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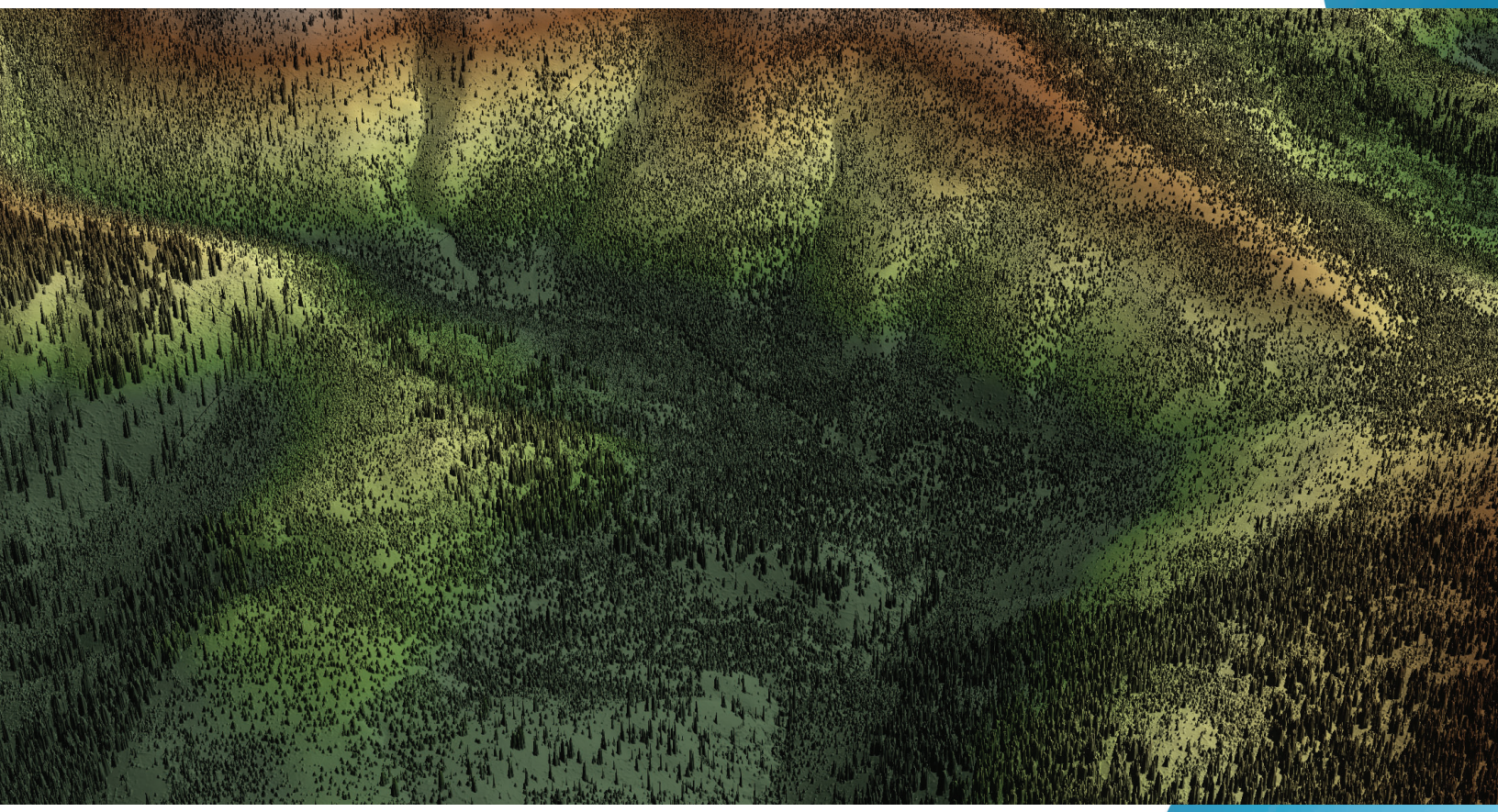

MT_RAVALLIGRANITECUSTERPOWDERRIVER_2019_B19 LIDAR PROCESSING REPORT

Work Package: 183671
Work Unit: 218301

2021

Submitted: May 20, 2021

Prepared for:

USGS science for a changing world

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1. Summary / Scope

1.1. Summary

This report contains a summary of the MT_RavalliGraniteCusterPowderRiver_2019_B19, Work Unit 218301 lidar acquisition task order, issued by USGS under their Contract G16PC00016 on September 23, 2019. This delivery includes QL2 data yielded a project area covering approximately 2,394 square miles over Montana. The intent of this document is only to provide specific validation information for the data acquisition/collection, processing, and production of deliverables completed as specified in the task order.

1.2. Scope

Aerial topographic LiDAR was acquired using state of the art technology along with the necessary surveyed ground control points (GCPs) and airborne GPS and inertial navigation systems. The aerial data collection was designed with the following specifications listed in Table 1 below.

Table 1. Originally Planned LiDAR Specifications

Average Point Density	Flight Altitude (AGL)	Field of View	Minimum Side Overlap	RMSEz
2 pts / m^2	2000-2300 m	58.5°	50%	≤ 10 cm

1.3. Coverage

The work unit boundary covers approximately 2,394 square miles over Montana. A buffer of 100 meters was created to meet task order specifications. Project extents are shown in Figure 1.

1.4. Duration

LiDAR data was acquired from October 25, 2019 to April 30, 2020 in 10 total lifts. See “Section: 2.4. Time Period” for more details.

1.5. Issues

There were no major issues to report for this project.

MT_RavalliGraniteCusterPowderRiver_2019_B19 Work Unit 218301 Projected Coordinate System: State Plane Montana FIPS 2500 Horizontal Datum: NAD 1983 (2011) Vertical Datum: NAVD88 (GEOID 12b) Units: Meters	
Lidar Point Cloud	Classified Point Cloud in .LAS 1.4 format
Rasters	• 1-meter Hydro-flattened Bare Earth Digital Elevation Model (DEM) in GeoTIFF format • 1-meter First Return Digital Surface Model (DSM) in GeoTIFF format • 1-meter Intensity images in GeoTIFF format
Vectors	Shapefiles (*.shp) • Project Boundary • LiDAR Tile Index • Calibration and QC Checkpoints (NVA/VVA) • Building Footprint Polygons Geodatabase (*.gdb) • Continuous Hydro-flattened Breaklines
Reports	Reports in PDF format • Focus on Delivery • Focus on Accuracy • Processing Report
Metadata	XML Files (*.xml) • Breaklines • Classified Point Cloud • DEM • Intensity Imagery • DSM

MT_RavalliGraniteCusterPowderRiver_2019_B19
Work Unit 218301 Boundary

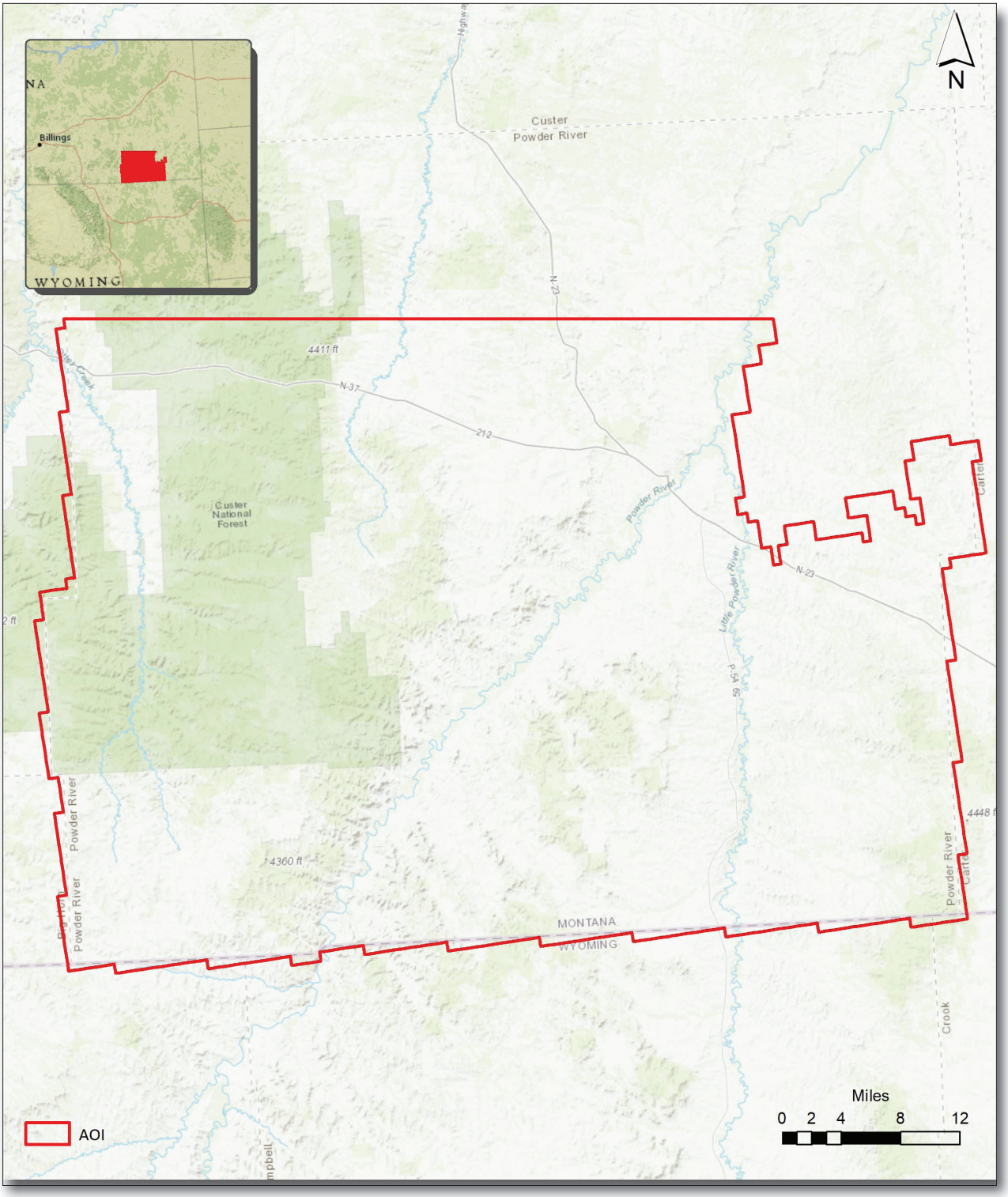


Figure 1. Work Unit AOI

2. Planning / Equipment

2.1. Flight Planning

Flight planning was based on the unique project requirements and characteristics of the project site. The basis of planning included: required accuracies, type of development, amount / type of vegetation within project area, required data posting, and potential altitude restrictions for flights in project vicinity.

Detailed project flight planning calculations were performed for the project using RiPARAMETER planning software. Planned flight lines are shown in Figure 2.

2.2. LiDAR Sensor

Quantum Spatial utilized Riegl VQ1560i LiDAR sensors (Figure 3), serial numbers 1264, 2738, and 3543, for lidar data collection.

The Riegl 1560i system has a laser pulse repetition rate of up to 2 MHz resulting in more than 1.3 million measurements per second. The system utilizes a Multi-Pulse in the Air option (MPIA). The sensor is also equipped with the ability to measure up to an unlimited number of targets per pulse from the laser.

A brief summary of the aerial acquisition parameters for the project are shown in the LiDAR System Specifications in Table 2.

MT_RavalliGraniteCusterPowderRiver_2019_B19
Work Unit 218301 Planned Flight Lines

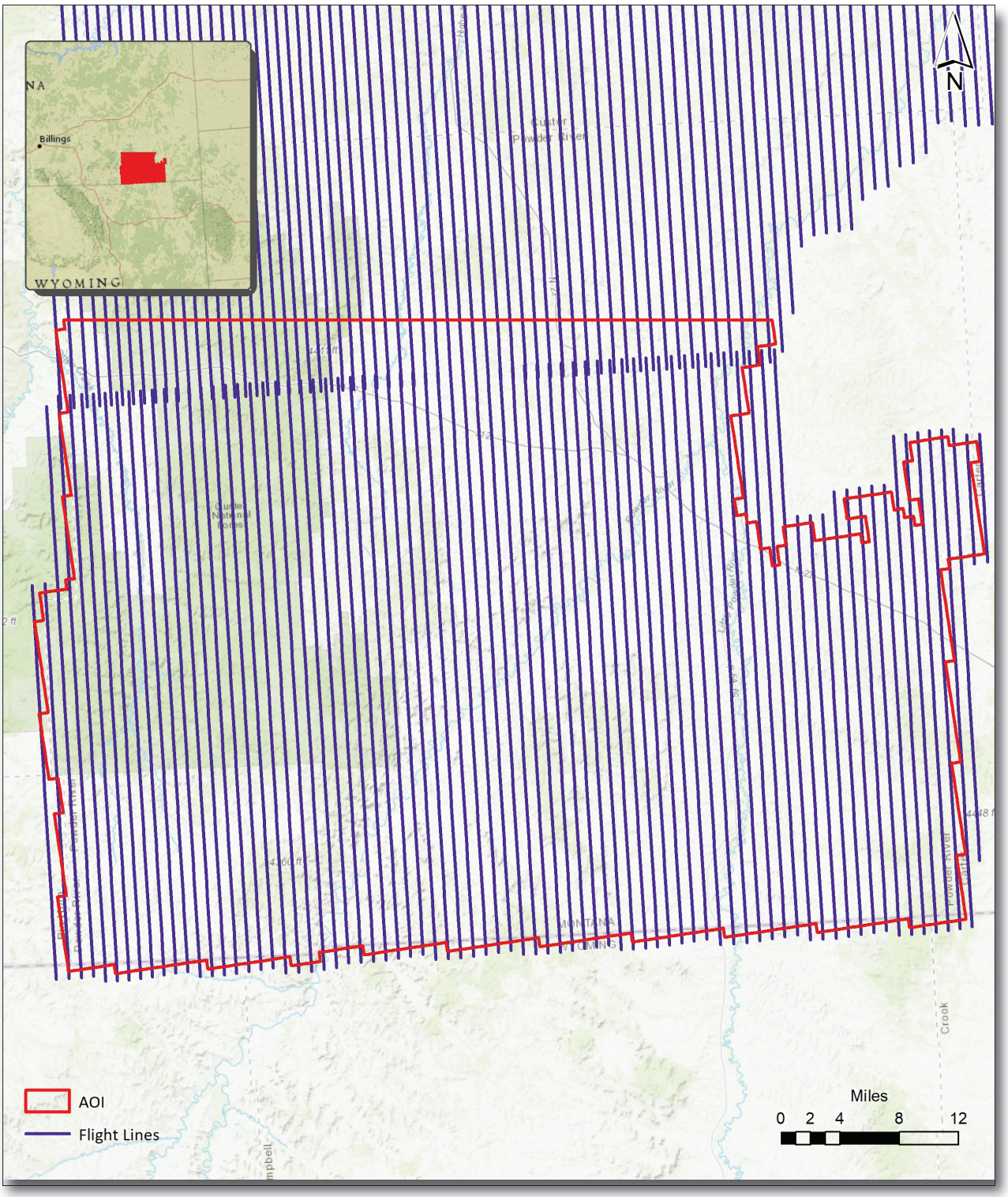


Figure 2. Planned Flight Lines

Table 2. LiDAR System Specifications

		Riegl VQ1560i (1264)	Riegl VQ1560i (3543 and 2738)
Terrain and Aircraft Scanner	Flying Height	2300 m	2000 m
	Recommended Ground Speed	160 kts	160 kts
Scanner	Field of View	58.5°	58.5°
	Scan Rate Setting Used	2 x 89 Hz	2 x 109 Hz
Laser	Laser Pulse Rate Used	2 x 400 kHz	2 x 500 kHz
	Multi Pulse in Air Mode	yes	yes
Coverage	Full Swath Width	2577 m	2241 m
	Line Spacing	1160 m	1009 m
Point Spacing and Density	Average Point Spacing	<0.7 m	<0.7 m
	Average Point Density	2.51 pts / m^2	3.61 pts / m^2

Figure 3. Riegl VQ1560i LiDAR Sensor

2.3. Aircraft

All flights for the project were accomplished through the use of customized planes. Plane type and tail numbers are listed below.

LiDAR Collection Planes

- Piper Navajo, Tail Numbers: C-FKMA, C-FFRY

These aircraft provided an ideal, stable aerial base for LiDAR acquisition. These aerial platforms have relatively fast cruise speeds, which are beneficial for project mobilization / demobilization while maintaining relatively slow stall speeds, proving ideal for collection of high-density, consistent data posting using a state-of-the-art Riegl VQ1560i LiDAR system. Some of Quantum Spatial's operating aircraft can be seen in Figure 4 below.

Figure 4. Some of Quantum Spatial's Planes

2.4. Time Period

Project specific flights were conducted between October 25, 2019 and April 30, 2020. Ten aircraft lifts were completed. Accomplished lifts are listed below.

- 10252019A (SN3543,C-FFRY)
- 03292020A (SN1264,C-FKMA)
- 03302020A (SN1264,C-FKMA)
- 03312020A (SN1264,C-FKMA)
- 04222020A (SN2738,C-FFRY)
- 04252020A (SN2738,C-FFRY)
- 04262020A (SN2738,C-FFRY)
- 04272020A (SN2738,C-FFRY)
- 04292020A (SN2738,C-FFRY)
- 04302020A (SN2738,C-FFRY)

3. Processing Summary

3.1. Flight Logs

Flight logs were completed by LIDAR sensor technicians for each mission during acquisition. These logs depict a variety of information, including:

- Job / Project #
- Flight Date / Lift Number
- FOV (Field of View)
- Scan Rate (HZ)
- Pulse Rate Frequency (Hz)
- Ground Speed
- Altitude
- Base Station
- PDOP avoidance times
- Flight Line #
- Flight Line Start and Stop Times
- Flight Line Altitude (AMSL)
- Heading
- Speed
- Returns
- Crab

Notes: (Visibility, winds, ride, weather, temperature, dew point, pressure, etc).

3.2. LiDAR Processing

Applanix + POSPac software was used for post-processing of airborne GPS and inertial data (IMU), which is critical to the positioning and orientation of the LiDAR sensor during all flights. Applanix POSPac combines aircraft raw trajectory data with stationary GPS base station data yielding a “Smoothed Best Estimate Trajectory” (SBET) necessary for additional post processing software to develop the resulting geo-referenced point cloud from the LiDAR missions.

During the sensor trajectory processing (combining GPS & IMU datasets) certain statistical graphs and tables are generated within the Applanix POSPac processing environment which are commonly used as indicators of processing stability and accuracy. This data for analysis include: max horizontal / vertical GPS variance, separation plot, altitude plot, PDOP plot, base station baseline length, processing mode, number of satellite vehicles, and mission trajectory.

Point clouds were created using RiPROCESS software. The generated point cloud is the mathematical three dimensional composite of all returns from all laser pulses as determined from the aerial mission. The point cloud is imported into GeoCue distributive processing software. Imported data is tiled and then calibrated using TerraMatch and proprietary software. Using TerraScan, the vertical accuracy of the surveyed ground control is tested and any bias is removed from the data. TerraScan and TerraModeler software packages are then used for automated data classification and manual cleanup. The data are manually reviewed and any remaining artifacts removed using functionality provided by TerraScan and TerraModeler.

DEMs and Intensity Images are then generated using proprietary software. In the bare earth surface model, above-ground features are excluded from the data set. Global Mapper is used as a final check of the bare earth dataset.

Finally, proprietary software is used to perform statistical analysis of the LAS files.

Software	Version
RiPROCESS	1.8.6
Applanix + POSPac	8.4
GeoCue	2017.1.14.1
Global Mapper	19.1;20.1
TerraModeler	20.004
TerraScan	20.011
TerraMatch	20.004

3.3. LAS Classification Scheme

The classification classes are determined by the USGS Version 1.3 specifications and are an industry standard for the classification of LIDAR point clouds. All data starts the process as Class 1 (Unclassified), and then through automated classification routines, the classifications are determined using TerraScan macro processing.

The classes used in the dataset are as follows and have the following descriptions:

Table 3. LAS Classifications

	Classification Name	Description
1	Processed, but Unclassified	Laser returns that are not included in the ground class, or any other project classification
2	Bare earth	Laser returns that are determined to be ground using automated and manual cleaning algorithms
6	Buildings	Points falling on buildings, structures inside of water bodies, docks, and piers.
7	Low Noise	Laser returns that are often associated with scaterring from reflective surfaces, or artificial points below the ground surface
9	Water	Laser returns that are found inside of hydro features
17	Bridge Deck	Laser returns falling on bridge decks
18	High Noise	Laser returns that are often associated with birds or artificial points above the ground surface
20	Ignored Ground	Ground points that fall within the given threshold of a collected hydro feature.
22	Temporal Exclusion	Points that are excluded due to differences in collection dates

3.4. Classified LAS Processing

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 flattening breaklines were then classified to water (ASPRS Class 9) using TerraScan macro functionality. A buffer of 3 feet was also used around each hydro flattened feature to classify these ground (ASPRS Class 2) points to Ignored ground (ASPRS Class 20). 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 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 identified using the Overlap Flag, per LAS 1.4 specifications.

All data was manually reviewed and any remaining artifacts removed using functionality provided by TerraScan and TerraModeler. Global Mapper is used as a final check of the bare earth dataset. GeoCue was then used to create the deliverable industry-standard LAS files for all point cloud data. Quantum Spatial's 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.

3.5. Hydro-Flattened Breakline Processing

Class 2 (ground) lidar points was 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 TerraModeler functionality.

Elevation values were assigned to all inland streams and rivers using Quantum Spatial's 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 3 feet was also used around each hydro-flattened feature. These points were moved from ground (ASPRS Class 2) to Ignored Ground (ASPRS Class 20).

The breakline files were then translated to Esri file geodatabase 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 Data Reviewer tools and proprietary tools.

3.6. Hydro-Flattened Raster DEM Processing

Class 2 LiDAR in conjunction with the hydro breaklines were used to create 1-meter, hydro-

flattened raster DEMs. Using automated scripting routines within proprietary software, a GeoTIFF file was created for each tile. Each surface is reviewed using Global Mapper to check for any surface anomalies or incorrect elevations found within the surface.

3.7. Intensity Image Processing

GeoCue software was used to create the deliverable intensity images. All overlap classes were ignored during this process. This helps to ensure a more aesthetically pleasing image. The GeoCue software was then used to verify full project coverage as well. GeoTIFF files with a cell size of 1-meter were then provided as the deliverable for this dataset requirement.

3.8. First Return DSM Processing

First return LiDAR points were used to create a 1-meter first-return raster DSM. Using automated scripting routines within proprietary software, GeoTIFF files were created for each tile. Each surface is reviewed using Global Mapper to check for any surface anomalies or incorrect elevations found within the surface.

MT_RavalliGraniteCusterPowderRiver_2019_B19
Work Unit 218301 Tile Layout

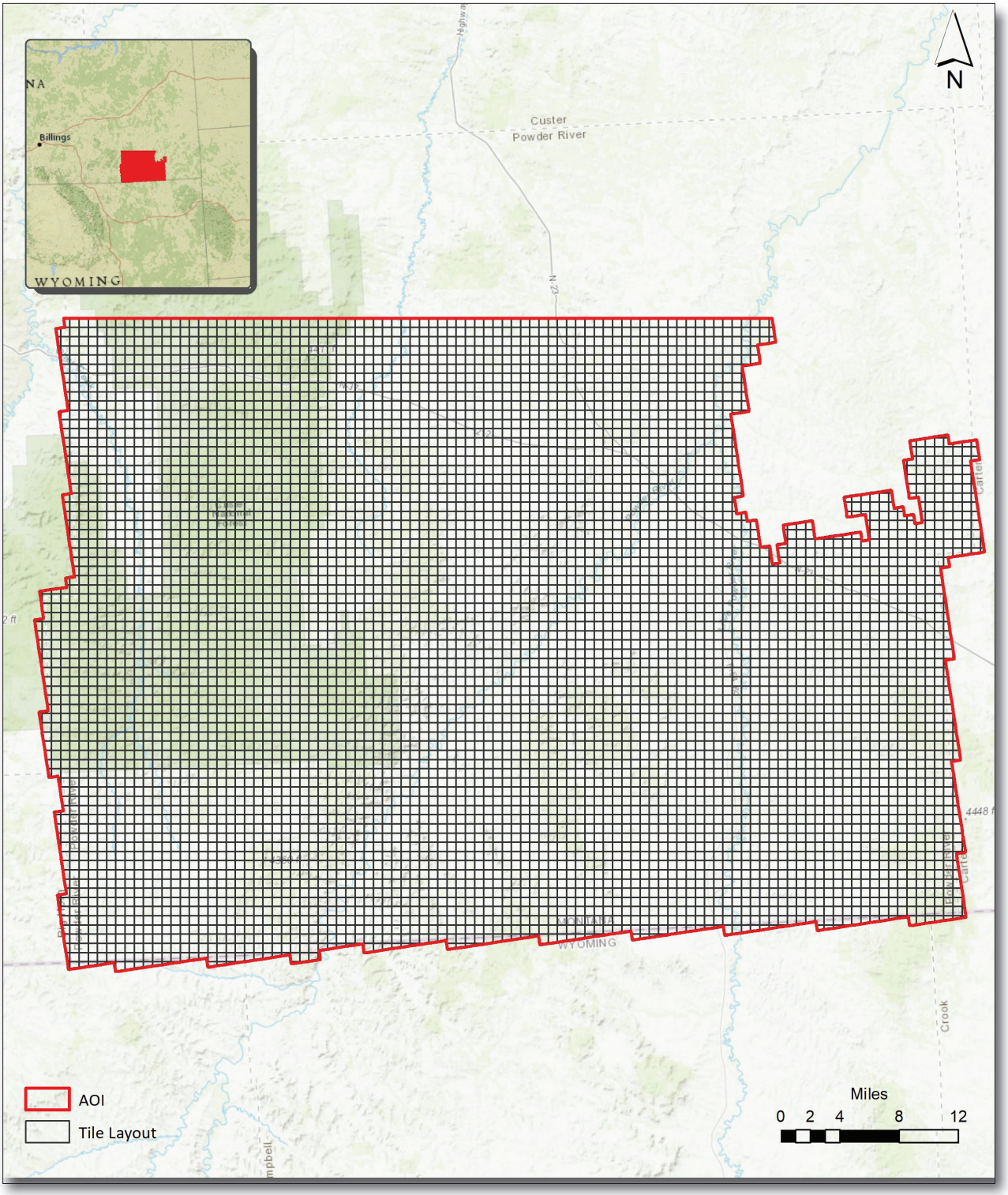


Figure 5. Lidar Tile Layout

4. Project Coverage Verification

Coverage verification was performed by comparing coverage of processed .LAS files captured during project collection to generate project shape files depicting boundaries of specified project areas. Please refer to Figures 6.

MT_RavalliGraniteCusterPowderRiver_2019_B19
Work Unit 218301 Coverage

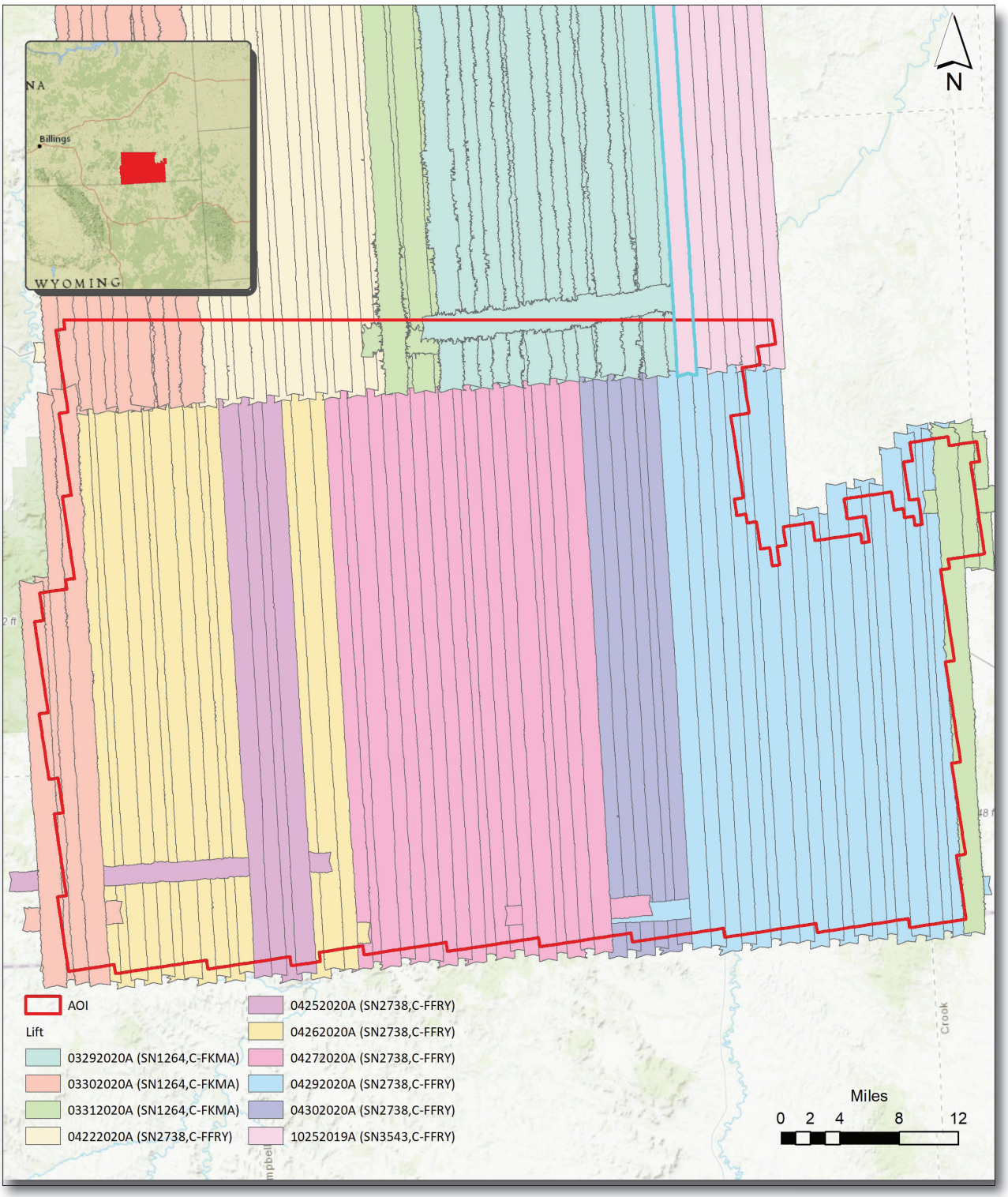


Figure 6. Lidar Coverage

5. Geometric Accuracy

5.1. Horizontal Accuracy

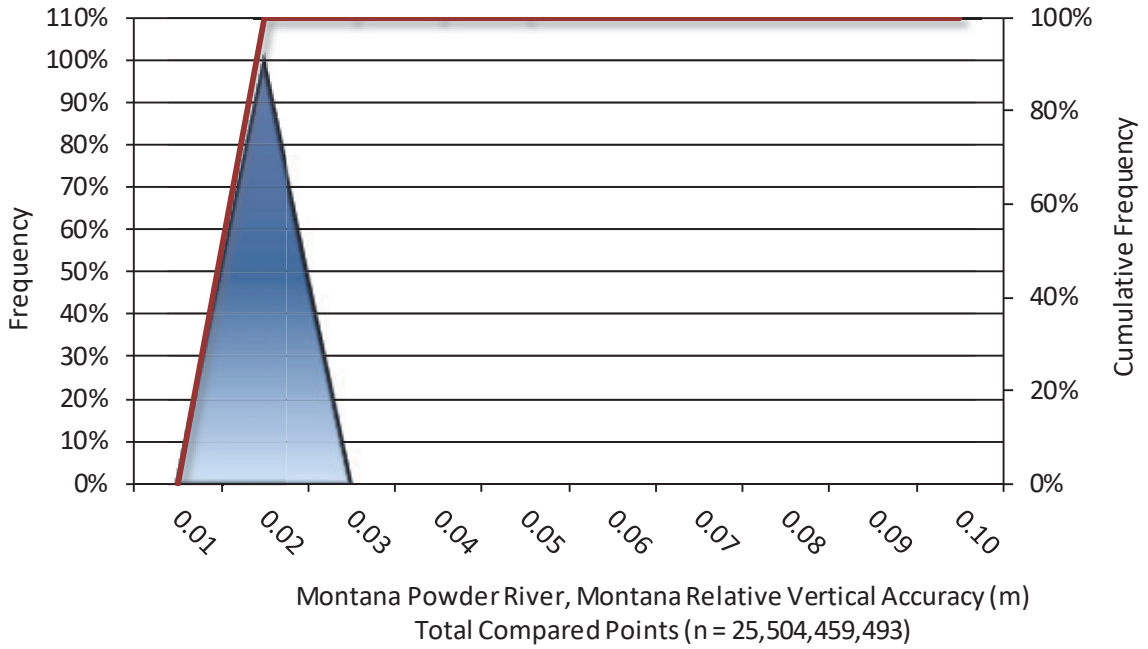
Lidar horizontal accuracy is a function of Global Navigation Satellite System (GNSS) derived positional error, flying altitude, and INS derived attitude error. The obtained $RMSE_r$ value is multiplied by a conversion factor of 1.7308 to yield the horizontal component of the National Standards for Spatial Data Accuracy (NSSDA) reporting standard where a theoretical point will fall within the obtained radius 95% of the time. Based on a flying altitude of 2300 meters, an IMU error of 0.002 decimal degrees, and a GNSS positional error of 0.015 meters, this project was compiled to meet 0.25 meter horizontal accuracy at the 95% confidence level. A summary is shown below.

Horizontal Accuracy	
$RMSE_r$	0.14 m
	0.47 ft
ACC_r	0.25 m
	0.82 ft

5.2. Relative Vertical Accuracy

Relative vertical accuracy refers to the internal consistency of the data set as a whole: the ability to place an object in the same location given multiple flight lines, GPS conditions, and aircraft attitudes. When the lidar system is well calibrated, the swath-to-swath vertical divergence is low (<0.10 meters). The relative vertical accuracy was computed by comparing the ground surface model of each individual flight line with its neighbors in overlapping regions. The average (mean) line to line relative vertical accuracy for Work Unit 218301 was 0.042 feet (0.013 meters). A summary is shown below.

Relative Vertical Accuracy	
Sample	158 flight line surfaces
Average	0.042 ft
	0.013 m
Median	0.042 ft
	0.013 m
RMSE	0.042 ft
	0.013 m
Standard Deviation (1σ)	0.002 ft
	0.001 m
1.96σ	0.004 ft
	0.001 m



Project Report Appendices

The following section contains the appendices as listed in the MT_RavalliGraniteCusterPowderRiver LiDAR Project Report.

Appendix A

Flight Logs

Julian Day 298	Flight A

LIDAR Flight Log

AIRBORNE IMAGING
A Clean Harbors Company

Date Oct 25, 2016	Aircraft C-FFRY
Project 3186 QSI POWDER..	Pilot MACQUARRIE
Location SHERIDAN, WYO	Operator WESTERGARD
Mission Objective	

System Reigl Q1560i	
Unit 43	
IMU	
GPS Rx Trimble	
Scanner 1 Drive	
Scanner 2 Drive	

Additional Notes

Time to next maintenance: _____ ☐ 50 hr ☐ 100 hr

Aircraft Block Time		
Engine On 1538	Takeoff 1555	
Engine Off 2153	Landing 2141	
Total 6.3 hrs	Total 5.8 hrs	

Mission Plan			
AGL Height	2000 m	Pulse Rate	500 Khz
Target Speed	160 kts	Scan Rate	109
Laser Current	100 %	FOV	60 degs

Static Alignment	GPS Time	
	Start	End
Pre Mission	1546	1551
Post Mission	2146	2151

Flight Line	LIDAR File Name	Flight Direction	GPS Time		Line Aborted		Mission ID Time Stamp 191025	Comments
			Start	End	Time	nmi to End		
test		∞	1619	1621			161930	test
figure 8		∞	1624	1629			—	inertial
X-LINE	431929801	85	1629	1639			162953	
3064	431929802	355	1644	1653			164440	
3063	431929803	175	1656	1705			165619	
3062	431929804	355	1707	1716			170757	
3061	431929805	175	1719	1729			171946	
3060	431929806	355	1732	1741			173211	
3059	431929807	175	1744	1755			174433	
3058	431929808	355	1757	1808			175746	
3057	431929809	175	1810	1821			181051	
3056	431929810	355	1824	1835			182433	
3055	431929811	175	1837	1849			183739	
3054	431929812	355	1853	1906			185331	
3053	431929813	175	1909	1922			190900	

Julian Day 298	Flight A

LIDAR Flight Log

AIRBORNE IMAGING
A Clean Harbors Company

Date Oct 25, 2019	Aircraft C-FFRY
Project 3186 QSI, Powder	Pilot MacQuarrie
Location Sheridan, WYO	Operator Westergard
Mission Objective	

System Reigl Q1560i
Unit 43
IMU
GPS Rx Trimble
Scanner 1 Drive
Scanner 2 Drive

Additional Notes

Time to next maintenance: _____ ☐ 50 hr ☐ 100 hr

Aircraft Block Time		
Engine On 1538	Takeoff 1555	
Engine Off 2153	Landing 2141	
Total 6.3 hrs	Total 5.8 hrs	

Mission Plan			
AGL Height	2000 m	Pulse Rate	500 kHz
Target Speed	160 kts	Scan Rate	109
Laser Current	100 %	FOV	60 degs

Static Alignment	GPS Time	
	Start	End
Pre Mission	1546	1551
Post Mission	2146	2151

Flight Line	LIDAR File Name	Flight Direction	GPS Time		Line Aborted		Mission ID Time Stamp 191025	Comments
			Start	End	Time	nmi to End		
3052	431929814	355	1925	1938			192512	
3051	431929815	175	1941	1954			194114	
3050	431929816	355	1957	2011			195700	
3049	431929817	175	2013	2027			201354	
3048	431929818	355	2029	2044			202942	
3047	431929819	175	2046	2059			204630	
figure 8		∞	2059	2105			—	inertial

Julian Day	089	Flt	A

LIDAR Flight Log

AIRBORNE IMAGING INC

Date	March 29, 2020	Aircraft	CFKMA
Project	3186 QSI Powder River	Pilot	N. Emson
Location	Sheridan, WY	Operator	B. Eisenbart
Mission Objective			

System	LMS-1560
Unit	64
IMU	**Applanix AP60**
GPS Rx	**Trimble**
Scanner 1 Drive	1
Scanner 2 Drive	2

Additional Notes

Aircraft Block Time					
Engine On	15:39	Ramp Out		Takeoff	15:58
Engine Off	22:17	Ramp In		Landing	22:06
Total	6.6 **hrs**	Total	**hrs**	Total	6.1 **hrs**

Mission Plan			
AGL Height	2300 **m**	Pulse Rep Rate	400 **kHz**
Ground Speed	160 **kts**	Scan Rate	89 **Hz**
Laser Current	100 **%**	FOV	60 **Deg's**

Static Alignment	GPS Time	
	Start	End
Pre Mission	15:42	15:47
Post Mission	22:10	22:15

Flight Line	LiDAR File Name	Flight Direction	GPS Time		Ln Aborted	Date Stamp	ALS Time Stamp	Comments
			Start	End	Time			
PPP-8	-		16:29	16:34			-	Figure 8
3046	6420089-01	351°	16:38	16:51		200329	163836	
3045	02	171°	16:55	17:08			165523	
3044	03	351°	17:12	17:26			171225	
3043	04	171°	17:30	17:44			173018	
3042	05	351°	17:47	18:01			174744	
3041	06	171°	18:05	18:18			180531	
3040	07	351°	18:22	18:35			1822125	
3039	08	171°	18:39	18:53			183927	
3038	09	351°	18:57	19:11			185711	
3037	10	171°	19:15	19:29			191502	
3036	11	351°	19:33	19:47			193307	
3035	12	171°	19:50	20:05			195048	
3034	13	351°	20:08	20:22			200856	
3033	14	171°	20:25	20:40			202541	

Julian Day	089	Flt	A

LIDAR Flight Log

AIRBORNE IMAGING INC

Date	March 29, 2020	Aircraft	CFKMA
Project	3186 QSI Powder River	Pilot	N. Emson
Location	Sheridan, WY	Operator	B. Eisenbart
Mission Objective			

System	LMS-1560
Unit	64
IMU	**Applanix AP50**
GPS Rx	**Trimble**
Scanner 1 Drive	1
Scanner 2 Drive	2

Additional Notes

Aircraft Block Time					
Engine On	15:39	Ramp Out		Takeoff	15:58
Engine Off	22:17	Ramp In		Landing	22:06
Total	6.6 **hrs**	Total	**hrs**	Total	6.1 **hrs**

Mission Plan			
AGL Height	2300 **m**	Pulse Rep Rate	400 **kHz**
Ground Speed	160 **kts**	Scan Rate	89 **Hz**
Laser Current	100 **%**	FOV	60 **Deg's**

Static Alignment	GPS Time	
	Start	End
Pre Mission	15:42	15:47
Post Mission	22:10	22:15

Flight Line	LiDAR File Name	Flight Direction	GPS Time		Ln Aborted	Date Stamp	ALS Time Stamp	Comments
			Start	End	Time			
3032	15	351°	20:44	20:57		200329	204406	
3031	16	171°	21:01	21:15			210118	
X-TIE	17	81°	21:19	21:25			211945	
PPP-8	-		21:25	21:30			-	Figure 8

Julian Day	089	Flt	A

LIDAR Flight Log

AIRBORNE IMAGING INC

Date	March 29, 2020	Aircraft	CFKMA
Project	3186 QSI Powder River	Pilot	N. Emson
Location	Sheridan, WY	Operator	B. Eisenbart
Mission Objective			

System	LMS-1560
Unit	64
IMU	**Applanix AP60**
GPS Rx	**Trimble**
Scanner 1 Drive	1
Scanner 2 Drive	2

Additional Notes

Aircraft Block Time					
Engine On	15:39	Ramp Out		Takeoff	15:58
Engine Off	22:17	Ramp In		Landing	22:06
Total	6.6 **hrs**	Total	**hrs**	Total	6.1 **hrs**

Mission Plan			
AGL Height	2300 **m**	Pulse Rep Rate	400 **kHz**
Ground Speed	160 **kts**	Scan Rate	89 **Hz**
Laser Current	100 **%**	FOV	60 **Deg's**

Static Alignment	GPS Time	
	Start	End
Pre Mission	15:42	15:47
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Flight Line	LiDAR File Name	Flight Direction	GPS Time		Ln Aborted	Date Stamp	ALS Time Stamp	Comments
			Start	End	Time			
PPP-8	-		16:29	16:34			-	Figure 8
3046	6420089-01	351°	16:38	16:51		200329	163836	
3045	02	171°	16:55	17:08			165523	
3044	03	351°	17:12	17:26			171225	
3043	04	171°	17:30	17:44			173018	
3042	05	351°	17:47	18:01			174744	
3041	06	171°	18:05	18:18			180531	
3040	07	351°	18:22	18:35			1822125	
3039	08	171°	18:39	18:53			183927	
3038	09	351°	18:57	19:11			185711	
3037	10	171°	19:15	19:29			191502	
3036	11	351°	19:33	19:47			193307	
3035	12	171°	19:50	20:05			195048	
3034	13	351°	20:08	20:22			200856	
3033	14	171°	20:25	20:40			202541	

Julian Day	089	Flt	A

LIDAR Flight Log

Date	March 29, 2020	Aircraft	CFKMA
Project	3186 QSI Powder River	Pilot	N. Emson
Location	Sheridan, WY	Operator	B. Eisenbart
Mission Objective			

System	LMS-1560
Unit	64
IMU	**Applanix AP60**
GPS Rx	**Trimble**
Scanner 1 Drive	1
Scanner 2 Drive	2

Additional Notes

Aircraft Block Time					
Engine On	15:39	Ramp Out		Takeoff	15:58
Engine Off	22:17	Ramp In		Landing	22:06
Total	6.6 **hrs**	Total	**hrs**	Total	6.1 **hrs**

Mission Plan			
AGL Height	2300 **m**	Pulse Rep Rate	400 **kHz**
Ground Speed	160 **kts**	Scan Rate	89 **Hz**
Laser Current	100 **%**	FOV	60 **Deg's**

Static Alignment	GPS Time	
	Start	End
Pre Mission	15:42	15:47
Post Mission	22:10	22:15

Flight Line	LiDAR File Name	Flight Direction	GPS Time		Ln Aborted	Date Stamp	ALS Time Stamp	Comments
			Start	End	Time			
3032	15	351°	20:44	20:57		200329	204406	
3031	16	171°	21:01	21:15			210118	
X-TIE	17	81°	21:19	21:25			211945	
PPP-8	-		21:25	21:30			-	Figure 8

Julian Day	089	Flt	A

LIDAR Flight Log

AIRBORNE IMAGING INC

Date	March 29, 2020	Aircraft	CFKMA
Project	3186 QSI Powder River	Pilot	N. Emson
Location	Sheridan, WY	Operator	B. Eisenbart
Mission Objective			

System	LMS-1560
Unit	64
IMU	**Applanix AP60**
GPS Rx	**Trimble**
Scanner 1 Drive	1
Scanner 2 Drive	2

Additional Notes

Aircraft Block Time					
Engine On	15:39	Ramp Out		Takeoff	15:58
Engine Off	22:17	Ramp In		Landing	22:06
Total	6.6 **hrs**	Total	**hrs**	Total	6.1 **hrs**

Mission Plan			
AGL Height	2300 **m**	Pulse Rep Rate	400 **kHz**
Ground Speed	160 **kts**	Scan Rate	89 **Hz**
Laser Current	100 **%**	FOV	60 **Deg's**

Static Alignment	GPS Time	
	Start	End
Pre Mission	15:42	15:47
Post Mission	22:10	22:15

Flight Line	LiDAR File Name	Flight Direction	GPS Time		Ln Aborted	Date Stamp	ALS Time Stamp	Comments
			Start	End	Time			
PPP-8	-		16:29	16:34			-	Figure 8
3046	6420089-01	351°	16:38	16:51		200329	163836	
3045	02	171°	16:55	17:08			165523	
3044	03	351°	17:12	17:26			171225	
3043	04	171°	17:30	17:44			173018	
3042	05	351°	17:47	18:01			174744	
3041	06	171°	18:05	18:18			180531	
3040	07	351°	18:22	18:35			1822125	
3039	08	171°	18:39	18:53			183927	
3038	09	351°	18:57	19:11			185711	
3037	10	171°	19:15	19:29			191502	
3036	11	351°	19:33	19:47			193307	
3035	12	171°	19:50	20:05			195048	
3034	13	351°	20:08	20:22			200856	
3033	14	171°	20:25	20:40			202541	

Julian Day 089	Flight A

LIDAR Flight Log

AIRBORNE IMAGING
A Clean Harbors Company

Date	March 29, 2020	**Aircraft**	CFKMA
Project	3186 QSI Powder River	**Pilot**	N. Emson
Location	Sheridan, WY	**Operator**	B. Eisenbart
Mission Objective	Weather: KAR location:		

System LMS-1560	
Unit 64	
IMU Applanix	
GPS Rx Trimble	
Scanner 1 Drive	
Scanner 2 Drive	

Additional Notes

29.1 - today = hrs to 100hr

Time to next maintenance: _____ ☐ 50 hr ☐ 100 hr

Aircraft Block Time		
Engine On 14:53	**Takeoff**	
Engine Off 21:56	**Landing**	
Total 7.1 hrs	**Total** 6.5 hrs	

Mission Plan			
AGL Height 2000	m	**Pulse Rate** 500	
Target Speed 160	kts	**Scan Rate** 109Hz	
Laser Current 100	%	**FOV**	60 degs

Static Alignment	GPS Time Start	GPS Time End
Pre Mission	14:56	15:01
Post Mission	21:49	21:54

Flight Line	LiDAR File Name	Flight Direction	GPS Time Start	GPS Time End	Line Aborted Time	Line Aborted nmi to End	Mission ID Time Stamp 200422	Comments
TEST			1516	1516			161538	
F8			1533	1538				
XTIE			1538	1548			153905	
3027			1552	1606			155257	
3026			1610	1623			161002	
3025			1626	1639			162625	
3024			1643	1657			164316	
3023			1700	1714			170002	
3022			1716	1730			171635	
3021			1732	1745			173042	
3020			1748	1801			174858	
3019			1806	1819			180603	
3018			1822	1836			182249	
3017			1839	1852			183922	
3016			1856	1910			185604	

Julian Day 089	Flight A

LIDAR Flight Log

AIRBORNE IMAGING
A Clean Harbors Company

Date	March 29, 2020	**Aircraft**	CFKMA
Project	3186 QSI Powder River	**Pilot**	N. Emson
Location	Sheridan, WY	**Operator**	B. Eisenbart
Mission Objective	Weather: KAR location:		

System	LMS-1560
Unit	64
IMU	Applanix
GPS Rx	Trimble
Scanner 1 Drive	
Scanner 2 Drive	

Additional Notes

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Aircraft Block Time		
Engine On 14:53	**Takeoff**	
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Mission Plan			
AGL Height 2000	m	**Pulse Rate** 500	
Target Speed 160	kts	**Scan Rate** 109Hz	
Laser Current 100	%	**FOV**	60 degs

Static Alignment	GPS Time Start	GPS Time End
Pre Mission	14:56	15:01
Post Mission	21:49	21:54

Flight Line	LiDAR File Name	Flight Direction	GPS Time Start	GPS Time End	Line Aborted Time	Line Aborted nmi to End	Mission ID Time Stamp 200422	Comments
3015			1912	1925			191222	
3014			1928	1943			192834	
3013			1945	1959			194509	
3012			2001	2015			200123	
3008			2017	2030			201752	
3007			2034	2047			203409	
3006			2050	2103			205043	
F8			2104	2109				

Julian Day 089	Flight A

LIDAR Flight Log

AIRBORNE IMAGING
A Clean Harbors Company

Date	March 29, 2020	**Aircraft**	CFKMA
Project	3186 QSI Powder River	**Pilot**	N. Emson
Location	Sheridan, WY	**Operator**	B. Eisenbart
Mission Objective	Weather: KAR location:		

System LMS-1560	
Unit 64	
IMU Applanix	
GPS Rx Trimble	
Scanner 1 Drive	
Scanner 2 Drive	

Additional Notes

29.1 - today = hrs to 100hr

Time to next maintenance: _____ ☐ 50 hr ☐ 100 hr

Aircraft Block Time			
Engine On 14:53	**Takeoff**		
Engine Off 21:56	**Landing**		
Total 7.1 hrs	**Total** 6.5 hrs		

Mission Plan			
AGL Height 2000	m	**Pulse Rate** 500	
Target Speed 160	kts	**Scan Rate** 109Hz	
Laser Current 100	%	**FOV**	60 degs

Static Alignment	GPS Time Start	GPS Time End
Pre Mission	14:56	15:01
Post Mission	21:49	21:54

Flight Line	LiDAR File Name	Flight Direction	GPS Time Start	GPS Time End	Line Aborted Time	Line Aborted nmi to End	Mission ID Time Stamp 200422	Comments
TEST			1516	1516			161538	
F8			1533	1538				
XTIE			1538	1548			153905	
3027			1552	1606			155257	
3026			1610	1623			161002	
3025			1626	1639			162625	
3024			1643	1657			164316	
3023			1700	1714			170002	
3022			1716	1730			171635	
3021			1732	1745			173042	
3020			1748	1801			174858	
3019			1806	1819			180603	
3018			1822	1836			182249	
3017			1839	1852			183922	
3016			1856	1910			185604	

Julian Day 089	Flight A

LIDAR Flight Log

AIRBORNE IMAGING
A Clean Harbors Company

Date	March 29, 2020	**Aircraft**	CFKMA
Project	3186 QSI Powder River	**Pilot**	N. Emson
Location	Sheridan, WY	**Operator**	B. Eisenbart
Mission Objective	Weather: KAR location:		

System LMS-1560	
Unit 64	
IMU Applanix	
GPS Rx Trimble	
Scanner 1 Drive	
Scanner 2 Drive	

Additional Notes

29.1 - today = hrs to 100hr

Time to next maintenance: _____ ☐ 50 hr ☐ 100 hr

Aircraft Block Time		
Engine On 14:53	**Takeoff**	
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Total 7.1 hrs	**Total** 6.5 hrs	

Mission Plan			
AGL Height 2000	m	**Pulse Rate** 500	
Target Speed 160	kts	**Scan Rate** 109Hz	
Laser Current 100	%	**FOV**	60 degs

Static Alignment	GPS Time Start	GPS Time End
Pre Mission	14:56	15:01
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Flight Line	LiDAR File Name	Flight Direction	GPS Time Start	GPS Time End	Line Aborted Time	Line Aborted nmi to End	Mission ID Time Stamp 200422	Comments
TEST			1516	1516			161538	
F8			1533	1538				
XTIE			1538	1548			153905	
3027			1552	1606			155257	
3026			1610	1623			161002	
3025			1626	1639			162625	
3024			1643	1657			164316	
3023			1700	1714			170002	
3022			1716	1730			171635	
3021			1732	1745			173042	
3020			1748	1801			174858	
3019			1806	1819			180603	
3018			1822	1836			182249	
3017			1839	1852			183922	
3016			1856	1910			185604	

Julian Day 089	Flight A

LIDAR Flight Log

AIRBORNE IMAGING
A Clean Harbors Company

Date	March 29, 2020	**Aircraft**	CFKMA
Project	3186 QSI Powder River	**Pilot**	N. Emson
Location	Sheridan, WY	**Operator**	B. Eisenbart
Mission Objective	Weather: KAR location:		

System	LMS-1560
Unit	64
IMU	Applanix
GPS Rx	Trimble
Scanner 1 Drive	
Scanner 2 Drive	

Additional Notes

Time to next maintenance: _____ ☐ 50 hr ☐ 100 hr

Aircraft Block Time		
Engine On 14:53	**Takeoff**	
Engine Off 21:56	**Landing**	
Total 7.1 hrs	**Total** 6.5 hrs	

Mission Plan			
AGL Height 2000	m	**Pulse Rate** 500	
Target Speed 160	kts	**Scan Rate** 109Hz	
Laser Current 100	%	**FOV**	60 degs

Static Alignment	GPS Time Start	GPS Time End
Pre Mission	14:56	15:01
Post Mission	21:49	21:54

Flight Line	LiDAR File Name	Flight Direction	GPS Time Start	GPS Time End	Line Aborted Time	Line Aborted nmi to End	Mission ID Time Stamp 200422	Comments
3015			1912	1925			191222	
3014			1928	1943			192834	
3013			1945	1959			194509	
3012			2001	2015			200123	
3008			2017	2030			201752	
3007			2034	2047			203409	
3006			2050	2103			205043	
F8			2104	2109				

Julian Day 089	Flight A

LIDAR Flight Log

AIRBORNE IMAGING
A Clean Harbors Company

Date	March 29, 2020	**Aircraft**	CFKMA
Project	3186 QSI Powder River	**Pilot**	N. Emson
Location	Sheridan, WY	**Operator**	B. Eisenbart
Mission Objective	Weather: KAR location:		

System LMS-1560	
Unit 64	
IMU Applanix	
GPS Rx Trimble	
Scanner 1 Drive	
Scanner 2 Drive	

Additional Notes

29.1 - today = hrs to 100hr

Time to next maintenance: _____ ☐ 50 hr ☐ 100 hr

Aircraft Block Time		
Engine On 14:53	**Takeoff**	
Engine Off 21:56	**Landing**	
Total 7.1 hrs	**Total** 6.5 hrs	

Mission Plan			
AGL Height 2000	m	**Pulse Rate** 500	
Target Speed 160	kts	**Scan Rate** 109Hz	
Laser Current 100	%	**FOV**	60 degs

Static Alignment	GPS Time Start	GPS Time End
Pre Mission	14:56	15:01
Post Mission	21:49	21:54

Flight Line	LiDAR File Name	Flight Direction	GPS Time Start	GPS Time End	Line Aborted Time	Line Aborted nmi to End	Mission ID Time Stamp 200422	Comments
TEST			1516	1516			161538	
F8			1533	1538				
XTIE			1538	1548			153905	
3027			1552	1606			155257	
3026			1610	1623			161002	
3025			1626	1639			162625	
3024			1643	1657			164316	
3023			1700	1714			170002	
3022			1716	1730			171635	
3021			1732	1745			173042	
3020			1748	1801			174858	
3019			1806	1819			180603	
3018			1822	1836			182249	
3017			1839	1852			183922	
3016			1856	1910			185604	

Julian Day 089	Flight A

LIDAR Flight Log

AIRBORNE IMAGING
A Clean Harbors Company

Date	March 29, 2020	**Aircraft**	CFKMA
Project	3186 QSI Powder River	**Pilot**	N. Emson
Location	Sheridan, WY	**Operator**	B. Eisenbart
Mission Objective	Weather: KAR location:		

System	LMS-1560
Unit	64
IMU	Applanix
GPS Rx	Trimble
Scanner 1 Drive	
Scanner 2 Drive	

Additional Notes

Time to next maintenance: _____ ☐ 50 hr ☐ 100 hr

Aircraft Block Time		
Engine On 14:53	**Takeoff**	
Engine Off 21:56	**Landing**	
Total 7.1 hrs	**Total** 6.5 hrs	

Mission Plan			
AGL Height 2000	m	**Pulse Rate** 500	
Target Speed 160	kts	**Scan Rate** 109Hz	
Laser Current 100	%	**FOV**	60 degs

Static Alignment	GPS Time Start	GPS Time End
Pre Mission	14:56	15:01
Post Mission	21:49	21:54

Flight Line	LiDAR File Name	Flight Direction	GPS Time Start	GPS Time End	Line Aborted Time	Line Aborted nmi to End	Mission ID Time Stamp 200422	Comments
3015			1912	1925			191222	
3014			1928	1943			192834	
3013			1945	1959			194509	
3012			2001	2015			200123	
3008			2017	2030			201752	
3007			2034	2047			203409	
3006			2050	2103			205043	
F8			2104	2109				

Julian Day 120	Flight A

LIDAR Flight Log

AIRBORNE IMAGING
A Clean Harbors Company

Date 4/29/2020	**Aircraft** CFFRY
Project 3186_QSI_PowderRiver_QL2	**Pilot** J.MATHIESON
Location KSHR	**Operator** C.EDGAR
Mission Objective	

System VQ-1560I
Unit 38
IMU Applanix
GPS Rx Trimble
Scanner 1 Drive
Scanner 2 Drive

Additional Notes

Time to next maintenance: _____ ☐ 50 hr ☐ 100 hr

Aircraft Block Time		
Engine On 15:01	**Takeoff** 15:17	
Engine Off 21:40	**Landing** 21:28	
Total 6.7 hrs	**Total** 6.2 hrs	

Mission Plan			
AGL Height 2000	m	**Pulse Rate** 500	
Target Speed 160	kts	**Scan Rate** 109Hz	
Laser Current 100	%	**FOV** 60	degs

Static Alignment	GPS Time Start	GPS Time End
Pre Mission	15:03	15:08
Post Mission	21:33	21:38

Flight Line	LiDAR File Name	Flight Direction	GPS Time Start	GPS Time End	Line Aborted Time	Line Aborted nmi to End	Mission ID Time Stamp 200429	Comments
F8			1540	1546				
XTIE	382012001		1547	1556			154700	
4066	382012002		1600	1611			160031	
4065	382012003		1615	1627			161528	
4064	382012004		1629	1641			162947	
4063	382012005		1644	1656			165904	
4062	382012006		1659	1710			165904	
4061	382012007		1713	1724			171334	
4060	382012008		1727	1728			172737	
4059	382012009		1741	1751			174122	
4058	382012010		1754	1805			175448	
4057	382012011		1808	1818			480846	
4056	382012012		1821	1830			182126	
4055	382012013		1833	1845			183344	
4054	382012014		1847	1900			184728	

Julian Day 120	Flight A

LIDAR Flight Log

AIRBORNE IMAGING
A Clean Harbors Company

Date 4/29/2020	**Aircraft** CFFRY
Project 3186_QSI_PowderRiver_QL2	**Pilot** J.MATHIESON
Location KSHR	**Operator** C.EDGAR
Mission Objective	

System VQ-1560I
Unit 38
IMU Applanix
GPS Rx Trimble
Scanner 1 Drive
Scanner 2 Drive

Additional Notes

Time to next maintenance: _____ ☐ 50 hr ☐ 100 hr

Aircraft Block Time		
Engine On 15:01	**Takeoff** 15:17	
Engine Off 21:40	**Landing** 21:28	
Total 6.7 hrs	**Total** 6.2 hrs	

Mission Plan			
AGL Height 2000	m	**Pulse Rate** 500	
Target Speed 160	kts	**Scan Rate** 109Hz	
Laser Current 100	%	**FOV** 60	degs

Static Alignment	GPS Time	
	Start	**End**
Pre Mission	15:03	15:08
Post Mission	21:33	21:38

Flight Line	LiDAR File Name	Flight Direction	GPS Time		Line Aborted		Mission ID Time Stamp 200429	Comments
			Start	End	Time	nmi to End		
4053	382012015		1903	1916			190346	
4052	382012016		1919	1933			191945	
4051	382012017		1935	1950			193544	
4050	382012018		1952	2006			195205	
4049	382012019		2008	2023			200848	
4048	382012020		2025	2039			202546	
4047	382012021		2042	2055			204216	
F8			2056	2101				

Julian Day 089	Flight A

LIDAR Flight Log

AIRBORNE IMAGING
A Clean Harbors Company

Date	March 29, 2020	**Aircraft**	CFKMA
Project	3186 QSI Powder River	**Pilot**	N. Emson
Location	Sheridan, WY	**Operator**	B. Eisenbart
Mission Objective	Weather: KAR location:		

System LMS-1560	
Unit 64	
IMU Applanix	
GPS Rx Trimble	
Scanner 1 Drive	
Scanner 2 Drive	

Additional Notes

29.1 - today = hrs to 100hr

Time to next maintenance: _____ ☐ 50 hr ☐ 100 hr

Aircraft Block Time			
Engine On 14:53	**Takeoff**		
Engine Off 21:56	**Landing**		
Total 7.1 hrs	**Total** 6.5 hrs		

Mission Plan			
AGL Height 2000	m	**Pulse Rate** 500	
Target Speed 160	kts	**Scan Rate** 109Hz	
Laser Current 100	%	**FOV**	60 degs

Static Alignment	GPS Time Start	GPS Time End
Pre Mission	14:56	15:01
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XTIE			1538	1548			153905	
3027			1552	1606			155257	
3026			1610	1623			161002	
3025			1626	1639			162625	
3024			1643	1657			164316	
3023			1700	1714			170002	
3022			1716	1730			171635	
3021			1732	1745			173042	
3020			1748	1801			174858	
3019			1806	1819			180603	
3018			1822	1836			182249	
3017			1839	1852			183922	
3016			1856	1910			185604	