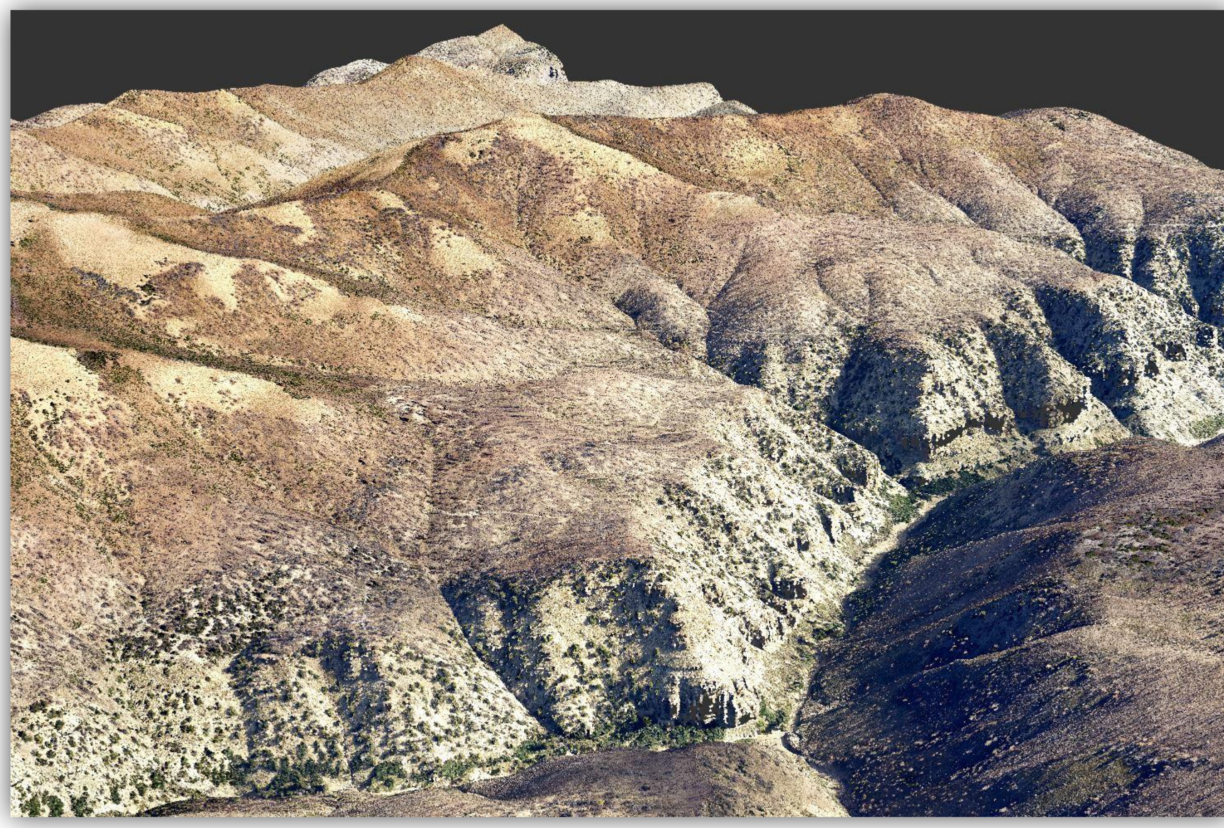
aero-graphics

FINAL PROJECT REPORT

STRAWBERRY RIVER AERIAL SURVEY

WASATCH AND DUCHESNE COUNTIES, UTAH

August 2019



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Final Project Report
Strawberry River
Wasatch and Duchesne Counties, UT

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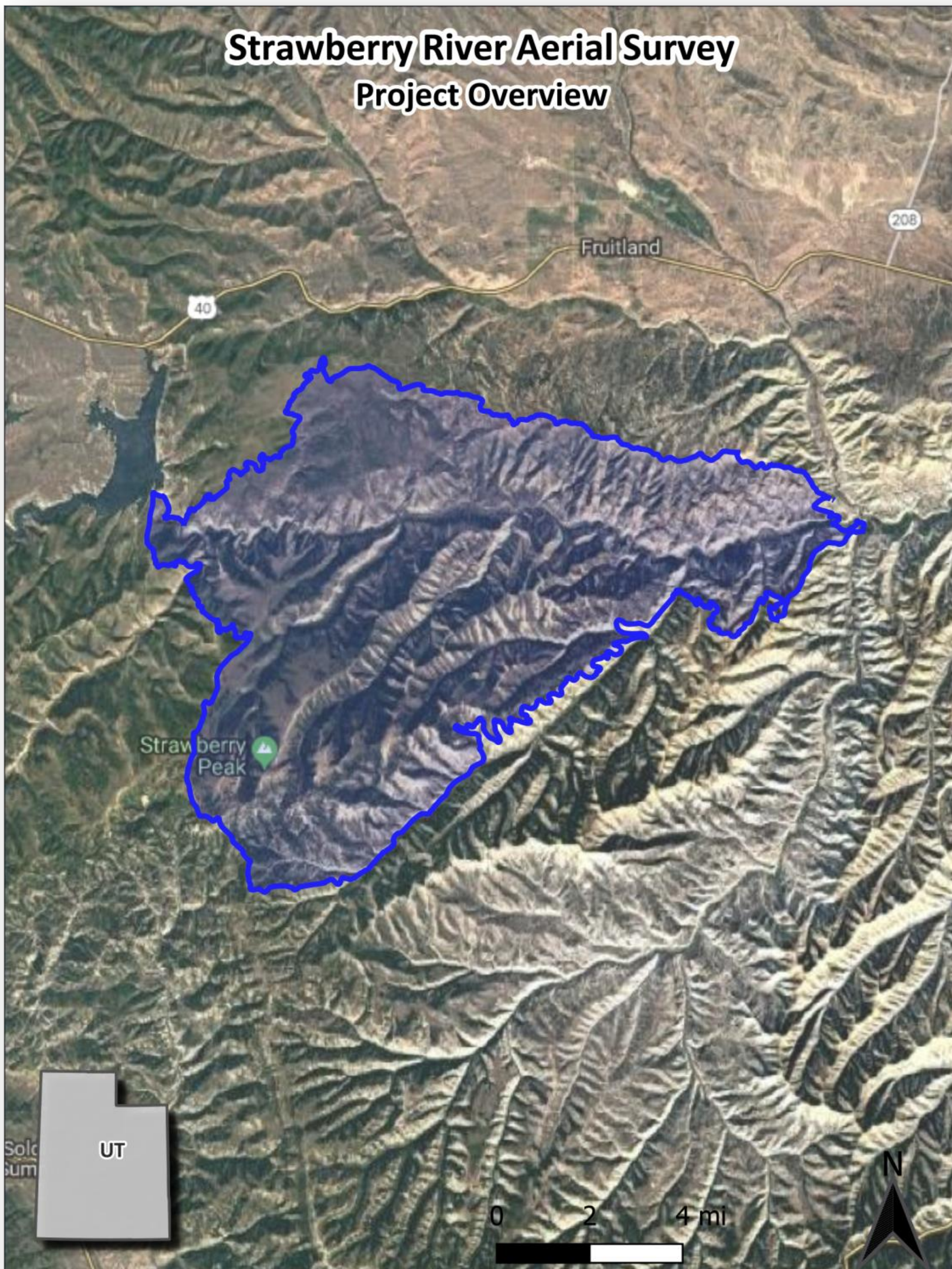
1. Overview

Aero-Graphics, Inc. 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 USGS Quality Level 1 LiDAR specifications as well as high-resolution ortho imagery. The project area covers approximately 88.6 square miles located in Wasatch and Duchesne Counties, Utah.

Exhibit 1: *Strawberry River project boundary*



2. Acquisition – Equipment and Methodology

2.1 LiDAR Acquisition

LiDAR acquisition for the Strawberry River project was performed on August 15 and 16, 2019, with an Optech Galaxy PRIME LiDAR sensor. Aero-Graphics flew at an average altitude of 4,250 ft AGL (above ground level) and made appropriate adjustments to compensate for topographic relief. The PRF (pulse rate frequency) used for collection was 600 kHz, scan frequency 66.7 Hz, and scan angle +/- 23° from the nadir position (full scan angle 46°). LiDAR acquisition was performed with 30% overlap and yielded an average 16.1 points per square meter throughout the project area.

Exhibit 2: *Summary of planned LiDAR flight parameters*

Altitude (ft AGL)	Overlap (%)	Speed (kts)	PRF (kHz)	Scan Freq (Hz)	Scan Angle ° (full)
4,250	30	115	600	66.7	46

PPM^2 (mean)	Post spacing Cross Track (m)	Post Spacing Down Track (m)	Swath Width (m)	# Flightlines
9.22	0.28	0.44	1,100	23

Product Characterization Report

The Optech Galaxy PRIME is one of the most productive sensors available in the industry. This sensor features SwathTRAK technology, which dynamically adjusts the scan FOV in real time during data acquisition. It also features a 1MHz effective pulse rate, providing on-the-ground point density and efficiency formerly reserved for dual-beam sensors. Up to 8 returns per pulse are possible for increased vertical resolution of complex targets without the need for full waveform recording and processing. Industry-leading data precision and accuracy (<5cm RMSEz) results in the highest-quality datasets possible.

Exhibit 3: *The acquisition platform for the Strawberry River project was a turbocharged Cessna 206. Our 206 has been customized for LiDAR and other airborne sensors with an upgraded power system and avionics. The stability of the Cessna 206 is ideal for LiDAR collection*

Aero-Graphics utilizes Optech's Airborne Mission Manager(AMM) software to plan flight lines and sensor settings. AMM allows the aerial department to simulate the effects of different sensors, mounts, and settings, ensuring the flight plan will meet the needs of the project while being as efficient as possible. To compliment the flight planning process the Galaxy PRIME LiDAR sensor is equipped with FMS Nav, the latest data collection and navigation software release from Optech. The use of FMS Nav helps ensure an accurate and consistent acquisition mission with real-time quality assurance while still airborne. The system operator can monitor the point density and swath coverage during the mission to confirm adequate coverage within the area of interest, as shown in **Exhibit 4.**

Exhibit 4: *Swath data for the Strawberry River project was recorded and viewed real-time by the sensor operator.*

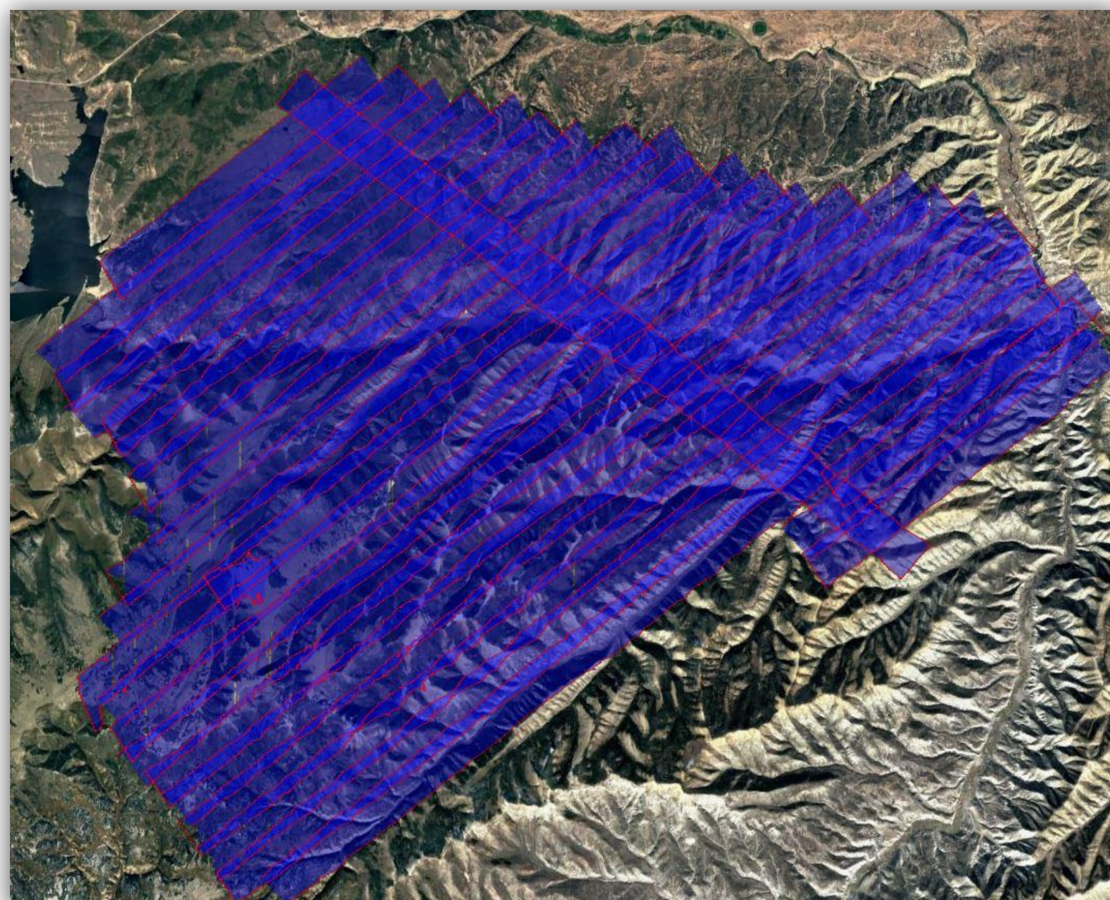
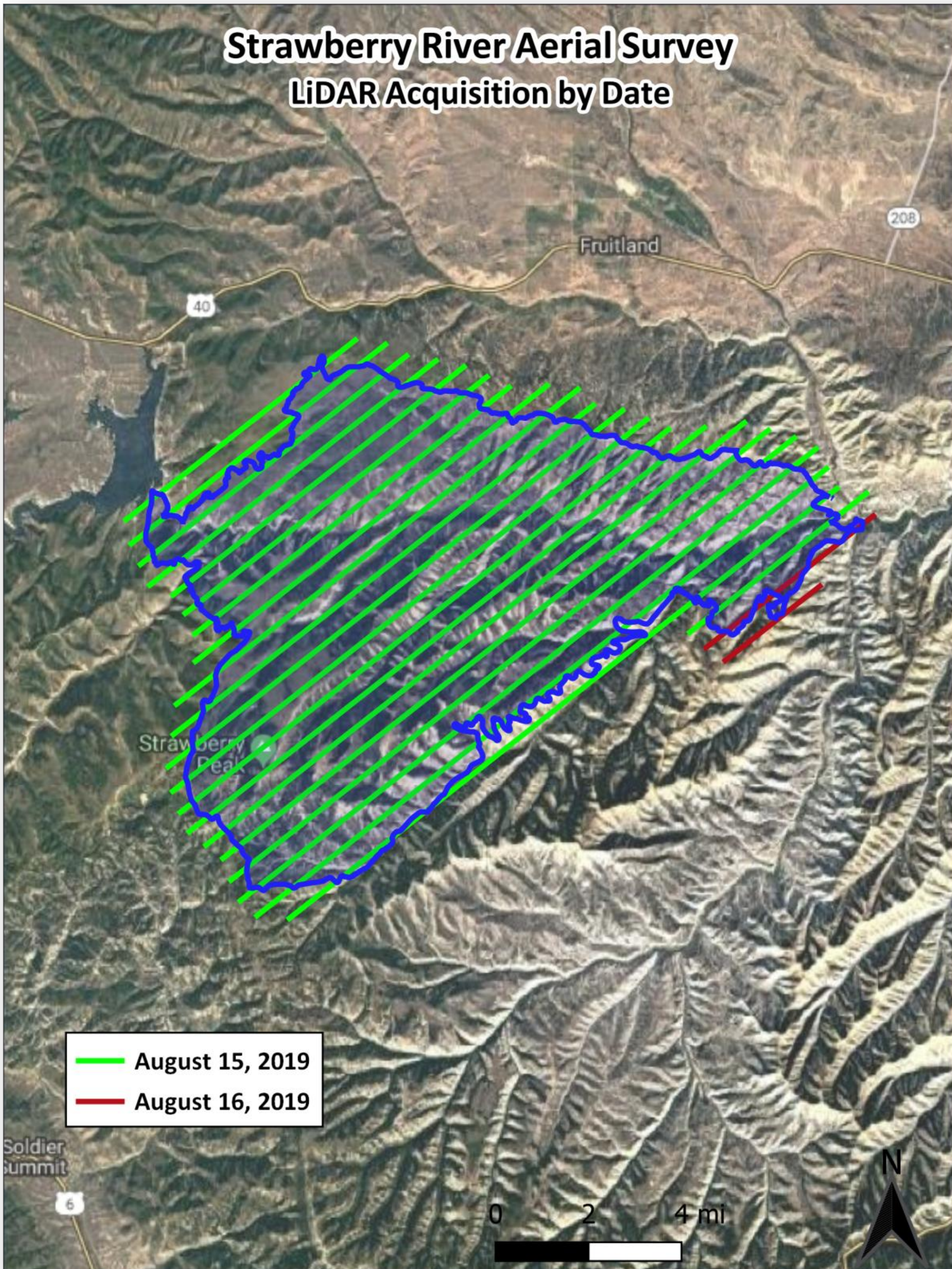


Exhibit 5: *Flight line swath coverage symbolized by date*



2.2 Imagery Acquisition

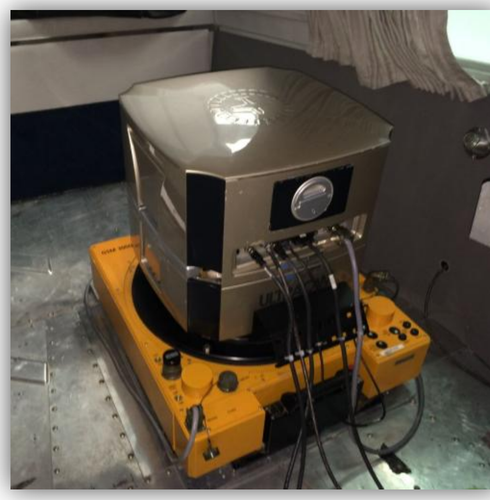
Imagery acquisition was performed using the Ultracam Eagle (UCE) Mark 1 and PhaseOne aerial camera systems. A brief report providing relevant background information regarding imagery acquisition is included in Appendix C. Exhibits **6** and **7** summarize the planned flight parameters for the two sets of imagery.

Exhibit 6: *Summary of planned **imagery** acquisition flight parameters - PhaseOne*

Altitude (ft AGL)	Overlap (%)	Sidelap (%)	GSD (cm)	# Flightlines	# Images
4,250	60	30	11.91	23	1,014

Exhibit 7: *Summary of planned **imagery** acquisition flight parameters - UCE*

Altitude (ft AGL)	Overlap (%)	Sidelap (%)	GSD (cm)	# Flightlines	# Images
8,410	60	30	10.1	11	335



The UCE Mark 1 collected 4-band imagery at a 16 bit radiometric resolution. The imagery was then output to 3-bands with 8-bit radiometric resolution to create the final images. Aero-Graphic's UCE utilized a 100 mm length focal lens which allowed for flying at higher altitudes without an increase in GSD. The UCE is equipped with precision GPS/IMU to accurately position the raw imagery for orthorectification. In addition, it is equipped with Forward Motion Compensation and mounted in a GSM-4000 gyro-stabilized mount that works together with the IMU to automatically correct up to 5° roll, 8.4° pitch, and 6.2° yaw before each exposure is fired. The imagery was reviewed for completeness before mobilizing the imagery back to the office.

Exhibit 8: *The imagery acquisition platform for the Strawberry River project was a turbocharged Cessna 310. Our 310 has been customized for imagery and other airborne sensors with an upgraded power system and avionics. The stability of the 310 is ideal for imagery collection.*

3. Ground Survey – Equipment and Methodology

Aero-Graphics surveyed 20 ground control points for use in data calibration as well as 79 QC check points in Vegetated and Non-Vegetated land cover classifications as an independent test of accuracy for this project. 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. Spatial distribution of the surveyed points was limited due to extreme terrain variation and fire conditions throughout the majority of the project area. Calibration control point and QC check point coordinates can be found in Appendix A. LiDAR positional accuracy results can be found in Section 5.

Exhibit 9: *Calibration Control Point (Target)*

Exhibit 10: *Calibration Control Point (Aerotas target)*

4. LiDAR Processing Workflow

a. **Absolute Sensor Calibration.** Our absolute sensor calibration adjusted for the difference in roll, pitch, heading, and scale between the raw laser point cloud from the sensor and surveyed control points on the ground.

b. **Kinematic Air Point Processing.** Differentially corrected the 1-second airborne GPS positions using Applanix's industry-leading POSPac MMS GNSS Inertial software (PP-RTX); combined and refined the GPS positions with 1/200-second IMU (roll-pitch-yaw) data through development of a smoothed best estimate of trajectory (SBET).

c. **Raw LiDAR Point Processing (Calibration).** Combined SBET with raw LiDAR range data; solved real-world position for each laser point; produced point cloud data by flight strip in ASPRS v1.4 .LAS format; output in NAD83 (2011) UTM Zone 12, meters.

d. **Relative Calibration.** Performed relative calibration by correcting for roll, pitch, heading, and scale discrepancies between adjacent flightlines; tested resulting relative accuracy. Results presented in Section 5.

e. **Vertical Accuracy Assessment.** Performed comparative tests that showed Z-differences between surveyed points and the laser point surface. Results presented in Section 5.

f. **Tiling & Long/Short Filtering.** Cut data into project-specified tiles and filtered out grossly long and short returns.

g. **Classified LAS Processing.** The point classification is performed as described below. The bare earth surface is then manually reviewed to ensure correct classification on the Class 2 (Ground) points. After the bare-earth surface is finalized, it is then used to generate all hydro-breaklines through heads-up digitization.

   All ground (ASPRS Class 2) LiDAR data inside of the Lake Pond and Double Line Drain hydro-flattened breaklines were then classified to Water (ASPRS Class 9) using TerraScan macro functionality. A buffer of 1 meter was also used around each hydro-flattened feature to classify these ground (ASPRS Class 2) points to Ignored ground (ASPRS Class 10). All Lake Pond Island and Double Line Drain Island features were checked to ensure that the ground (ASPRS Class 2) points were reclassified to the correct classification after the automated classification was completed. All bridge decks were classified to Class 17. All overlap data was processed through automated functionality provided by TerraScan to classify the overlapping flight line data to approved classes by USGS. The overlap data was classified using standard LAS overlap bit. These classes were created through automated processes only and were not verified for classification accuracy.

   All data was manually reviewed and any remaining artifacts removed using functionality provided by TerraScan and TerraModeler. LP360 was used as a final check of the bare earth dataset. LP360 was then used to create the deliverable industry-standard LAS files for both the All Point Cloud Data and the Bare Earth. Aero-Graphics, Inc. proprietary software was used to perform final statistical analysis of the classes in the LAS files, on a per tile level to verify final classification metrics and full LAS header information.

Exhibit 11: *USGS Version 1.3 minimum point cloud classification scheme used for this project*

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
10	Ignored ground (near a breakline)	Points near breakline features; ignored in DEM creation process
17	Bridge decks	Points on bridge decks
18	High noise	High points identified above surface

h. **Hydro-Flattened Breakline Creation.** Class 2 (ground) LiDAR points were used to create a bare earth surface model. The surface model was then 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, 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 (ASPRS Class 2) LiDAR data inside of the collected inland breaklines were then classified to Water (ASPRS Class 9) using TerraScan macro functionality. A buffer of 1 meter was also used around each hydro-flattened feature. These points were moved from ground (ASPRS Class 2) to Ignored Ground (ASPRS Class 10).

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

i. **Hydro-Flattened Raster DEM Creation.** Class 2 (Ground) LiDAR points in conjunction with the hydro breaklines were used to create a 0.5 meter hydro-flattened raster DEM. Using LP360 along with automated scripting routines within ArcMap, an ERDAS Imagine .IMG file was created for each tile. Each surface is reviewed using ESRI ArcMap and ArcScene to check for any surface anomalies or incorrect elevations found within the surface.

j. **First Return Raster DSM Creation.** First return LiDAR points were used to create a 0.5 meter first-return raster DEM. Using LP360 along with automated scripting routines within ArcMap, a TIF file was created for each tile. Each surface is reviewed using ESRI ArcMap and ArcScene to check for any surface anomalies or incorrect elevations found within the surface.

k. **Issues.** There were no issues to report for this project.

5. Accuracy Testing and Results

5.1 Relative Calibration Accuracy Results

Between-swath relative accuracy is defined as the elevation difference in overlapping areas between a given set of two adjacent flightlines. The statistics are based on the comparison of the flightlines and points listed below.

Strawberry River project area: (27 flightlines, > 2.7 billion points)

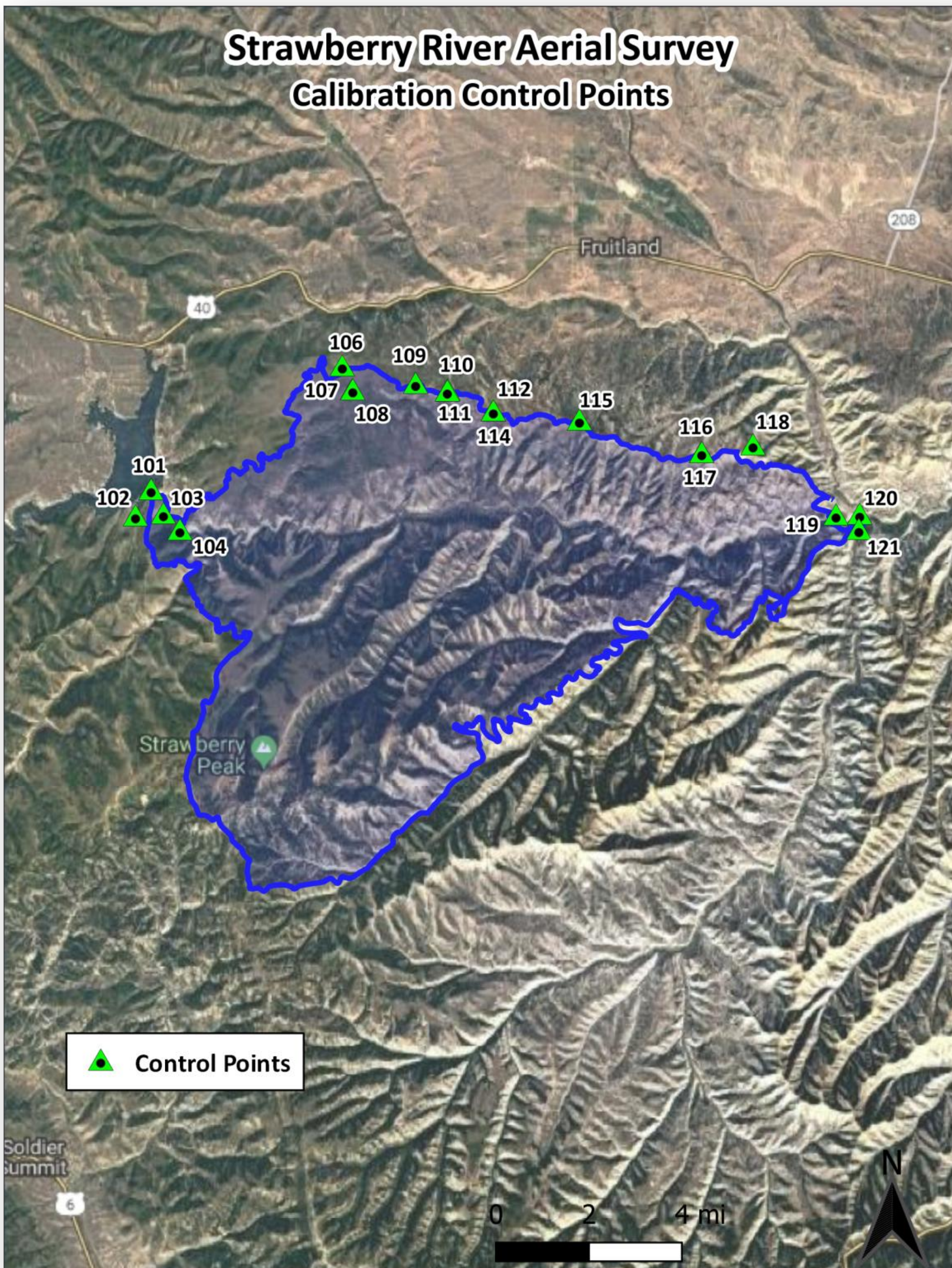
- Between-swath relative accuracy **average** of 0.0495 meters

Within-swath relative accuracy is the amount of vertical separation, or "noise," among a set of points on open, paved ground that should have the same elevation. The within-swath relative accuracy average is less than **0.008 meters.**

5.2 Calibration Control Point Testing

Calibration Control Point reports were generated as a quality assurance check. Note that the results are not an independent assessment of the accuracy of the project deliverables, but rather an additional indication of the overall accuracy of the dataset. The location of each control point is displayed below. Detailed results are included in **Appendix B**.

Exhibit 12: *Calibration Control Point locations for the Strawberry River project*



5.3 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 33 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 0.082 meters in terms of the RMSEz. The resulting NVA stated as the 95% confidence level (RMSEz x 1.96) is 0.161 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). Individual point results are included in Appendix B.

5.4 Digital Elevation Model (DEM) 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 95^{th} percentile error. The NVA for this project was tested with 20 check points. The VVA was tested with 46 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 0.064 meters in terms of the RMSEz. The resulting accuracy stated as the 95% confidence level (RMSEz x 1.96) is 0.125 meters. Therefore this dataset meets the required NVA of 0.196 meters at the 95% confidence level. Individual point results are included in Appendix B.

The tested Vegetated Vertical Accuracy (VVA) for this dataset captured from the DEM using bi-linear interpolation for all classes was found to be 0.167 meters. Therefore this dataset meets the required VVA of 0.294 meters based on the 95^{th} percentile error. Individual point results are included in Appendix B.

Exhibit 13: *NVA Check Point locations for the Strawberry River project*

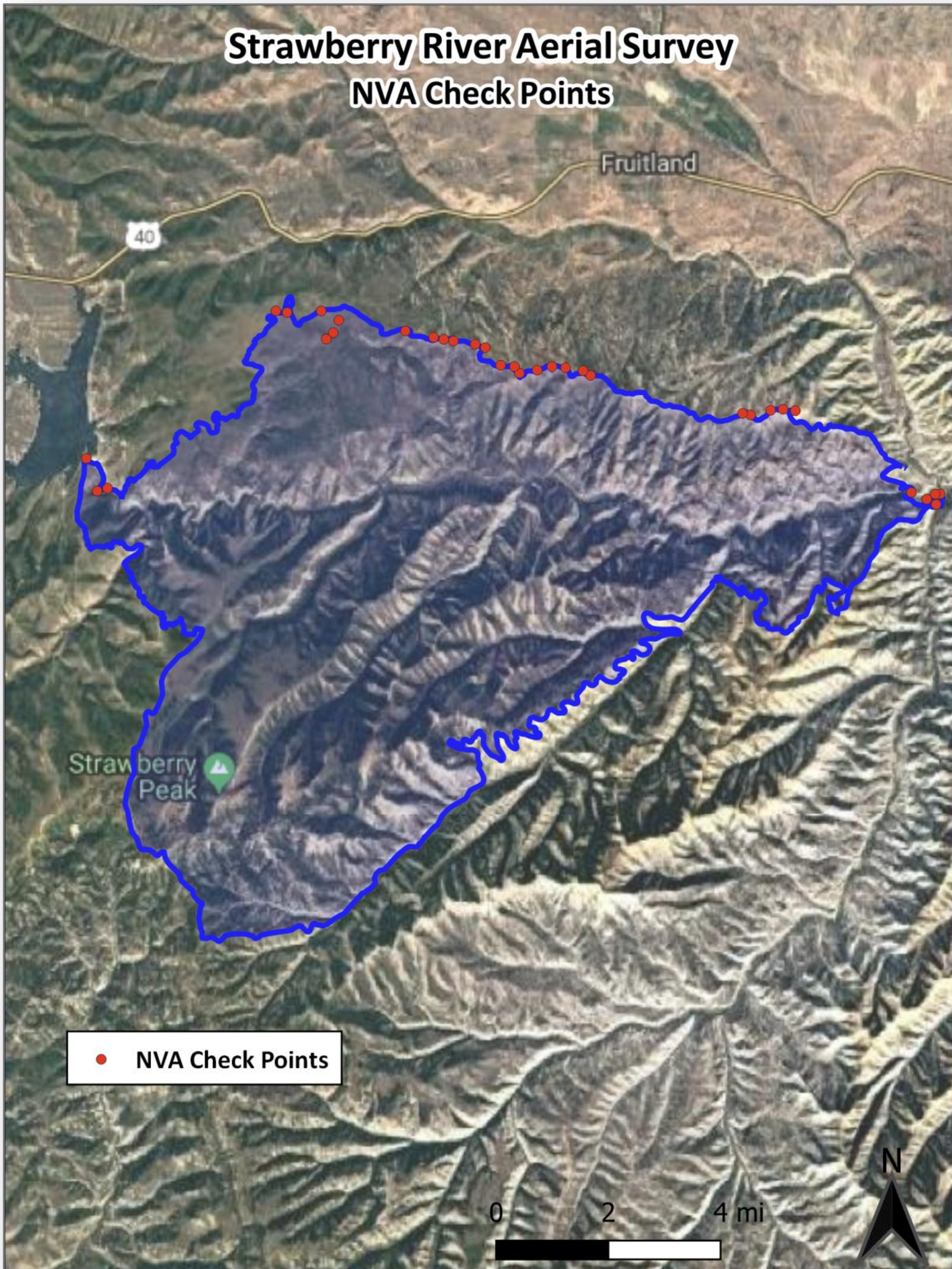
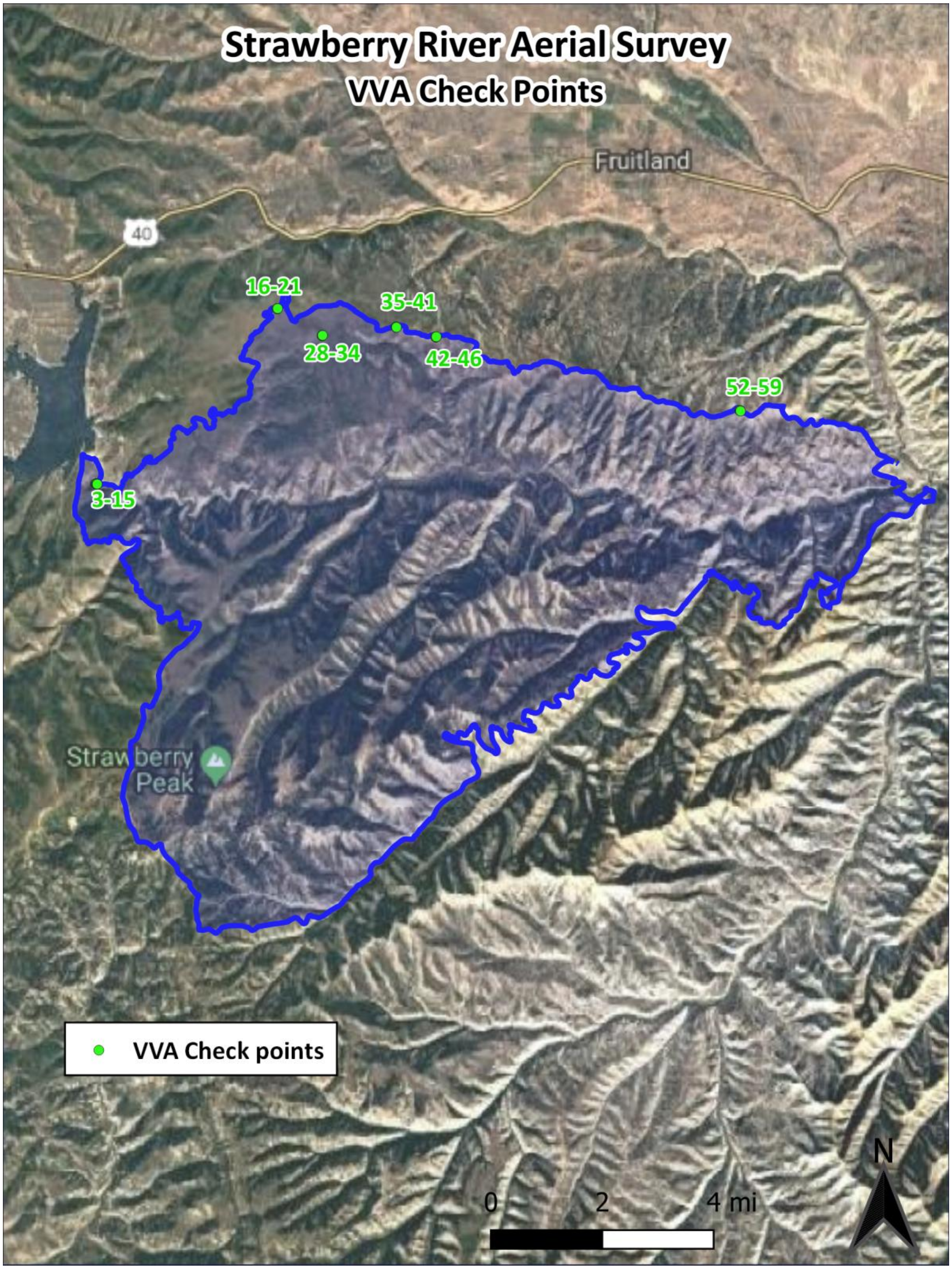


Exhibit 14: *VVA Check Point locations for the Strawberry River project*



5.5 Data Density

The requirement for this project was to achieve a LiDAR point density of **8** points per square meter. The acquisition mission achieved an actual average of **16.1** points per square meter. The following two exhibits show the density of **all collected points.**

Exhibit 15: ***Strawberry River – All returns*** *Laser Point Density by Frequency, points/m^2. Demonstrates the percentage of project tiles with points in a given density range*

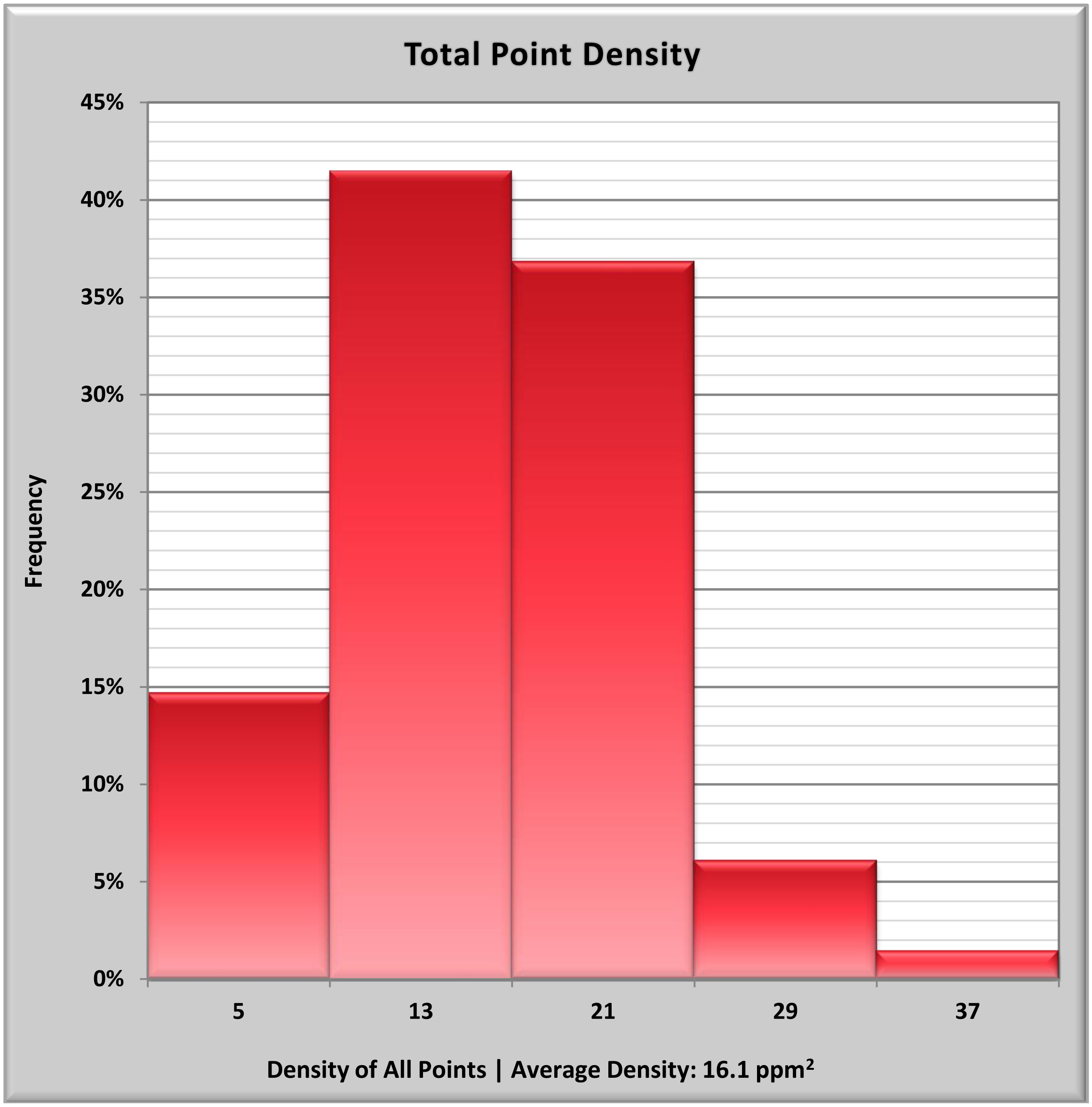
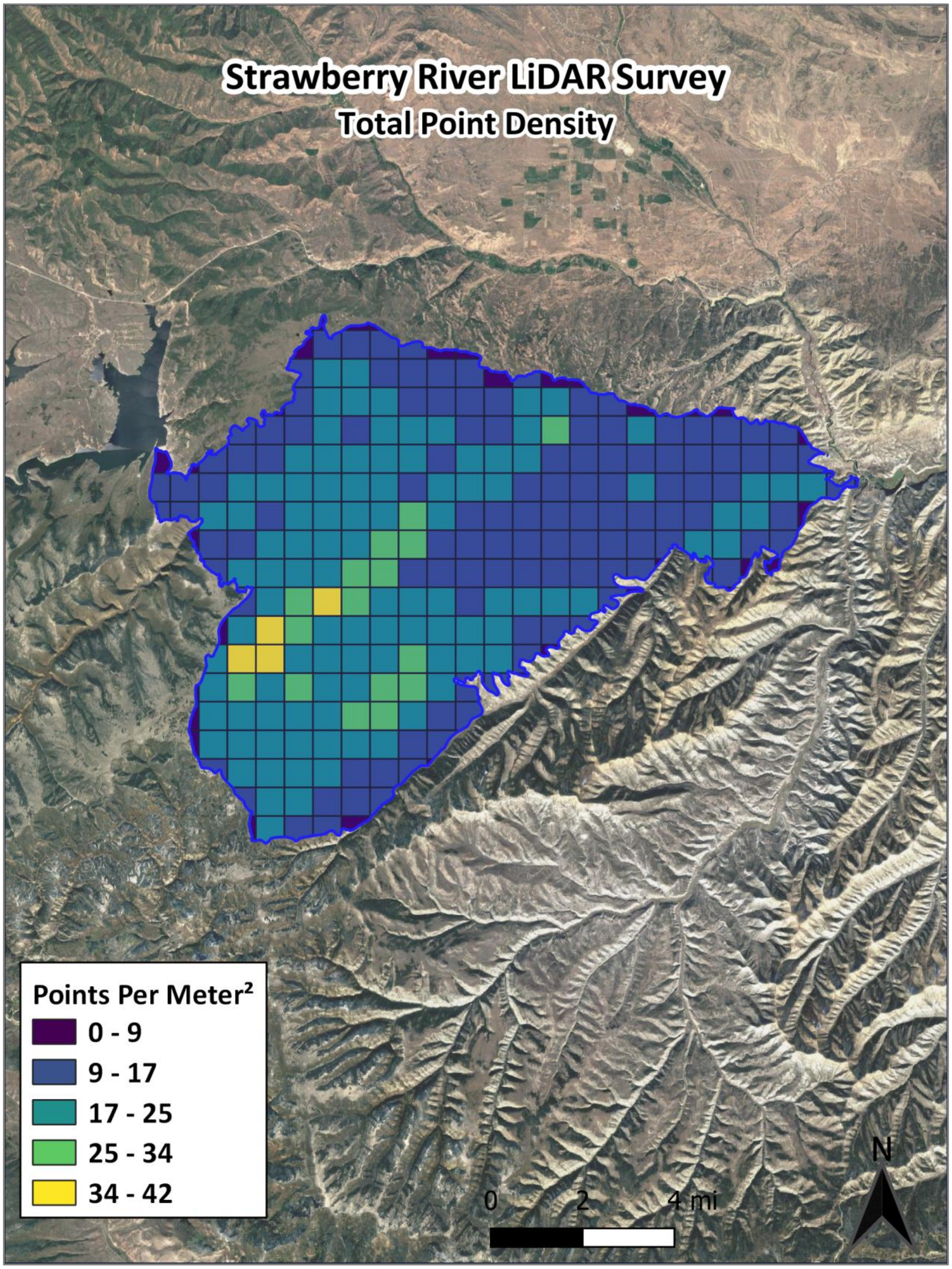
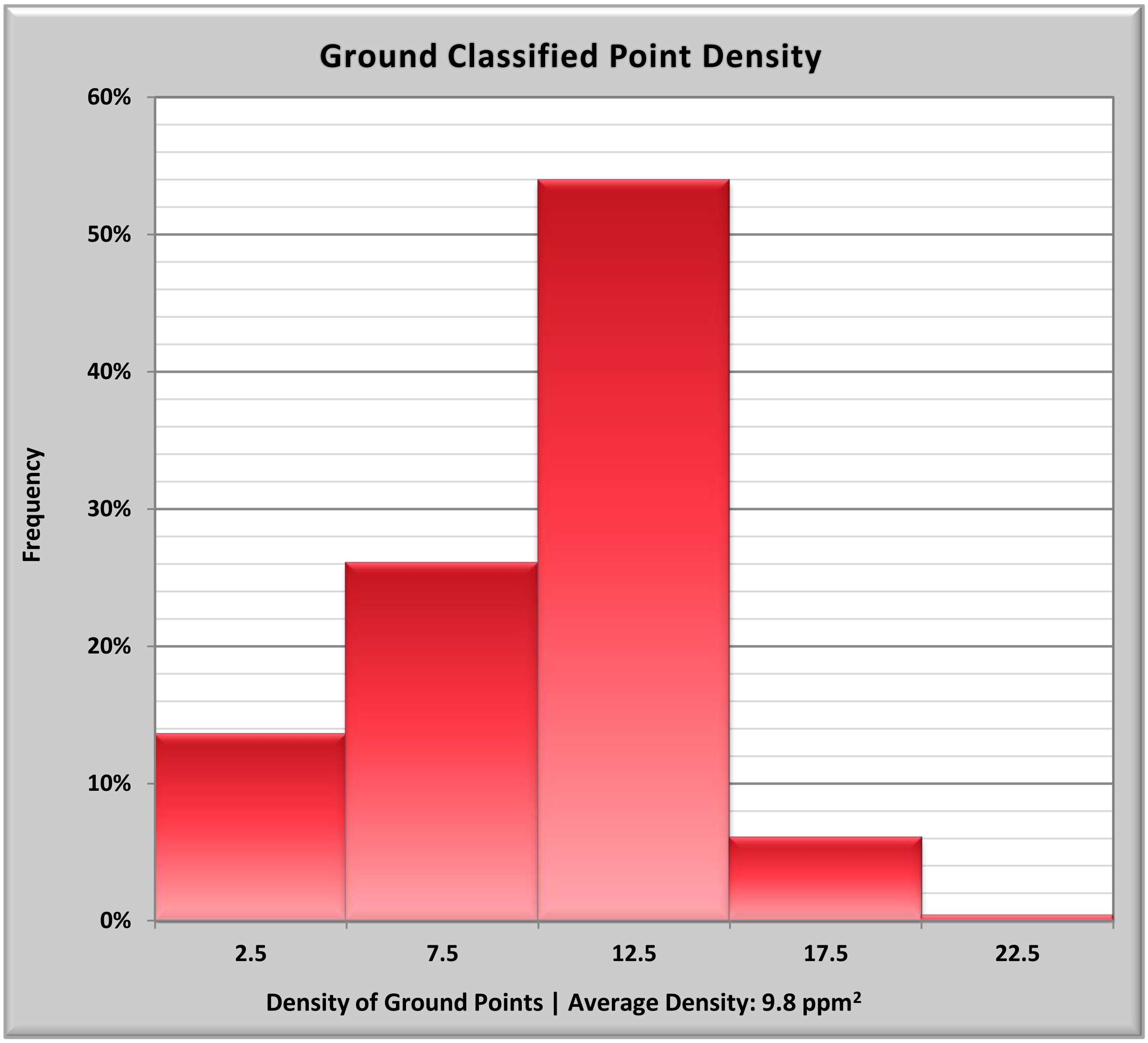


Exhibit 16: *Laser Point Density of All Returns by Tile, points/m²*

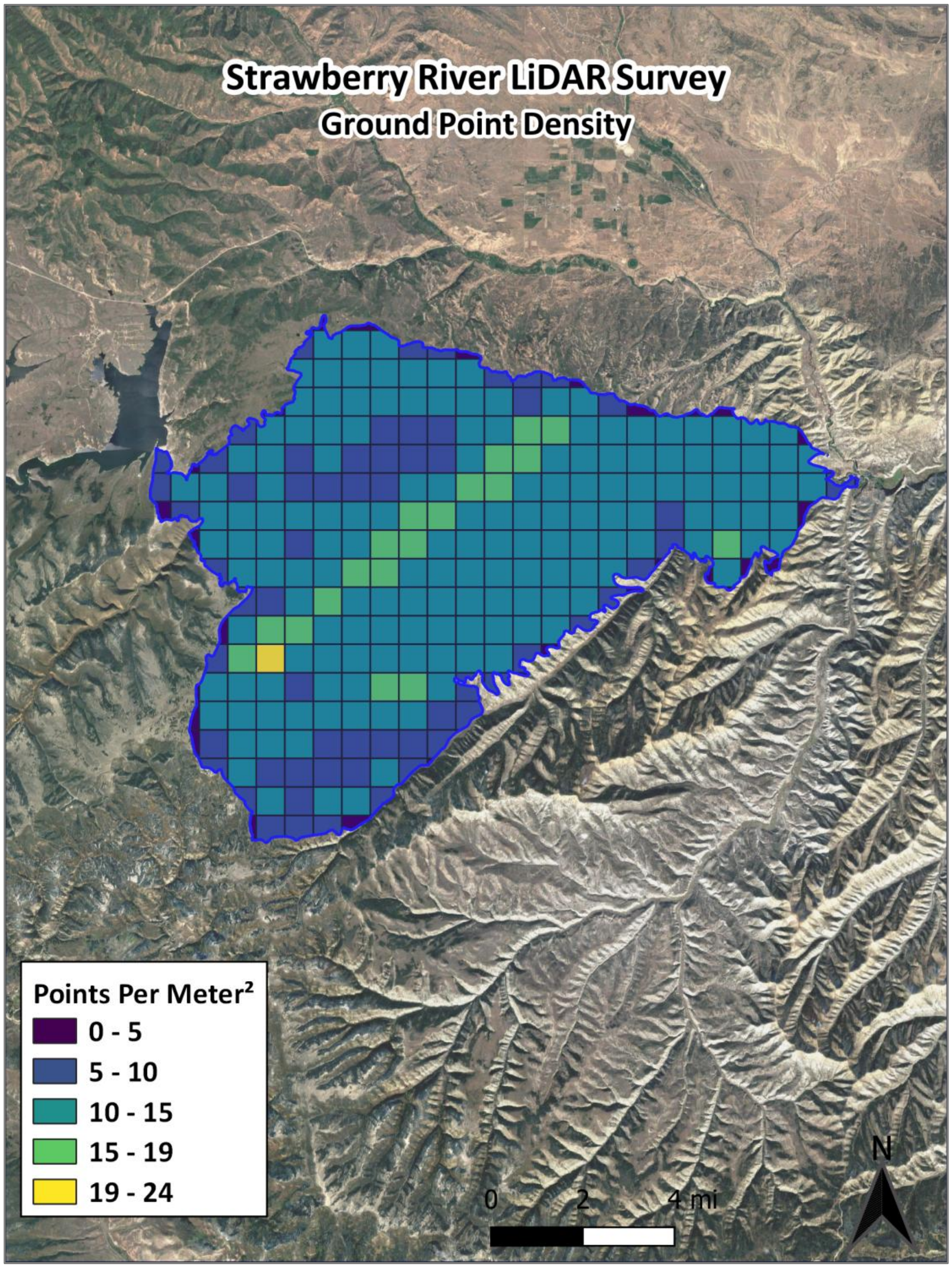


The following two exhibits show the density of **ground classified points**. Factors such as vegetation, water, and buildings will reduce the density of points classified to the ground. For the Strawberry River project, an average of **9.8** ground classified points per square meter was achieved.

***<u>Exhibit 17:</u>* Strawberry River - Ground Classified** *Laser Point Density by Frequency, points/m^2. Demonstrates the percentage of project tiles with points in a given density range*



<u>Exhibit 18:</u> *Ground Classified Laser Point Density by Tile, points/m²*



5.6 Data Density Summary

Strawberry River	Goal	Actual (mean)
Total Point Density:	8 points/m^2	16.1 points/m^2
Ground Classified Point Density:	-------	9.8 points/m^2

5.7 Orthophoto Accuracy

Horizontal accuracy of the orthophoto is dependent upon the quality of the aerotriangulation solution and the resulting ortho surface creation. Each bundle-adjusted AT solution is checked visually with the stereoimagery to ensure the surveyed control point falls directly on the center of the target and within a specified vertical tolerance (one-quarter the equivalent contour interval). If these tolerances are met, horizontal accuracy is always acceptable. In addition, Aero-Graphics utilized the project's survey grade control throughout the block to verify the integrity of the ortho's positional accuracy. Control points yielded a 0.78' RMSE XY.

6. Projection, Datums, and Mapping Units

<table>
<tr><th colspan="2">Projection:</th><td>UTM Zone 12N</td></tr>
<tr><th rowspan="2">Datum</th><th>Vertical:</th><td>NAVD88 (GEOID12B)</td></tr>
<tr><th>Horizontal:</th><td>NAD83 (2011)</td></tr>
<tr><th colspan="2">Units:</th><td>Meters</td></tr>
<tr><th colspan="2">WKID</th><td>6341</td></tr>
</table>

7. Deliverables

LiDAR Point Data:	• Raw and ground classified LiDAR point cloud data in LAS v1.4 format
Raster Data:	• 4-band orthorectified imagery in TIF format at a 12cm resolution • Bare-earth and first return DEMs with a cell size of 0.5 meters in TIF format
Vector Data:	• Shapefiles containing processing boundary and tile index • Shapefiles containing all breaklines used for hydro-flattening • Separate shapefiles for control points and check points
Metadata:	• FGDC compliant metadata files in XML format
Report of Survey:	• Technical Project Report including methodology, accuracy, and results

8. Highlighted Images

Exhibit 19: *PhaseOne: Tile "12TWK1240"*

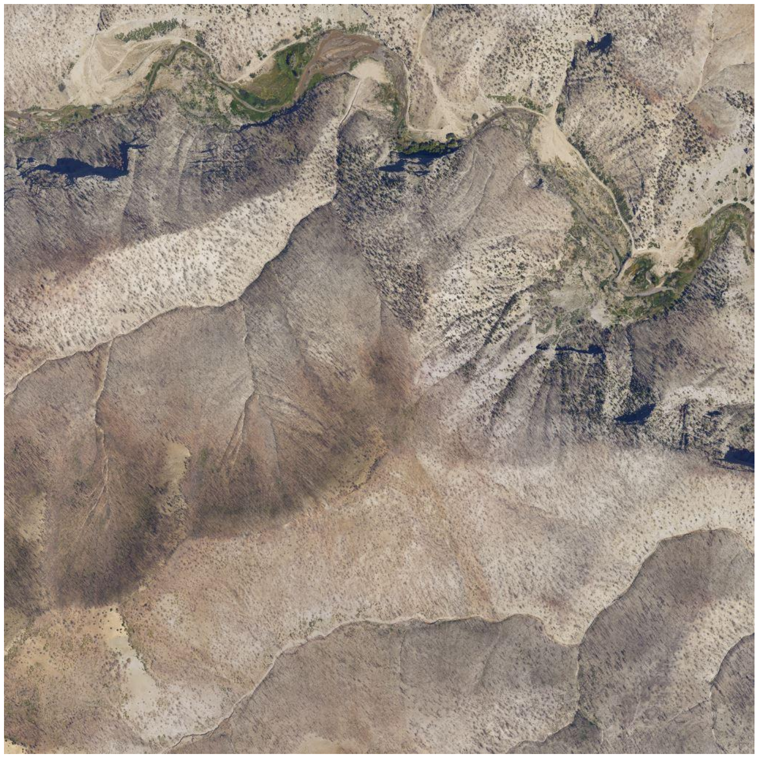


Exhibit 20: *UCE: Tile "12TWK1240"*

Appendix A

Control Point Coordinates

Point	NAD83 (2011) UTM Zone 12		NAVD88 (GEOID12B)
	Easting	Northing	Elevation
101	497447.331	4442845.979	2325.555
102	496907.182	4441941.327	2321.450
103	497874.013	4442015.915	2268.353
104	498443.175	4441455.832	2229.525
105	503105.218	4447082.280	2436.158
106	504063.587	4447132.426	2437.953
107	504412.465	4446312.516	2456.408
108	504426.656	4446305.625	2456.711
109	506601.071	4446527.074	2464.915
110	507715.971	4446292.043	2480.805
111	507698.703	4446261.681	2476.999
112	509287.036	4445574.581	2531.593
114	509291.514	4445574.006	2531.722
115	512271.536	4445256.918	2473.587
116	516497.069	4444133.116	2431.739
117	516503.702	4444130.088	2431.956
118	518277.942	4444397.988	2414.499
119	521150.123	4441970.019	1855.442
120	521970.739	4441995.616	1857.437
121	521941.968	4441467.704	1848.483

QC Check Point Coordinates - NVA

Point	Type	NAD83 (2011) UTM Zone 12		NAVD88 (GEOID12B)
		Easting	Northing	Elevation
2201338	NVA	503299.405	4447073.920	2439.452
2202159	NVA	504276.408	4447116.788	2437.547
2204947	NVA	504620.192	4446495.379	2439.853
2209289	NVA	506690.982	4446541.888	2465.938
2212701	NVA	507789.989	4446300.349	2482.676
2212833	NVA	508690.961	4446162.263	2476.817
2217324	NVA	509423.216	4445563.096	2534.005
2217521	NVA	510467.784	4445419.437	2528.399
2217656	NVA	511282.155	4445491.332	2503.082
2224634	NVA	517520.012	4444296.345	2434.423
2224681	NVA	517162.642	4444271.061	2461.186
2224800	NVA	516585.672	4444134.998	2436.534
2228608	NVA	522024.118	4441872.504	1846.423
2228706	NVA	521638.720	4441718.247	1849.201
2232123	NVA	521908.861	4441570.398	1849.691
2242273	NVA	497540.490	4442886.932	2321.825
2242423	NVA	498147.344	4442033.944	2294.304
25	NVA	497852.402	4441954.501	2255.835
26	NVA	521201.467	4441914.681	1854.484
27	NVA	521882.655	4441866.349	1847.041
33	NVA	516358.390	4444182.749	2437.583
35	NVA	517871.985	4444253.690	2415.849
38	NVA	509959.481	4445333.878	2541.273
39	NVA	512000.859	4445266.874	2497.718
46	NVA	504420.586	4446308.114	2456.628
47	NVA	508068.344	4446256.653	2489.298
48	NVA	508981.664	4446067.124	2498.392
49	NVA	509815.591	4445523.859	2534.947
50	NVA	510892.566	4445523.010	2510.446
51	NVA	511782.948	4445403.448	2512.251
59	NVA	502975.483	4447119.227	2436.371
61	NVA	504779.173	4446848.879	2433.020
64	NVA	507497.753	4446359.081	2485.608

QC Check Point Coordinates - VVA

Point	Type	NAD83 (2011) UTM Zone 12		NAVD88 (GEOID12B)
		Easting	Northing	Elevation
3	VVA	497866.454	4442016.164	2268.488
4	VVA	497869.680	4442012.650	2268.403
5	VVA	497870.065	4442020.389	2268.384
6	VVA	497870.188	4442024.526	2268.423
7	VVA	497880.697	4442010.612	2268.570
8	VVA	497887.447	4442012.373	2268.844
9	VVA	497890.161	4442023.799	2268.887
10	VVA	497903.697	4442013.162	2269.976
11	VVA	497907.283	4442001.710	2270.491
12	VVA	497908.366	4442004.234	2270.526
13	VVA	497915.541	4442009.406	2270.910
14	VVA	497920.280	4442002.568	2271.486
15	VVA	497920.699	4442011.880	2271.153
16	VVA	503115.312	4447083.488	2436.382
17	VVA	503116.987	4447075.139	2436.769
18	VVA	503116.112	4447088.204	2436.276
19	VVA	503120.187	4447069.298	2437.048
20	VVA	503125.808	4447075.493	2437.193
21	VVA	503133.860	4447084.086	2437.198
28	VVA	504414.571	4446300.918	2457.293
29	VVA	504417.895	4446302.775	2457.209
30	VVA	504418.702	4446290.379	2457.876
31	VVA	504419.019	4446298.838	2457.354
32	VVA	504416.290	4446306.999	2457.057
33	VVA	504428.346	4446302.587	2456.872
34	VVA	504431.397	4446307.712	2456.443
35	VVA	506549.258	4446540.337	2463.599
36	VVA	506549.290	4446550.216	2464.189
37	VVA	506551.785	4446560.331	2464.606
38	VVA	506553.667	4446551.250	2464.371
39	VVA	506554.721	4446556.007	2464.463
40	VVA	506561.766	4446538.743	2464.144
41	VVA	506566.930	4446542.569	2464.461
42	VVA	507702.962	4446249.448	2476.308
43	VVA	507696.084	4446273.170	2478.099
44	VVA	507711.949	4446271.749	2478.528
45	VVA	507714.862	4446264.139	2477.812
46	VVA	507718.313	4446269.803	2478.444
52	VVA	516478.750	4444134.144	2431.086
53	VVA	516482.022	4444129.625	2430.702

54	VVA	516484.588	4444133.563	2431.284
55	VVA	516484.802	4444143.495	2432.164
56	VVA	516488.506	4444137.209	2431.636
57	VVA	516490.372	4444141.836	2431.997
58	VVA	516497.384	4444140.41	2432.001
59	VVA	516505.153	4444123.156	2431.806

Appendix B

Calibration Control Vertical Accuracy Report

Point	Easting	Northing	Known Z	Laser Z	Dz
101	497447.331	4442845.979	2325.555	2325.540	-0.015
102	496907.182	4441941.327	2321.450	2321.430	-0.02
103	497874.013	4442015.915	2268.353	2268.330	-0.023
104	498443.175	4441455.832	2229.525	2229.510	-0.015
105	503105.218	4447082.282	2436.158	2436.130	-0.028
106	504063.587	4447132.426	2437.953	2437.930	-0.023
107	504412.465	4446312.516	2456.408	2456.410	0.002
108	504426.656	4446305.625	2456.711	2456.730	0.019
109	506601.071	4446527.074	2464.915	2464.930	0.015
110	507715.971	4446292.043	2480.805	2480.760	-0.045
111	507698.703	4446261.681	2476.999	2476.970	-0.029
112	509287.036	4445574.581	2531.593	2531.550	-0.043
114	509291.514	4445574.006	2531.722	2531.690	-0.032
115	512271.536	4445256.918	2473.587	2473.600	0.013
116	516497.069	4444133.116	2431.739	2431.720	-0.019
117	516503.702	4444130.088	2431.956	2431.910	-0.046
118	518277.942	4444397.988	2414.499	2414.510	0.011
119	521150.123	4441970.019	1855.442	1855.450	0.008
120	521970.739	4441995.616	1857.437	1857.460	0.023
121	521941.968	4441467.704	1848.483	1848.540	0.057

Average Dz	-0.009
Minimum Dz	-0.046
Maximum Dz	0.057
Root Mean Square	0.028
Std. Deviation	0.027

Raw NVA Check Point Report

Point	Easting	Northing	Known Z	Laser Z	Dz
2201338	503299.405	4447073.920	2439.452	2439.460	0.008
2202159	504276.408	4447116.788	2437.547	2437.610	0.063
2204947	504620.192	4446495.379	2439.853	2439.900	0.047
2209289	506690.982	4446541.888	2465.938	2465.970	0.032
2212701	507789.989	4446300.349	2482.676	2482.760	0.084
2212833	508690.961	4446162.263	2476.817	2476.690	-0.127
2217324	509423.216	4445563.096	2534.005	2534.030	0.025
2217521	510467.784	4445419.437	2528.399	2528.400	0.001
2217656	511282.155	4445491.332	2503.082	2503.140	0.058
2224634	517520.012	4444296.345	2434.423	2434.460	0.037
2224681	517162.642	4444271.061	2461.186	2461.210	0.024
2224800	516585.672	4444134.998	2436.534	2436.590	0.056
2228608	522024.118	4441872.504	1846.423	1846.350	-0.073
2228706	521638.720	4441718.247	1849.201	1849.280	0.079
2232123	521908.861	4441570.398	1849.691	1849.870	0.179
2242273	497540.490	4442886.932	2321.825	2321.840	0.015
2242423	498147.344	4442033.944	2294.304	2294.350	0.046
25	497852.402	4441954.501	2255.835	2255.880	0.045
26	521201.467	4441914.681	1854.484	1854.670	0.186
27	521882.655	4441866.349	1847.041	1847.270	0.229
33	516358.390	4444182.749	2437.583	2437.520	-0.063
35	517871.985	4444253.690	2415.849	2415.840	-0.009
38	509959.481	4445333.878	2541.273	2541.330	0.057
39	512000.859	4445266.874	2497.718	2497.840	0.122
46	504420.586	4446308.114	2456.628	2456.700	0.072
47	508068.344	4446256.653	2489.298	2489.250	-0.048
48	508981.664	4446067.124	2498.392	2498.410	0.018
49	509815.591	4445523.859	2534.947	2535.000	0.053
50	510892.566	4445523.010	2510.446	2510.530	0.084
51	511782.948	4445403.448	2512.251	2512.250	-0.001
59	502975.483	4447119.227	2436.371	2436.410	0.039
61	504779.173	4446848.879	2433.020	2433.110	0.09
64	507497.753	4446359.081	2485.608	2485.610	0.002

Average Dz	0.043
Minimum Dz	-0.127
Maximum Dz	0.229
Root Mean Square	0.082
Std. Deviation	0.071
95% Confidence Level	0.161

DEM - NVA Check Point Report

Point	Easting	Northing	Known Z	Laser Z	Dz
2202159	504276.408	4447116.788	2437.547	2437.600	0.053
2204947	504620.192	4446495.379	2439.853	2439.880	0.027
2209289	506690.982	4446541.888	2465.938	2465.950	0.012
2212701	507789.989	4446300.349	2482.676	2482.760	0.084
2212833	508690.961	4446162.263	2476.817	2476.700	-0.117
2224634	517520.012	4444296.345	2434.423	2434.470	0.047
2224681	517162.642	4444271.061	2461.186	2461.250	0.064
2224800	516585.672	4444134.998	2436.534	2436.610	0.076
2228608	522024.118	4441872.504	1846.423	1846.350	-0.073
2242273	497540.490	4442886.932	2321.825	2321.840	0.015
2242423	498147.344	4442033.944	2294.304	2294.380	0.076
25	497852.402	4441954.501	2255.835	2255.880	0.045
33	516358.390	4444182.749	2437.583	2437.520	-0.063
35	517871.985	4444253.690	2415.849	2415.860	0.011
39	512000.859	4445266.874	2497.718	2497.850	0.132
46	504420.586	4446308.114	2456.628	2456.700	0.072
47	508068.344	4446256.653	2489.298	2489.290	-0.008
48	508981.664	4446067.124	2498.392	2498.430	0.038
61	504779.173	4446848.879	2433.020	2433.090	0.07
64	507497.753	4446359.081	2485.608	2485.610	0.002

Average Dz	0.028
Minimum Dz	-0.117
Maximum Dz	0.132
Root Mean Square	0.064
Std. Deviation	0.059
95% Confidence Level	0.125

DEM - VVA Check Point Report

Point	Easting	Northing	Known Z	Laser Z	Dz
3	497866.454	4442016.164	2268.488	2268.460	-0.028
4	497869.680	4442012.650	2268.403	2268.390	-0.014
5	497870.065	4442020.389	2268.384	2268.410	0.026
6	497870.188	4442024.526	2268.423	2268.410	-0.013
7	497880.697	4442010.612	2268.570	2268.490	-0.08
8	497887.447	4442012.373	2268.844	2268.850	0.006
9	497890.161	4442023.799	2268.887	2268.870	-0.017
10	497903.697	4442013.162	2269.976	2270.130	0.155
11	497907.283	4442001.710	2270.491	2270.630	0.139
12	497908.366	4442004.234	2270.526	2270.530	0.004
13	497915.541	4442009.406	2270.910	2270.950	0.041
14	497920.280	4442002.568	2271.486	2271.440	-0.046
15	497920.699	4442011.880	2271.153	2271.130	-0.023
16	503115.312	4447083.488	2436.382	2436.510	0.129
17	503116.987	4447075.139	2436.769	2436.900	0.131
18	503116.112	4447088.204	2436.276	2436.310	0.034
19	503120.187	4447069.298	2437.048	2437.100	0.052
20	503125.808	4447075.493	2437.193	2437.250	0.057
21	503133.860	4447084.086	2437.198	2437.440	0.242
28	504414.571	4446300.918	2457.293	2457.360	0.068
29	504417.895	4446302.775	2457.209	2457.420	0.211
30	504418.702	4446290.379	2457.876	2457.970	0.095
31	504419.019	4446298.838	2457.354	2457.540	0.186
32	504416.290	4446306.999	2457.057	2457.080	0.023
33	504428.346	4446302.587	2456.872	2456.970	0.099
34	504431.397	4446307.712	2456.443	2456.530	0.087
35	506549.258	4446540.337	2463.599	2463.610	0.011
36	506549.290	4446550.216	2464.189	2464.170	-0.019
37	506551.785	4446560.331	2464.606	2464.600	-0.006
38	506553.667	4446551.250	2464.371	2464.430	0.059
39	506554.721	4446556.007	2464.463	2464.430	-0.034
40	506561.766	4446538.743	2464.144	2464.100	-0.044
41	506566.930	4446542.569	2464.461	2464.510	0.049
42	507702.962	4446249.448	2476.308	2476.290	-0.018
43	507696.084	4446273.170	2478.099	2478.040	-0.059
44	507711.949	4446271.749	2478.528	2478.420	-0.108
45	507714.862	4446264.139	2477.812	2477.740	-0.072
46	507718.313	4446269.803	2478.444	2478.380	-0.064
52	516478.750	4444134.144	2431.086	2431.070	-0.016
53	516482.022	4444129.625	2430.702	2430.670	-0.032
54	516484.588	4444133.563	2431.284	2431.200	-0.084
55	516484.802	4444143.495	2432.164	2432.230	0.066

56	516488.506	4444137.209	2431.636	2431.540	-0.096
57	516490.372	4444141.836	2431.997	2431.940	-0.057
58	516497.384	4444140.410	2432.001	2431.950	-0.051
59	516505.153	4444123.156	2431.806	2431.780	-0.026

Average Dz	0.021
Minimum Dz	-0.108
Maximum Dz	0.242
Root Mean Square	0.085
Std. Deviation	0.083
95th Percentile	0.167

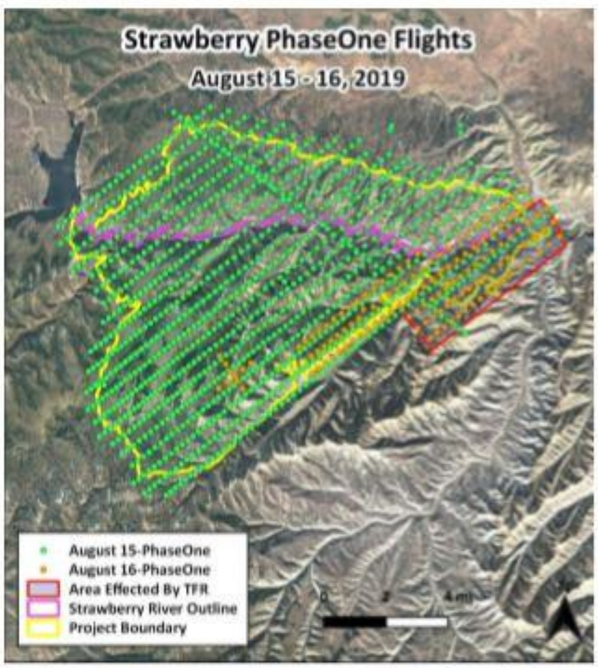
Appendix C – Imagery Acquisition Background

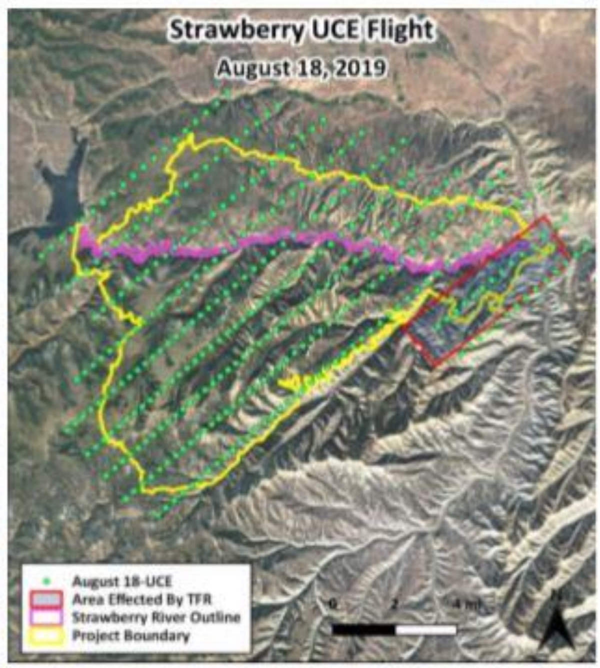
Strawberry River AGRC – September 20, 2019

Imagery Acquisition Background

On August 15, 2019 a Temporary Flight Restriction(TFR) was issued in the vicinity of the project forcing the flight crew to avoid 2 flightlines on the east side of the project. The window for acquisition also coincided with the temporary lowering of the Strawberry River, making acquisition of these final lines vital for consistent river levels across the dataset.

In order to mitigate any consequences smoke, river level, or adjusted AGL could have on the quality of the imagery, AGI decided to complete a second acquisition mission to ensure a consistent high quality imagery dataset. This second acquisition was completed in a single lift on August 18, 2019.





Flight Settings

Camera	Altitude(AGL)	Ground Sampling Distance(GSD)	Exposures Acquired
PhaseOne - August 15	4,250 ft.	11.91 cm.	1,095
PhaseOne - August 16	5,400 ft.	15.13 cm.	136
UltraCam Eagle – August 18	8,410 ft.	10.1 cm	335

http://www.aero-graphics.com/ 40 West Oakland Avenue Salt Lake City, UT 84115 801.487.3273