aero-graphics
GEOSPATIAL SERVICES

TECHNICAL PROJECT REPORT

UTAH AGRC FALL ADDITIONS - SECOND BLOCK

Project Name: UT_StatewideCenSouth_2020_A20
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Technical Project Report
Utah AGRC Fall Additions – QL2 Second Block

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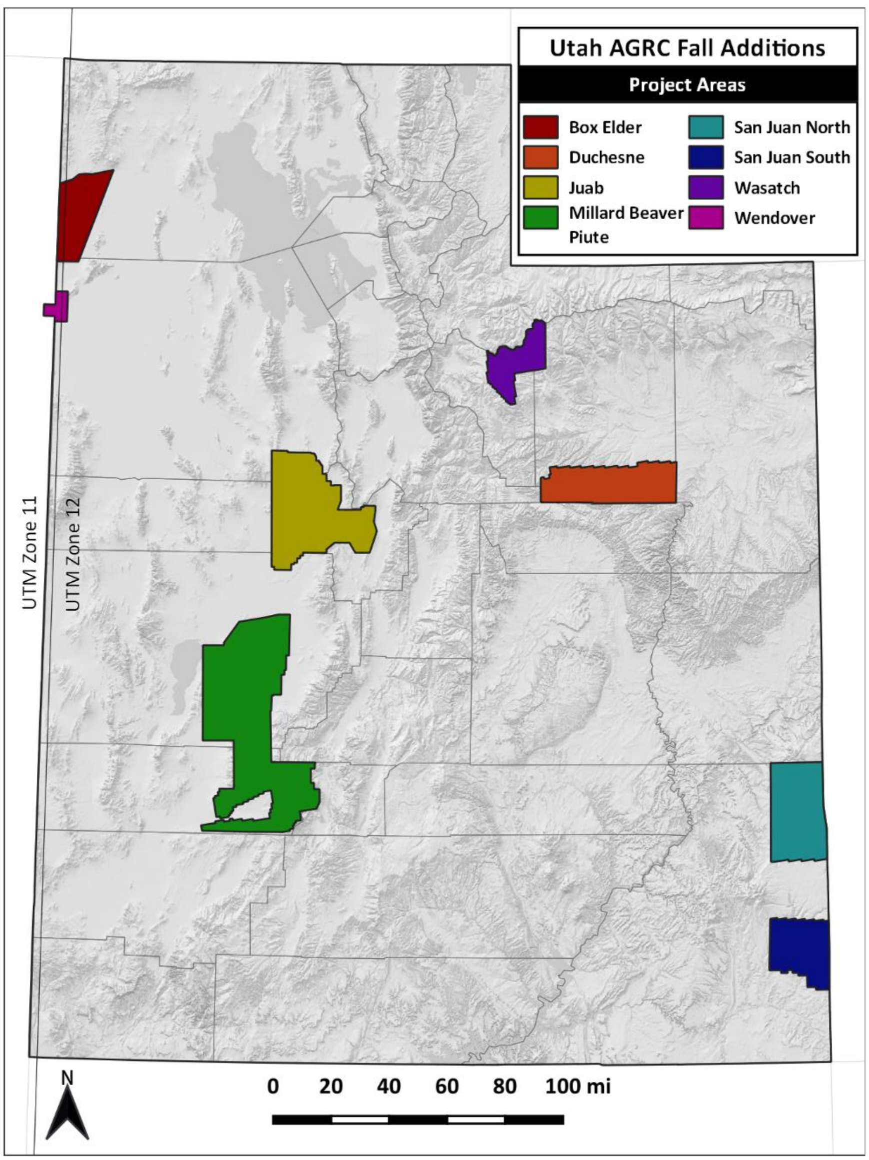
1. Overview

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 mi².

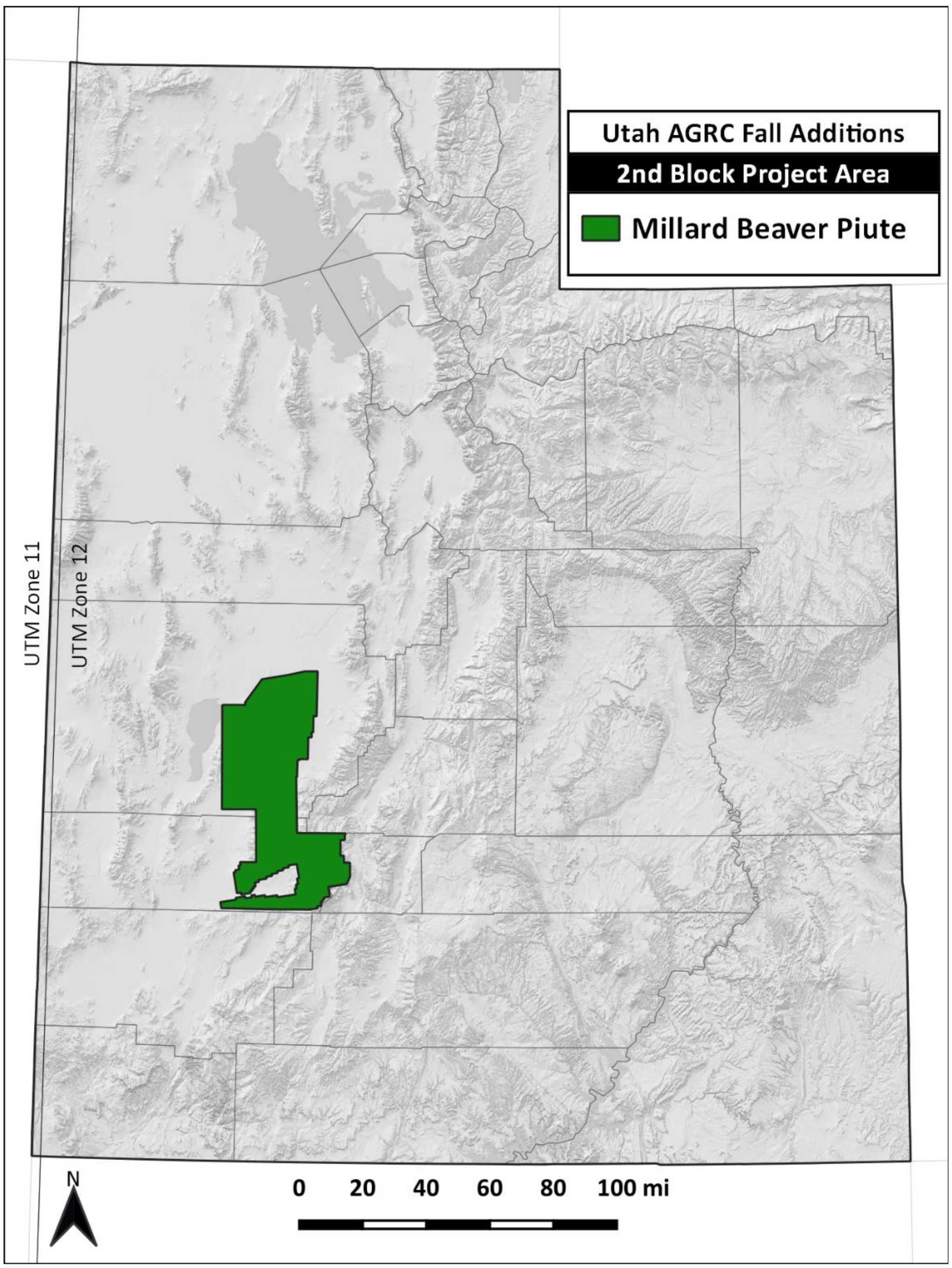
Exhibit 1: Overview of the Utah AGRC Fall Additions project by delivery areas.



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 second of two deliveries and focuses on the Millard Beaver Piute area which covers a total of 1,766 mi^2.

Exhibit 2: Overview of the Millard Beaver Piute project area.



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 12N**
EPSG		**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 site, 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 Millard Beaver Piute is outlined in **Exhibit 3**.

Exhibit 3: Summary of planned flight parameters and sensor settings

Planned Specifications		Optech Galaxy Prime	Optech Galaxy T2000	Optech Galaxy T2000	Optech Galaxy Prime (6/26/21 reflight)
Aircraft		Cessna 206	Cessna 206	Cessna 206	Cessna 206
Altitude (m above ground level)		1,600	2,100	2,250	1,450
Speed (kts)		120	120	120	120
PRF (kHz)		300	400	400	300
Scan frequency (Hz)		55.6	55.3	55.3	55.6
Scan Angle	From nadir	±23°	±22°	±22°	±23°
	Full	46°	44°	44°	46°
Planned Average Point Density (p/m^2)		3.24	3.45	3.22	3.58
Post Spacing at Nadir	Cross Track (m)	0.56	0.52	0.56	0.50
	Down Track (m)	0.56	0.56	0.56	0.56
Swath Width (m)		1,358	1,697	1,818	1,231
NPS (m)		0.56	0.54	0.56	0.50
Sidelap (%)		20	20	20	20

2.2 Data Acquisition

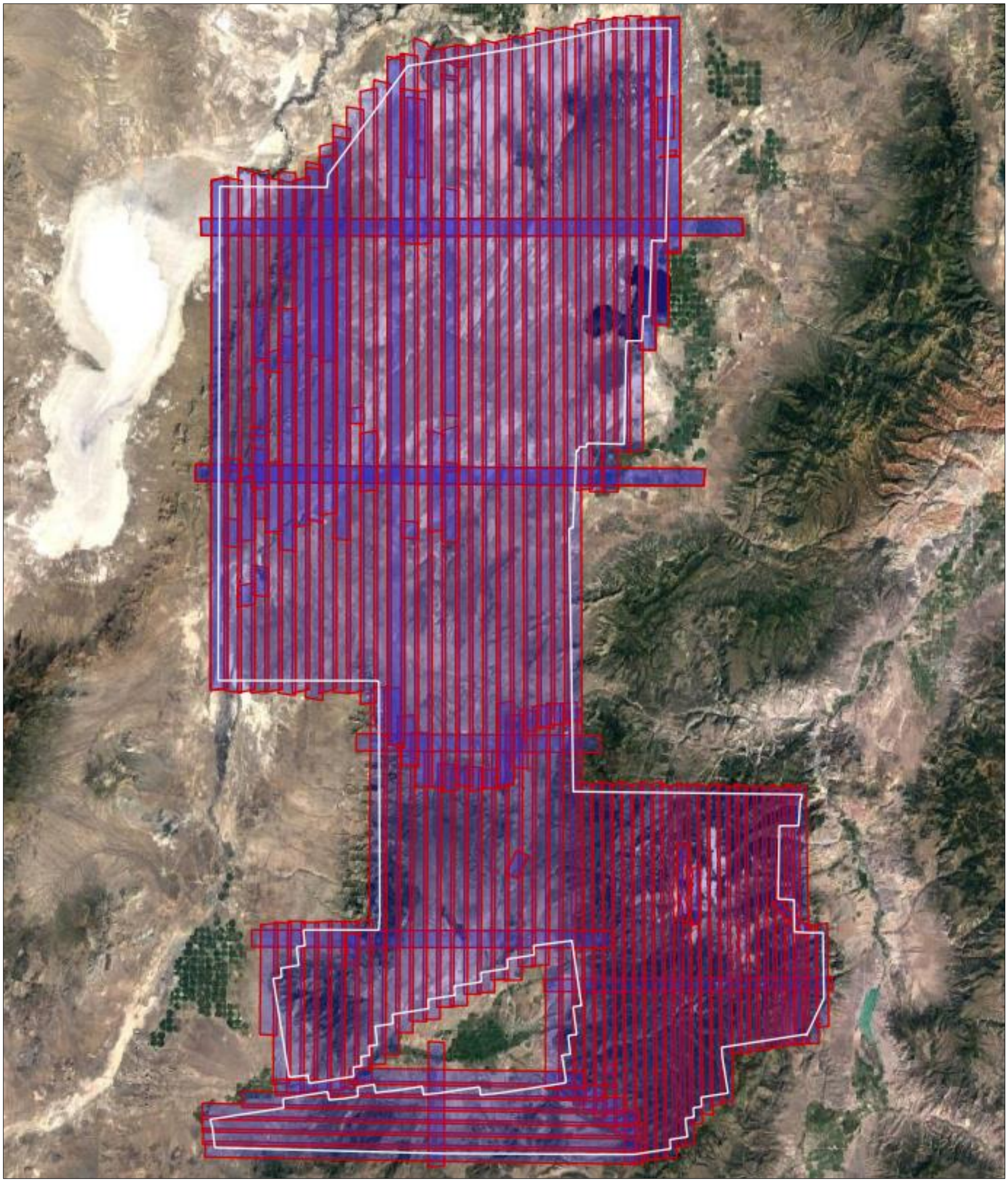
The acquisition platform was our turbocharged Cessna 206 (**Exhibit 4**). The stability of this platform is ideal for efficient data collection at high and low altitudes and at a variety of airspeeds. Additionally, our Cessna 206 has been customized to house a variety of airborne sensors, and the power systems and avionics have been upgraded specifically to meet aerial survey needs.

Exhibit 4: AGI used their Cessna 206 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 5**). 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 6**. 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 5: The Optech Galaxy Prime and T2000 were used for data acquisition

Exhibit 6: **Swath data for the project was recorded and viewed real-time by the sensor operator.**



2.3 Acquisition Summary

Acquisition for Millard Beaver Piute occurred between September 25 and October 13, 2020, and reflights were performed throughout the acquisition period and on October 17, 2020 and June 26, 2021. These flights took place when ground conditions were free of snow, ice, and standing water. A total of 11 lifts were required to complete lidar acquisition for the assigned Millard Beaver Piute area.

Exhibit 7: Flightlines by day of acquisition

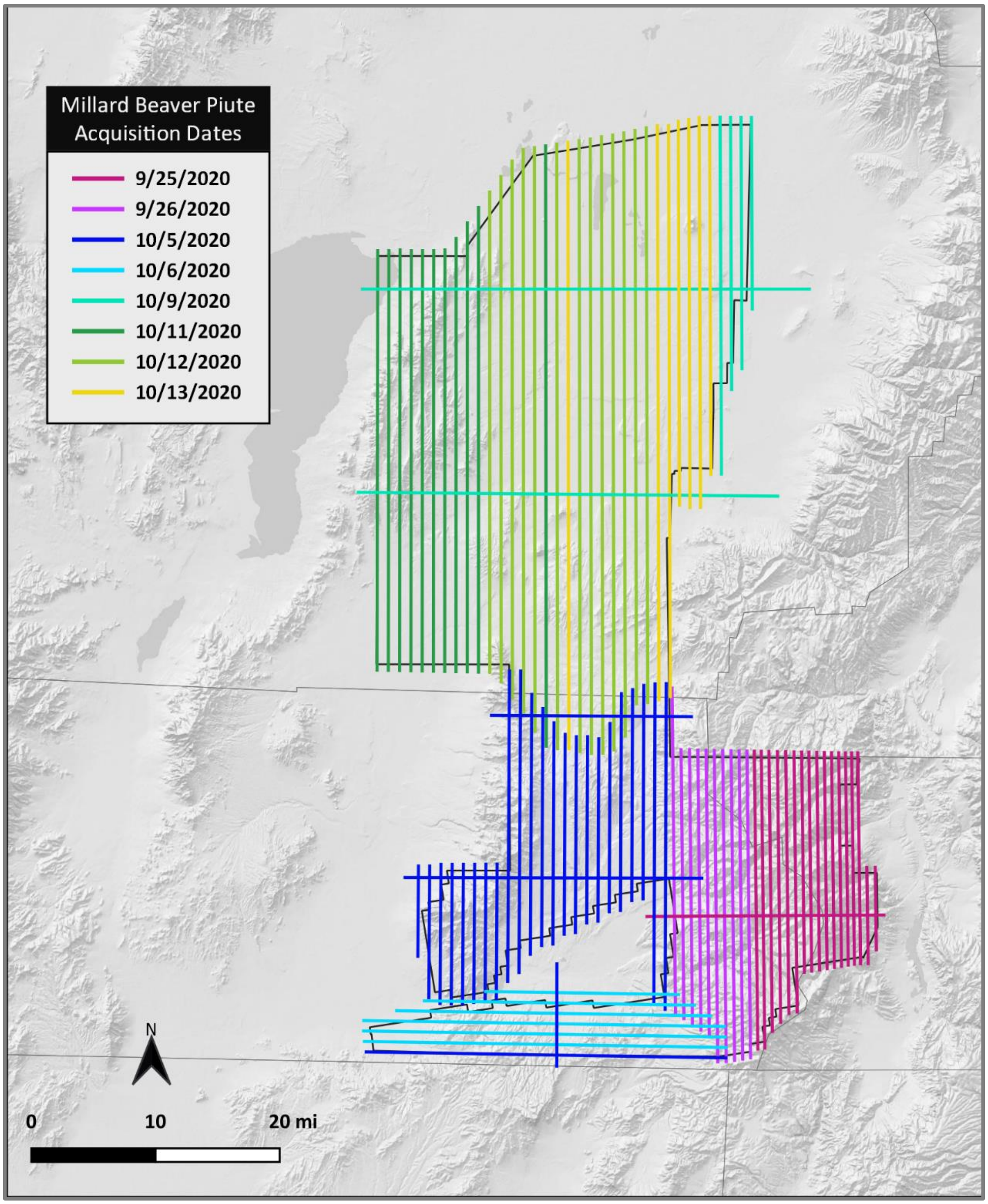
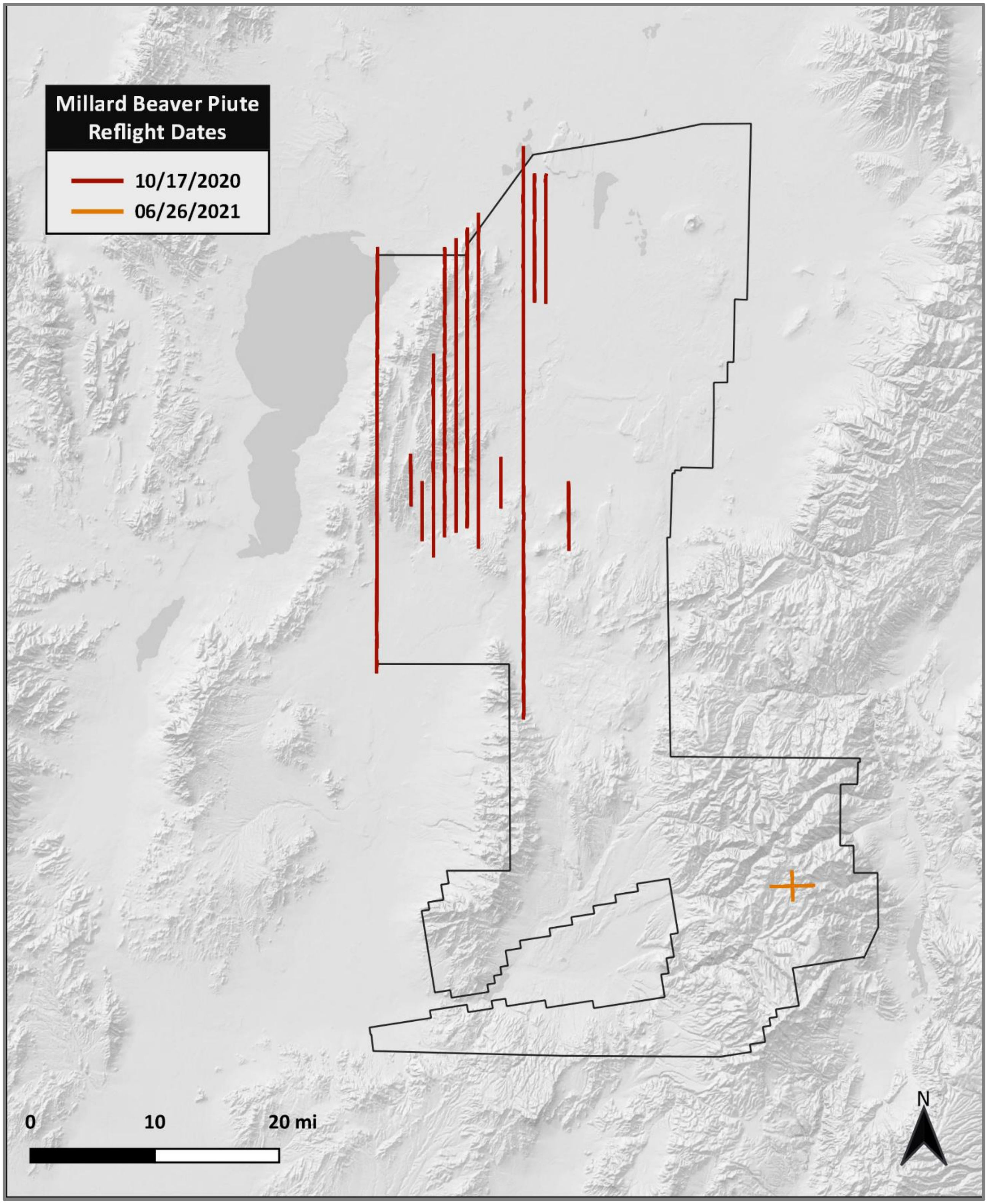


Exhibit 8: **Reflight lines by day of acquisition**



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.

Millard Beaver Piute Flight Logs											
Flight Date	**Lift ID**	**AOI Covered**	**Take-off Time (MT)**	**Landing Time (MT)**	**Weather Conditions**	**Ground Conditions**	**Sensor Name**	**Sensor Number**	**Aircraft Tail Number**	**In-flight Disturbances**	**Instrumental Anomalies**
9/25/2020	20200925_1_ 5060410	Millard Beaver Piute	08:15	13:45	Clear	Clear	Optech Galaxy Prime	5060410	N7269T	Some turbulence	None reported
9/26/2020	20200926_1_ 5060410	Millard Beaver Piute	08:00	11:45	Clear	Clear	Optech Galaxy Prime	5060410	N7269T	None reported	None reported
10/5/2020	20201005_1_ 5060452	Millard Beaver Piute	09:10	13:30	Clear	Clear	Optech Galaxy T2000	5060452	N27DV	None reported	None reported
	20201005_2_ 5060452	Millard Beaver Piute	15:05	18:25	Clear	Clear	Optech Galaxy T2000	5060452	N27DV	None reported	None reported
10/6/2020	20201006_1_ 5060452	Millard Beaver Piute	08:10	12:30	Hazy	Clear	Optech Galaxy T2000	5060452	N27DV	None reported	None reported
10/9/2020	20201009_1_ 5060452	Millard Beaver Piute	09:50	15:55	Clear	Clear	Optech Galaxy T2000	5060452	N27DV	None reported	None reported
10/11/2020	20201011_1_ 5060452	Millard Beaver Piute	08:40	15:00	Cloudy	Clear	Optech Galaxy T2000	5060452	N27DV	None reported	None reported
10/12/2020	20201012_1_ 5060452	Millard Beaver Piute	08:10	14:30	Clear	Clear	Optech Galaxy T2000	5060452	N27DV	None reported	None reported
10/13/2020*	20201013_1_ 5060452	Millard Beaver Piute	08:15	13:30	Clear	Clear	Optech Galaxy T2000	5060452	N27DV	None reported	None reported
10/17/2020*	20201017_1_ 5060452	Millard Beaver Piute	08:05	12:30	Clear	Clear	Optech Galaxy T2000	5060452	N27DV	None reported	None reported
6/26/2021*	20210626_1_ 5060410	Millard Beaver Piute	13:30	15:30	Clear	Clear	Optech Galaxy Prime	5060410	N27DV	None reported	Non reported

3. LiDAR Processing Workflow

1. **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.
2. **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.
3. **Absolute Sensor Calibration.** 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.
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. While the tiling schema for this project contains 4,894 tiles, the delivered data contains 4,893 LAS tiles (and 4,893 associated TIFF tiles); tile 12SUH4931 was less than 0.05 m² and did not contain any LiDAR data, so it is not included.

   Extremely long and short returns were then 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 1.3 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 then converted to ESRI shapefile format and 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 20 ground control points for use in data calibration as well as 125 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

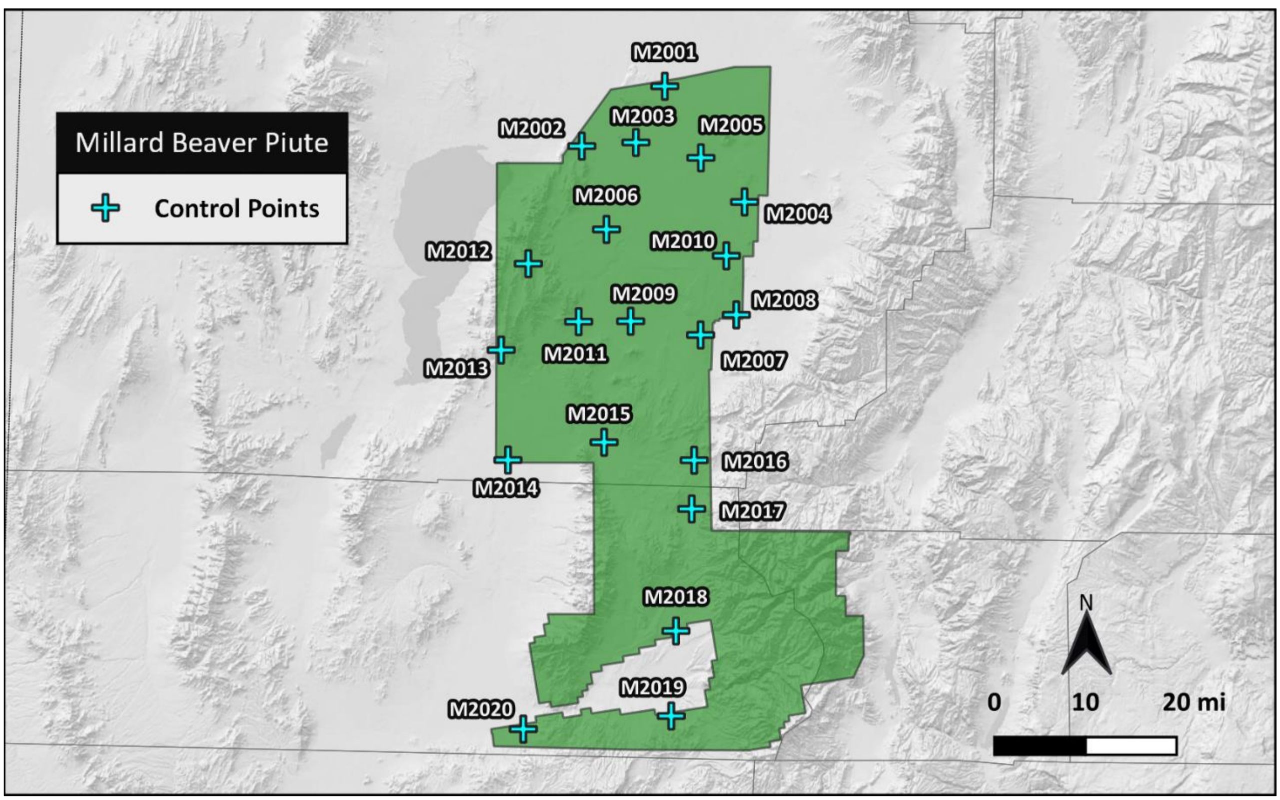


Exhibit 11: **Locations of NVA checkpoints throughout the project areas**

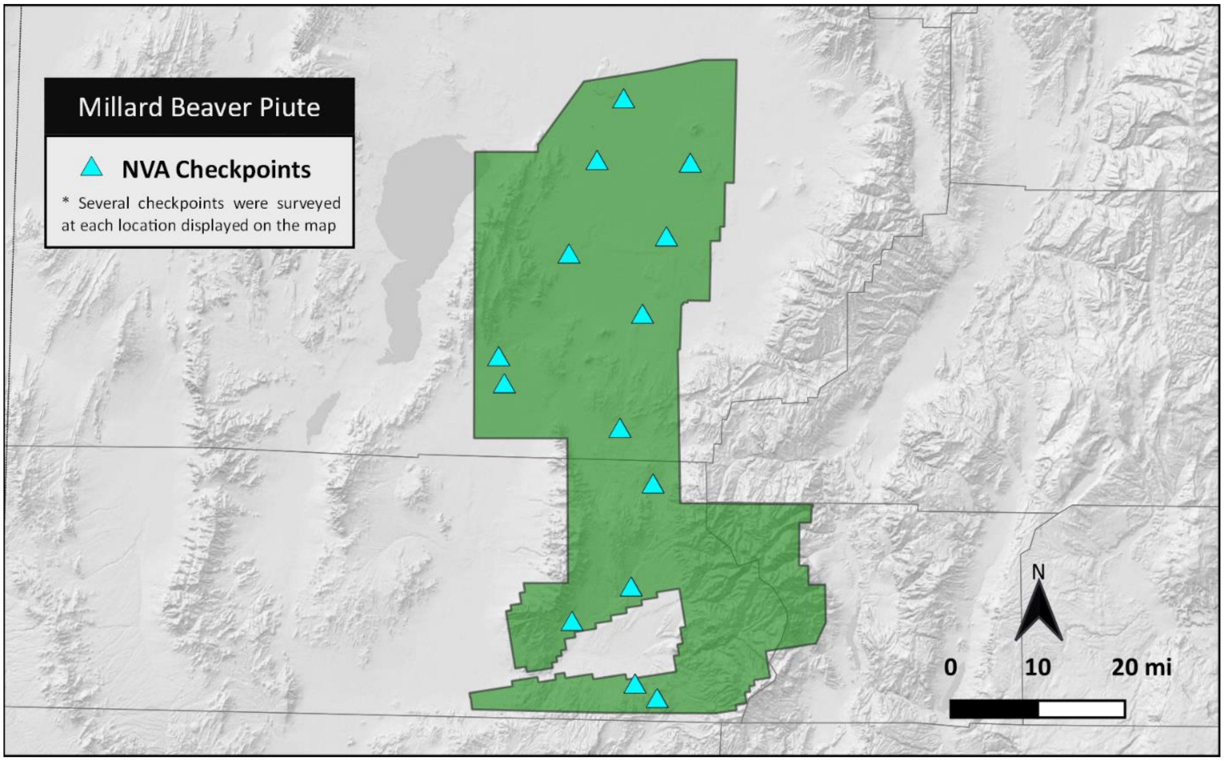
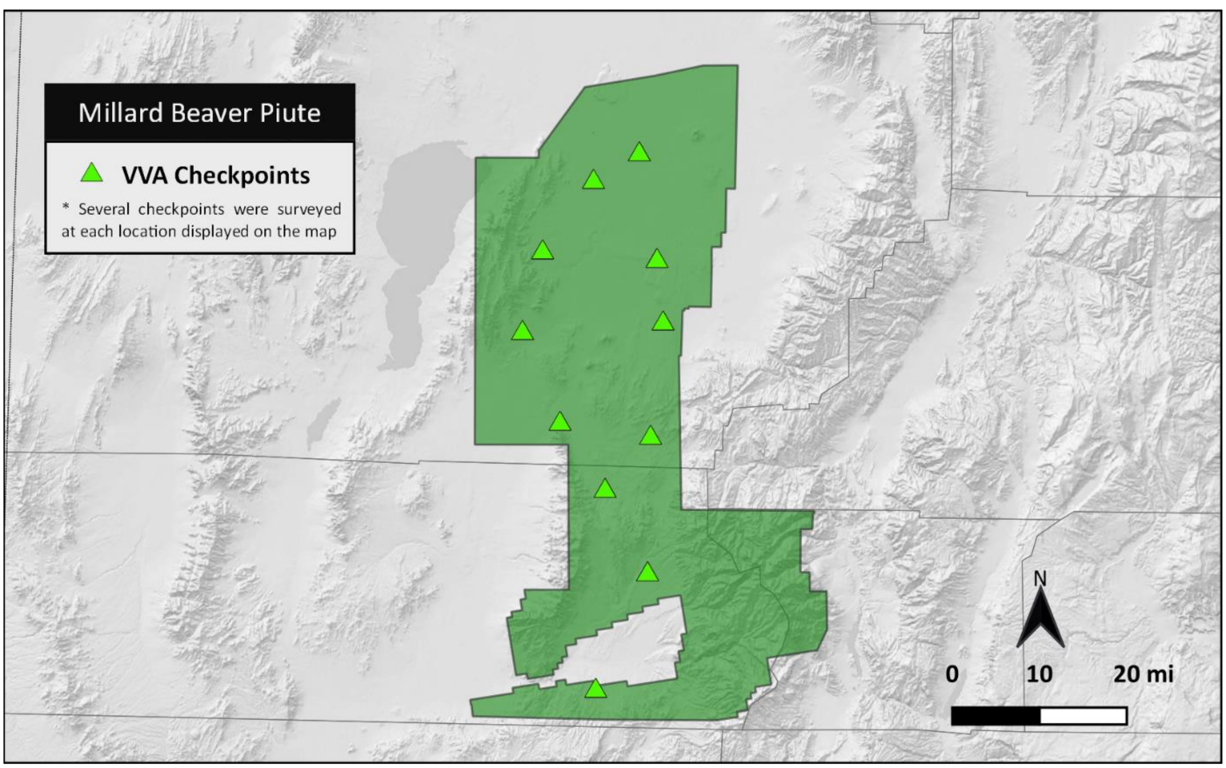


Exhibit 12: **Locations of VVA checkpoints throughout the project areas**



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 were 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 the project area, increasing the number of flightlines from what was originally planned.

Utah AGRC Fall Additions project area: (130 flightlines, > 19 billion points)

- Inter-swath relative accuracy **average** of 0.049 m

5.2 Calibration Control Vertical Accuracy

Calibration control point reports were generated as a quality assurance check. The results are shown below in **Exhibit 13**, and the location of each control point is displayed in Exhibit 9.

Exhibit 13: Calibration control vertical accuracy results summary

Calibration Control Accuracy$_Z$: Utah AGRC Fall Additions Project Area	
Average Error = +0.002 m	Average Magnitude = 0.042 m
Minimum Error = -0.170 m	RMSE = 0.059 m
Maximum Error = +0.110 m	σ = 0.060 m
Survey Sample Size: n = 20	

5.3 Absolute Horizontal Accuracy

The data set collected at 1,600 m AGL was produced to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 25.0 cm RMSEx / RMSEy Horizontal Accuracy Class which equates to Positional Horizontal Accuracy = +/- 43.1 cm at a 95% confidence level. The data sets collected at 2,100 m and 2,250 m AGL were produced to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 31.0 cm and 32.8 cm RMSEx / RMSEy Horizontal Accuracy Class, respectively, which equates to Positional Horizontal Accuracy = +/- 53.7 cm and +/- 56.9 cm, respectively, 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 70 check points. 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 0.047 meters, in terms of the RMSEz. The resulting NVA stated as the 95% confidence level (RMSEz x 1.96) is 0.092 meters. 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 70 check points. The VVA was tested with 55 check points.

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 0.049 meters in terms of the RMSEz. The resulting accuracy stated as the 95% confidence level (RMSEz x 1.96) is 0.096 meters. 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 0.051 meters. 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.**

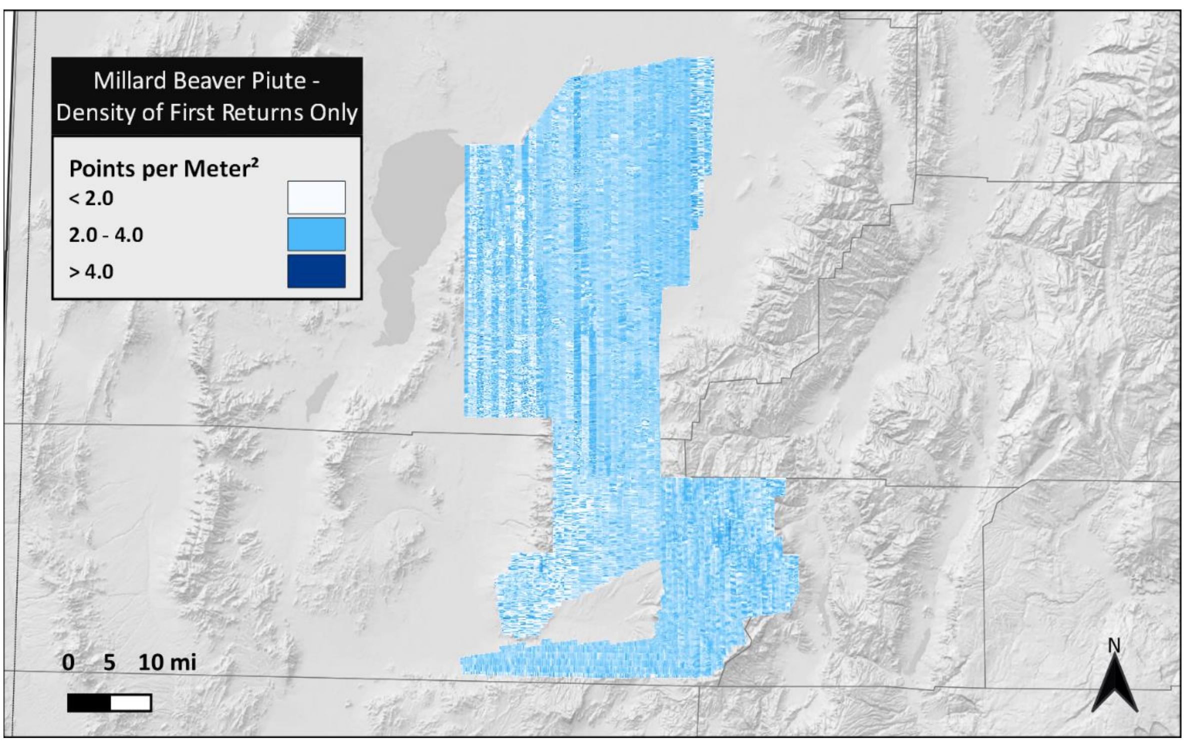
Exhibit 14: Summary of the data accuracy tests

Area	Raw Point Cloud NVA (m)	DEM NVA (m)	DEM VVA (m)	Points Tested NVA	Points Tested VVA
Millard Beaver Piute	0.047	0.049	0.051	70	55

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 2.0 points per meter². Average density for the Millard Beaver Piute QL2 project area 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. The Millard Beaver Piute area achieved and average density of 3.2 points per meter² for first returns.

Exhibit 15: Laser point density of first returns by tile, points/m²



APPENDIX A – GROUND CONTROL COORDINATES

Survey Point	Utah AGRC Fall Additions Aerial Survey		
	Northing	Easting	Elevation (m)
M2001	4341399.110	354782.830	1394.230
M2002	4330840.480	340120.630	1413.750
M2003	4331475.970	349677.980	1397.740
M2004	4320977.030	368873.280	1409.660
M2005	4328766.700	361160.310	1403.930
M2006	4316118.540	344482.320	1439.420
M2007	4297479.690	361109.700	1492.820
M2008	4301033.230	367418.810	1447.330
M2009	4299901.260	348752.290	1460.310
M2010	4311458.480	365656.230	1420.330
M2011	4299831.620	339564.670	1501.250
M2012	4310066.960	330666.210	1704.550
M2013	4294817.050	325871.420	1629.380
M2014	4275401.140	327074.280	1487.240
M2015	4278530.960	344063.690	1649.540
M2016	4275357.420	359978.370	1820.140
M2017	4266758.190	359542.960	1848.430
M2018	4245200.690	356761.160	1877.630
M2019	4230181.550	355922.070	1847.470
M2020	4227867.920	329782.930	1671.960