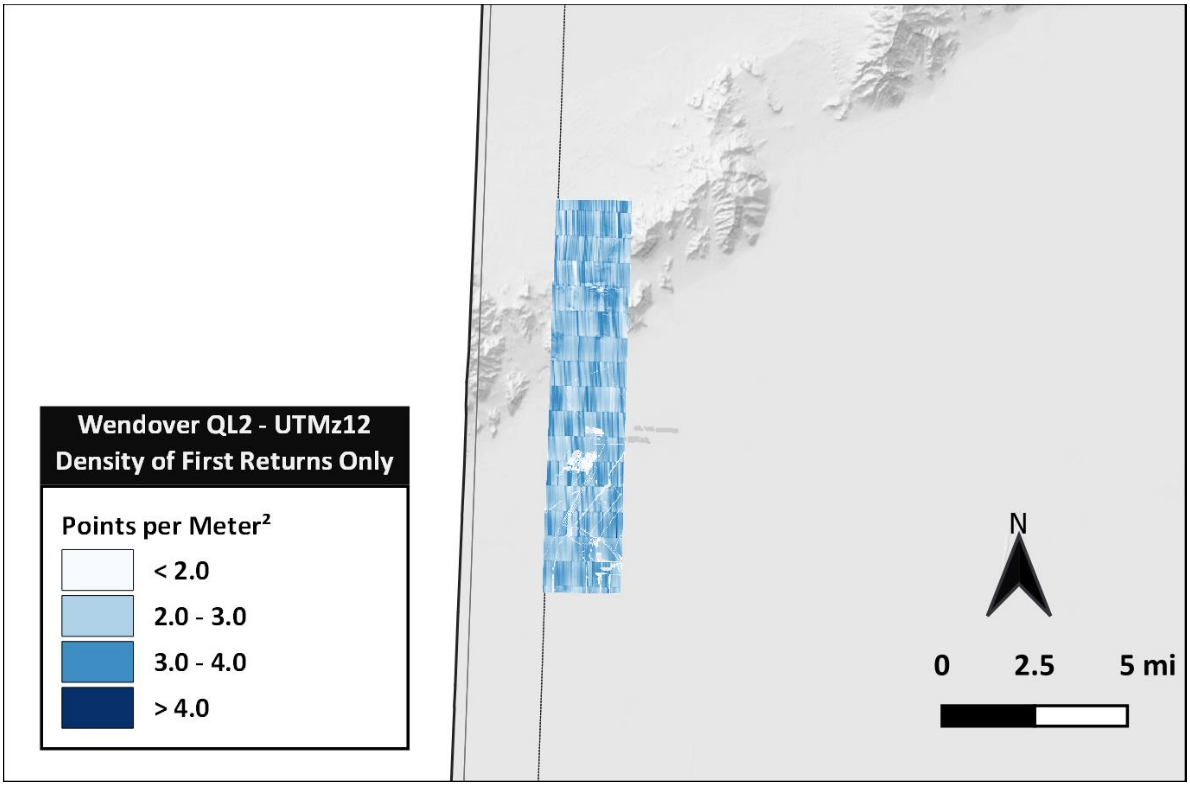
In order to fulfill USGS LBS 2.1 QL2 density requirements, the density of the point cloud must be greater than or equal to 2 points per meter^2. Average density for the first delivery project areas was calculated based on first returns only. **Exhibit 15** illustrates that the acquisition met or exceeded the required density except in areas where bodies of water impeded the collection of data or tiles contained a proportionally significant area outside of the project boundaries. The first delivery project achieved an average density of 3.4 points per meter^2 for first returns in UTMz11N and 3.3 points per meter^2 for first returns in UTMz12N.

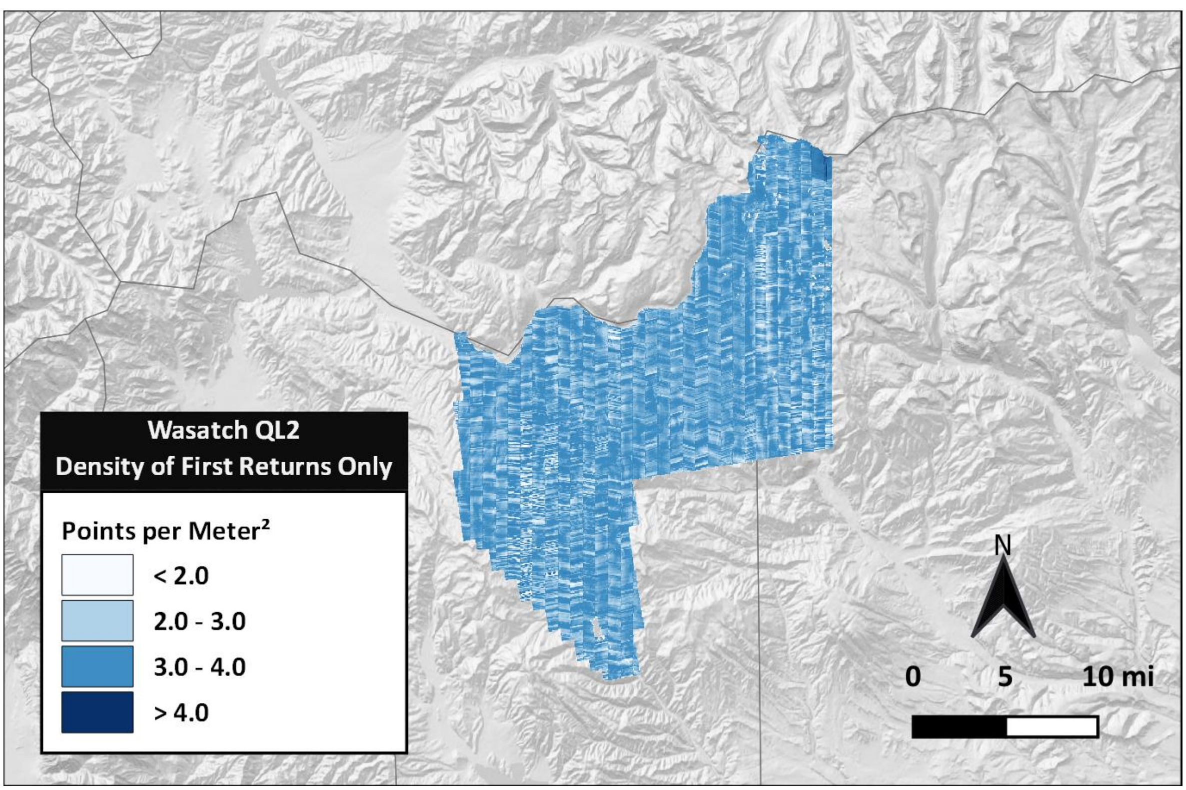
Exhibit 15: Laser point density of first returns, point/m^2

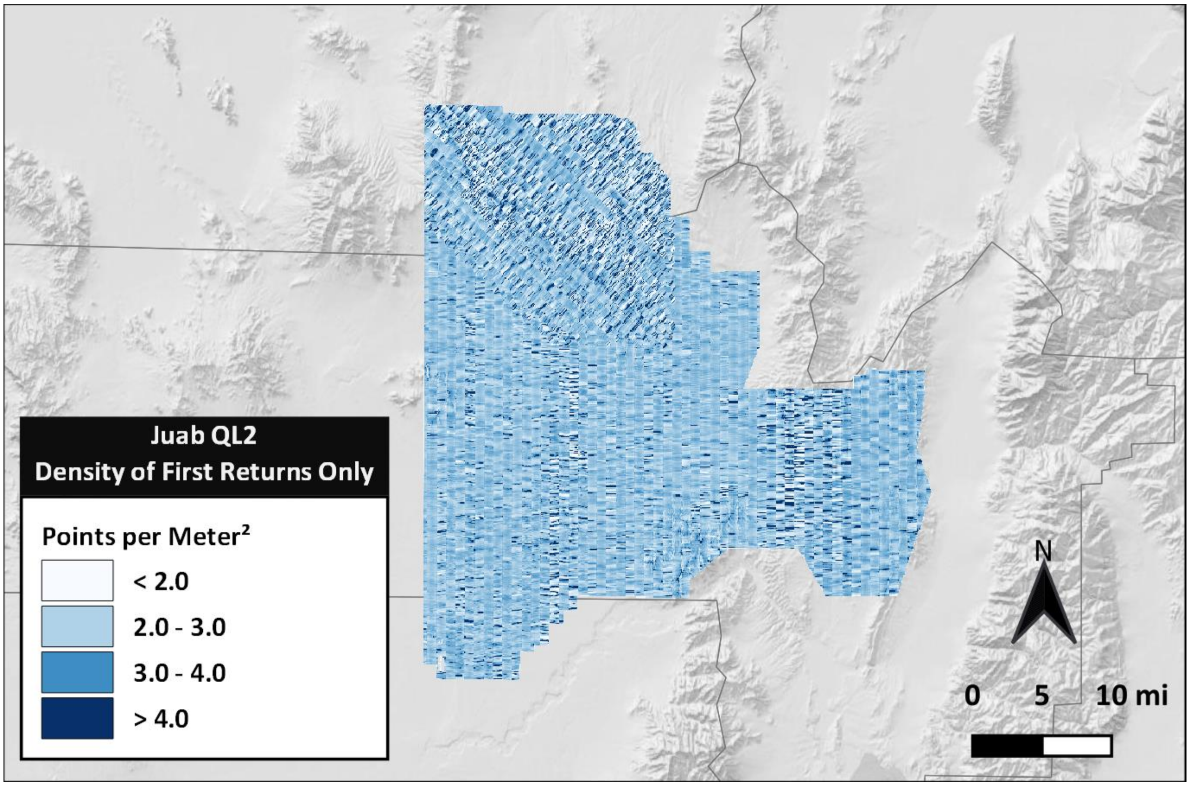


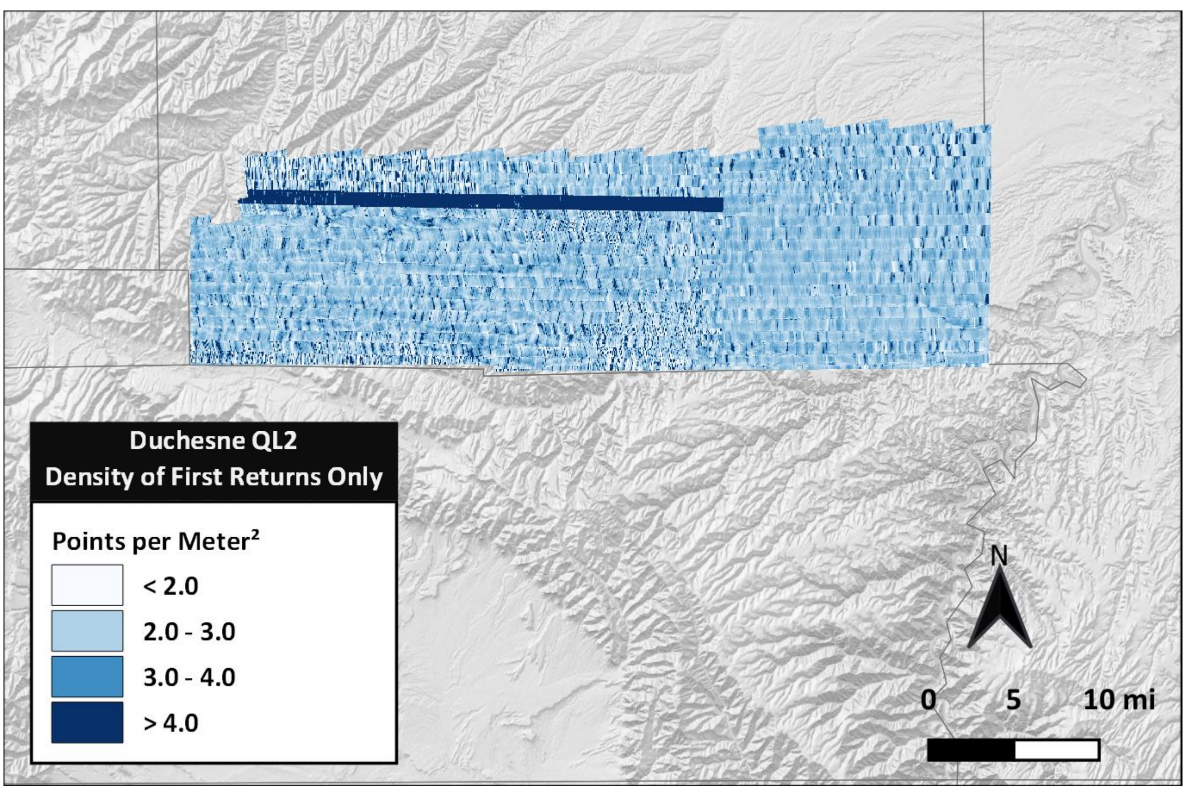

Wendover QL2 - UTMz11
Density of First Returns Only
Points per Meter²
< 2.0
2.0 - 3.0
3.0 - 4.0
> 4.0
N
0
2.5
5 mi

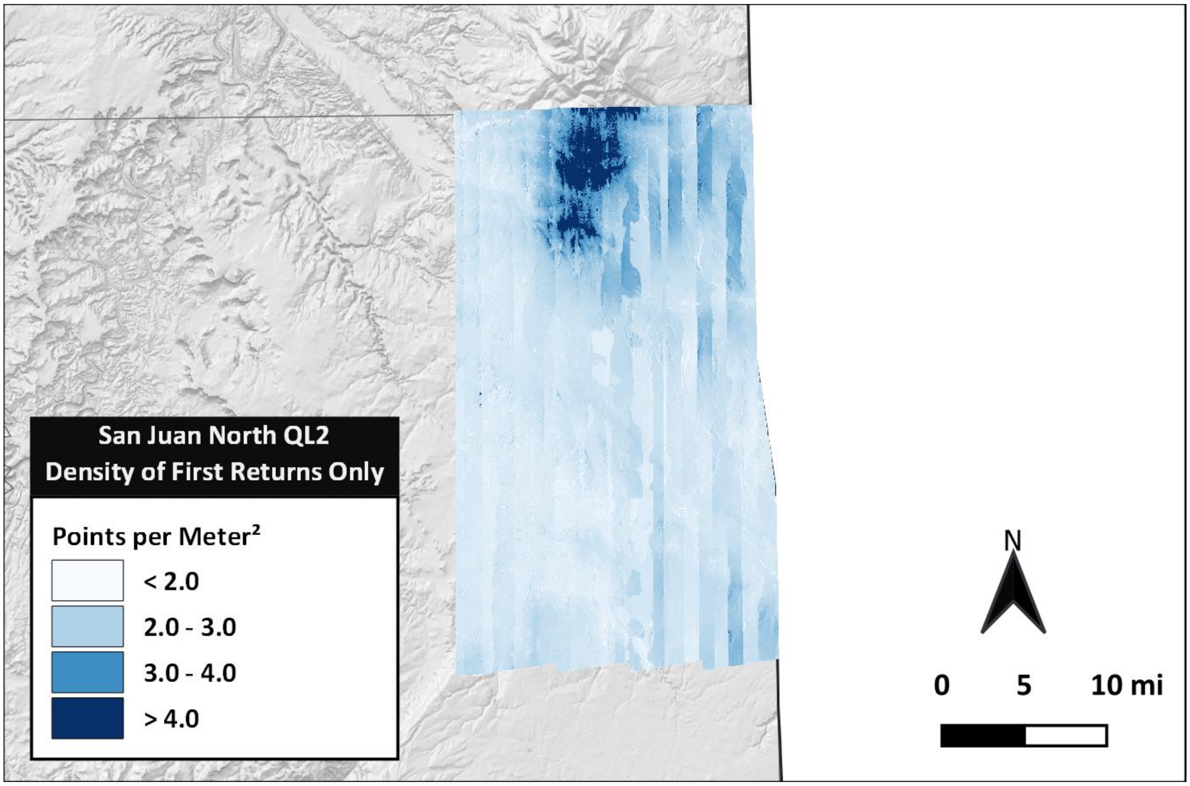

Box Elder QL2 - UTMz12
Density of First Returns Only
Points per Meter²
< 2.0
2.0 - 3.0
3.0 - 4.0
> 4.0
N
0
5
10 mi

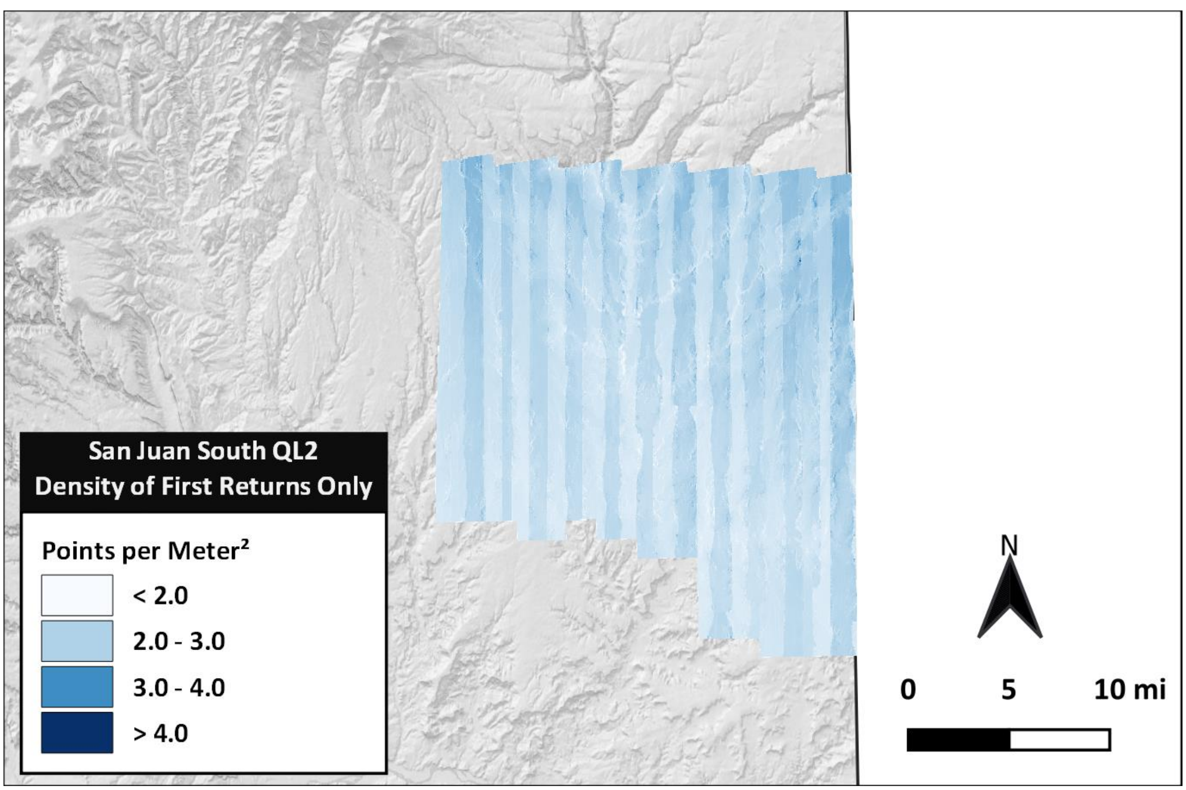

Wendover QL2 - UTMz12
Density of First Returns Only
Points per Meter²
< 2.0
2.0 - 3.0
3.0 - 4.0
> 4.0
N
0
2.5
5 mi


Wasatch QL2
Density of First Returns Only
Points per Meter²
< 2.0
2.0 - 3.0
3.0 - 4.0
> 4.0
N
0
5
10 mi


Juab QL2
Density of First Returns Only
Points per Meter²
< 2.0
2.0 - 3.0
3.0 - 4.0
> 4.0
N
0
5
10 mi


Duchesne QL2
Density of First Returns Only
Points per Meter²
< 2.0
2.0 - 3.0
3.0 - 4.0
> 4.0
N
0
5
10 mi


San Juan North QL2
Density of First Returns Only
Points per Meter²
< 2.0
2.0 - 3.0
3.0 - 4.0
> 4.0
N
0
5
10 mi


San Juan South QL2
Density of First Returns Only
Points per Meter²
< 2.0
2.0 - 3.0
3.0 - 4.0
> 4.0
N
0
5
10 mi

Appendix A – Ground Control Coordinates

Survey Point	Utah AGRC Fall Additions Aerial Survey		
	Northing	Easting	Elevation (m)
BE2001	4585202.719	249265.203	1415.205
BE2002	4591189.541	273712.930	1381.806
BE2003	4541225.194	248436.160	1311.522
BE2004	4563307.077	255405.075	1386.475
BE2005	4582275.240	257763.863	1376.452
BE2006	4564838.074	249325.454	1785.065
BE2007	4575119.590	267726.494	1317.386
D2001	4407726.380	518602.760	2218.040
D2003	4414447.060	519642.350	2732.100
D2004	4425149.780	532523.170	2163.710
D2005	4419766.260	527365.590	2339.530
D2006	4425788.550	585892.710	1669.430
D2007	4417665.480	582144.950	1927.300
D2008	4413655.210	582989.770	1978.570
D2009	4426968.850	571915.440	1876.910
D2010	4421970.610	567783.320	1988.320
D2011	4418031.640	565753.840	2086.870
D2012	4411208.800	563780.850	2008.920
D2013	4408918.490	548083.340	1996.580
D2013-ELE	4408916.250	548087.540	1996.540
D2014	4414472.890	536796.330	2314.720
J2001	4402271.590	399705.190	1688.250
J2002	4396639.560	396842.070	1586.510
J2003	4401056.070	388117.720	1644.060
J2004	4380377.130	384308.840	1468.320
J2005	4385696.180	402973.490	1542.120
J2006	4391670.570	411582.920	1665.780
J2007	4394645.110	417947.850	1680.730
J2008	4400003.710	417569.610	1807.690
J2009	4418854.570	393664.390	1863.230
J2010	4434458.310	385011.540	1740.780
J2011-A	4430130.140	375458.020	1824.710
J2011-B	4430125.300	375470.940	1824.650
J2012-A	4402814.180	375305.200	1580.250
J2012-B	4402807.100	375290.280	1579.550
J2013-A	4407013.280	363880.820	1540.170
J2013-B	4407022.280	363867.670	1539.470

J2014	4372108.260	367016.580	1442.790
SJ2001	4239728.435	641239.188	1847.121
SJ2002	4241789.581	652443.171	2118.384
SJ2003	4244215.509	661813.517	2184.263
SJ2004	4225951.016	641993.168	1794.020
SJ2005	4217727.295	643927.146	1853.550
SJ2006	4208797.869	644865.371	1899.422
SJ2007	4215450.347	653791.108	1804.217
SJ2008	4224225.552	662600.156	1943.917
SJ2009	4219445.057	667133.228	1934.860
SJ2010	4231278.145	655624.032	2085.775
SJ2011	4175269.339	641019.620	2084.045
SJ2012	4166215.373	646491.390	1880.720
SJ2013	4157301.318	642286.181	1743.537
SJ2014	4152620.843	652481.162	1659.580
SJ2015	4145715.174	657763.890	1455.543
SJ2016	4170042.935	665764.099	1855.966
SJ2017	4164306.159	670461.219	1959.431
SJ2018	4155121.385	663198.850	1674.380
SJ2019	4137946.252	667294.080	1612.194
SJ2020	4143443.092	671949.383	1678.579
W2001	4513270.453	237654.077	1382.312
W2002	4515990.403	237211.642	1471.137
W2003	4514233.386	241814.265	1332.640
W2004	4516613.589	249618.870	1287.582
W2005	4523793.339	243797.985	1419.062
WA2001	4464776.235	495755.594	2346.913
WA2002	4482825.315	492963.543	2584.761
WA2003	4482565.510	502432.967	2645.135
WA2004	4489117.447	484202.007	2146.622
WA2005	4491956.628	495994.562	2370.932
WA2007	4486959.751	510901.087	2265.115
WA2008	4505477.997	509819.970	3042.059