Elkhorn Mine & Mill LiDAR Mapping Report

Site:

Elkhorn Mine and Mill near Coolidge, MT

Project Location:

Area approximately 20 miles south of Wise River, MT

and 15 miles north or Polaris, MT near the Coolidge ghost town

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Referenced Files and Folders

File/Folder Name	Description
Elkhorn Mine & Mill LiDAR Report.PDF	This document. Details the data collection methods, processing procedures, and final quality evaluation of the LiDAR products.
Elkhorn Mine & Mill LiDAR Map Cert.PDF	Details the data collection testing methods and accuracy result.
Elkhorn Mine & Mill QA-QC Report.PDF	Details the QA/QC summary of field and office procedures.
Classified LAS *(folder)*	Tiled LAS 1.2 point cloud files. Point clouds are classified into the following classes: default, ground, model keypoints. Tiles are 300MB maximum.
Filtered LAS *(folder)*	Tiled LAS 1.2 point cloud files of only the model keypoints class. Tiles are 300MB maximum.
Tiling Grid *(folder)*	Linework used to create the point cloud tiles in shapefile format. Also contains a PDF map.
Elkhorn Mine and Mill LiDAR Truthing.XLSX	All truthing points used to control the point cloud

Summary

DJ&A, P.C. was contracted by the Big Hole Watershed Committee (BHWC) to complete LiDAR acquisition and topographic mapping for an abandoned mine and mill area approximately 1,972 acres in size surrounding the Coolidge, MT ghost town. The vertical accuracy of the LiDAR data meets or exceeds absolute vertical accuracy level 1 (USGS LBS QL1) for the acquisition area. This report details the acquisition methods, processing methods, and results of the quality control check performed on the final point cloud products.

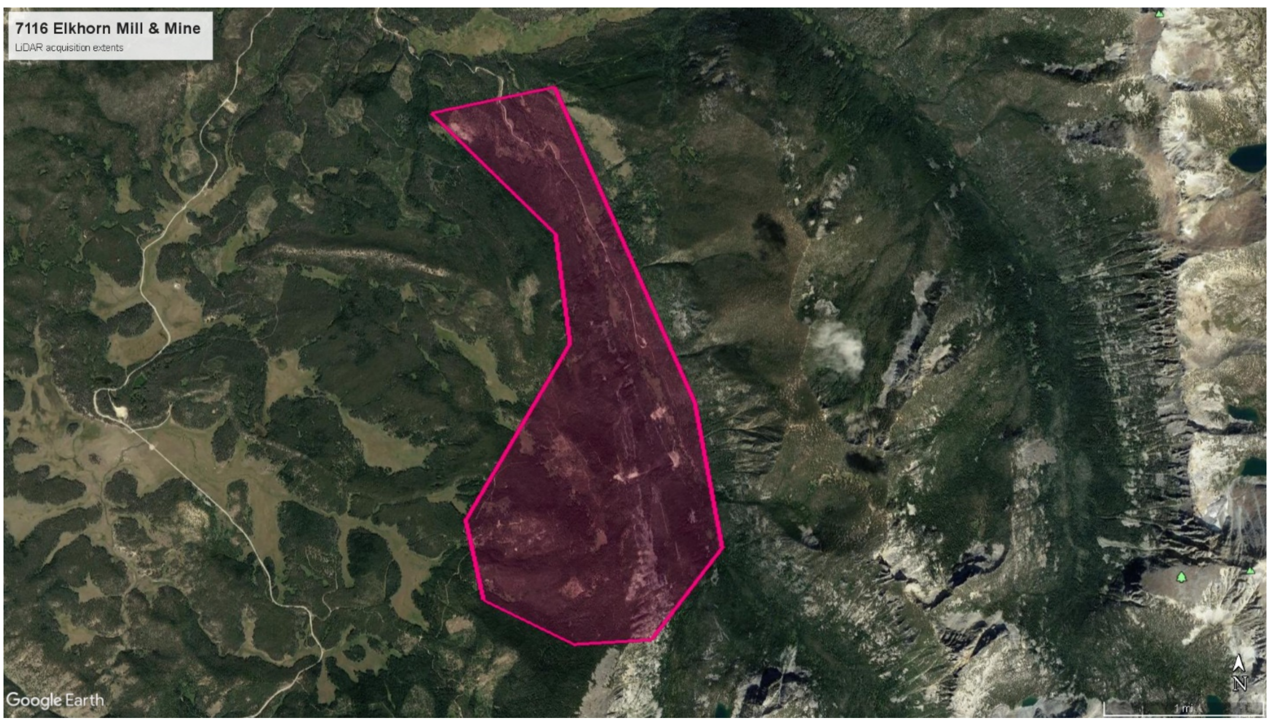

Figure 1. Elkhorn Mine and Mill LiDAR acquisition extents.

Data Collection Methods

LiDAR data was acquired using a Leica Geosystems CityMapper with Hyperion 2 LiDAR system. Data collection flights utilized for processing of final products are shown in the following table. DJ&A, P.C. collected ground shots throughout the site with Trimble R10 GNSS RTK receivers to serve as truthing points for the LiDAR point clouds.

Data Collection Flight	Date	Sensor Type	Sensor Start Time	Sensor Stop Time
Flight 1	July 21, 2020	Leica CityMapper w/ Hyperion 2 LiDAR	10:22AM MDT	12:58PM MDT

Table 1. LiDAR data collection flight information.

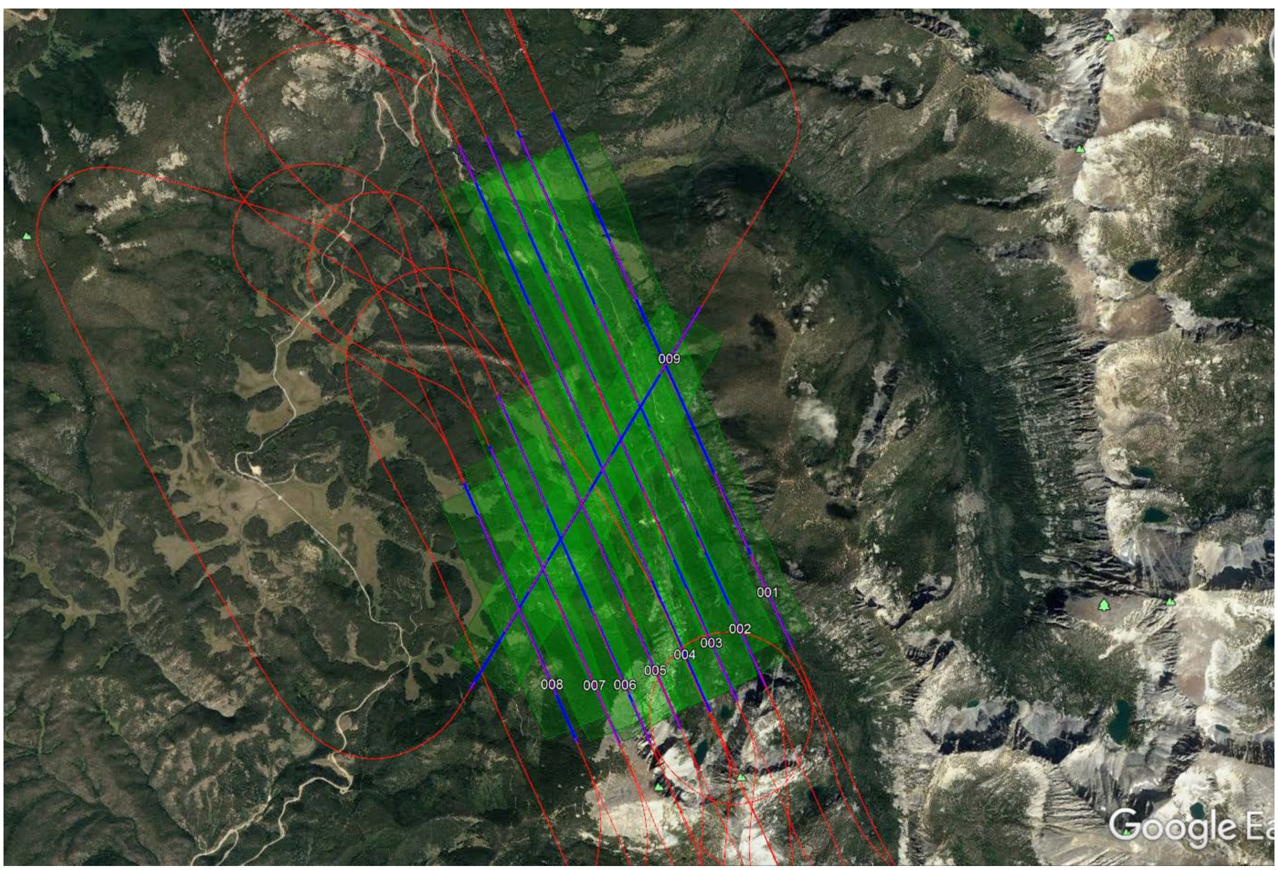

Figure 2. A total of nine flight lines were executed for LiDAR acquisition. Eight parallel lines and a ninth passing through the others.

GNSS Processing and Control

Two control points were utilized to control the airborne flight lines. Control points 1, 2, and 3, being 2 ½" aluminum caps stamped "DJ&A" on a 5/8" x 30" rebar, were set by DJ&A, P.C. for this project. Control points 1 and 3 were used to control LiDAR data. Point 2 was set for future site topographic survey need.

Geospatial Parameters

Parameter	Specification
Horizontal Datum	NAD83 (2011) (Epoch: 2010.0000)
Horizontal Projection	Montana State Plane
Vertical Datum	NAVD88
Geoid Model	Geoid 18
Horizontal Units	International Feet (SI)
Vertical Units	U.S. Survey Feet

Table 2. Project geospatial parameters.

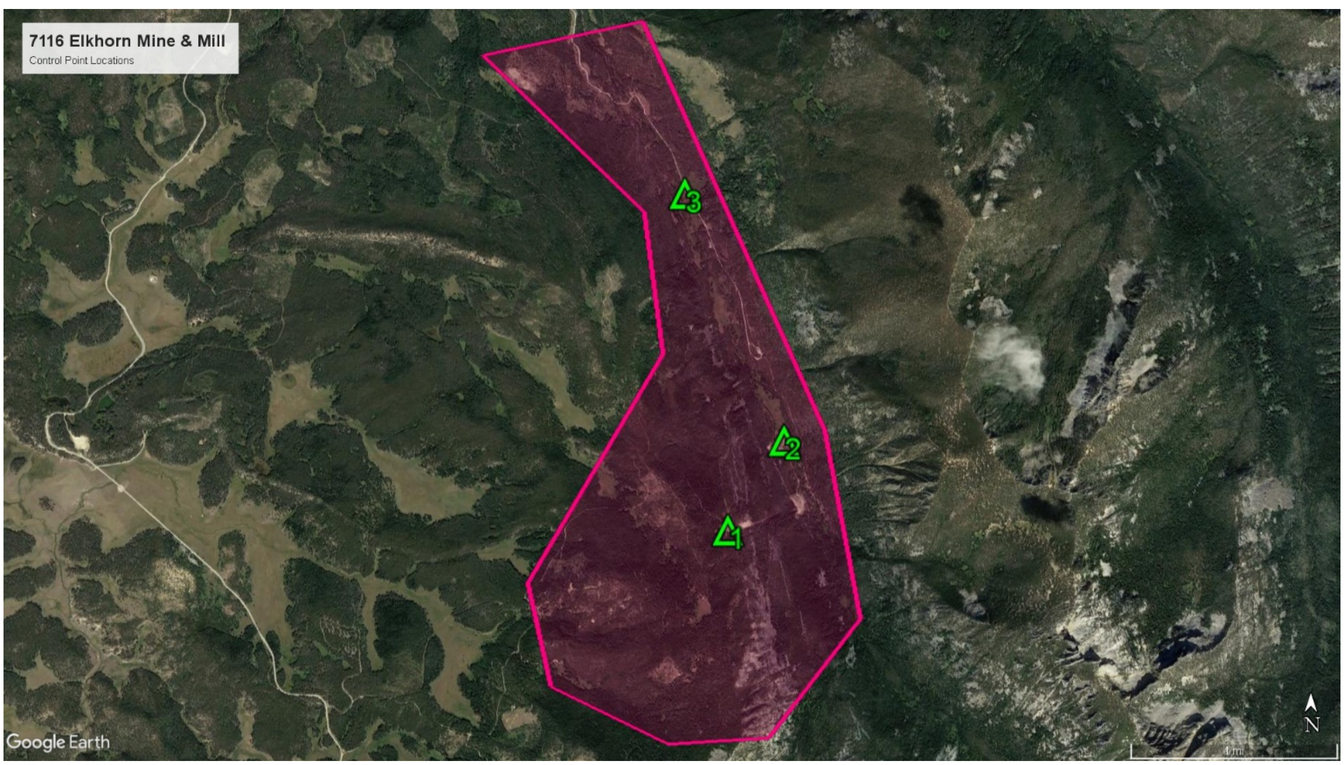

Figure 3. Control points set for LiDAR acquisition. Control points 1 and 3 were used to control LiDAR products. Control point 2 was set for future survey related tasks.

Trajectory Processing

Aerial (aerial, terrestrial, aquatic, etc.) LiDAR systems utilize a combination of GNSS and INS (Inertial Navigation System) systems to record information that allow the sensor's movement path through space to be determined. For each data collection run, the GNSS and inertial datasets are combined using PPK (Post Processing Kinematic) methods. Novatel Inertial Explorer is used to compute a fixed-bias carrier phase solution in both the forward and reverse chronological directions to resolve final SBETs (Smooth Best Estimate Trajectories) of the sensor's movement. These trajectories are the accurate and precise paths that the sensor moved along during data collection runs. The routine in Inertial Explorer also provides a file containing refined attitude data. High quality trajectories are critical for creating accurate survey products from LiDAR data.

Figures 4 and 5 show the quantity of GNSS satellites and PDOP observed during data collection runs, respectively. Brief changes in satellite numbers and occasional spikes in PDOP are normal and expected. GNSS satellite quantities of 6 or more are considered acceptable. PDOP at or below 4.0 is considered acceptable.

Figures 6, showing the linear separation between the sensor's GNSS and INS paths, is used to evaluate the quality of the final trajectories created by combining both datasets. The linear separations are shown in X, Y, Z (displayed as East, North, Elevation). GNSS and INS determined positions should be in close agreement with each other for a final trajectory to be considered high quality. X, Y, Z separation magnitudes of 0.02m or less are considered acceptable.

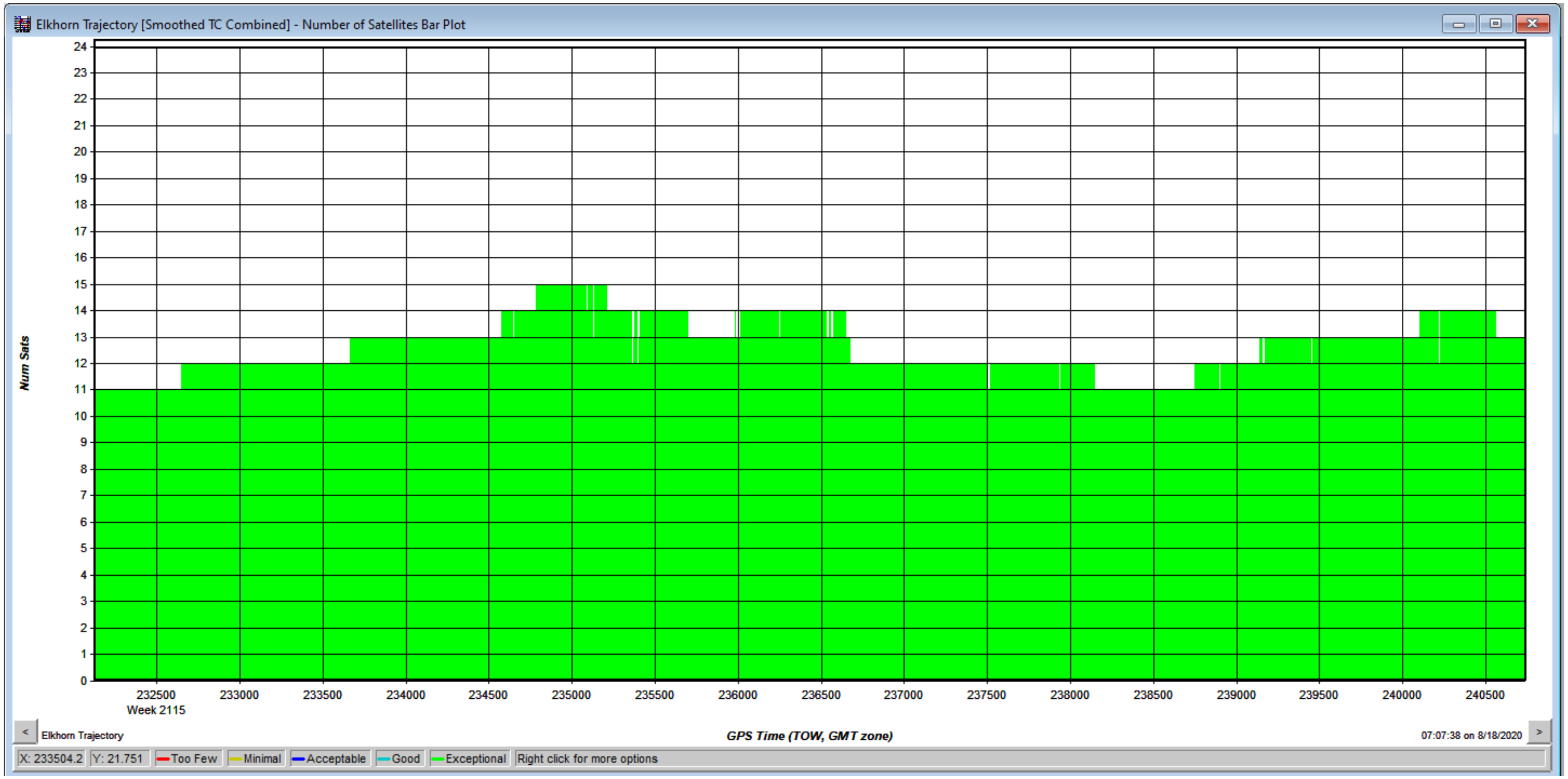

Figure 4. GNSS satellite quantities observed during data collection flight.

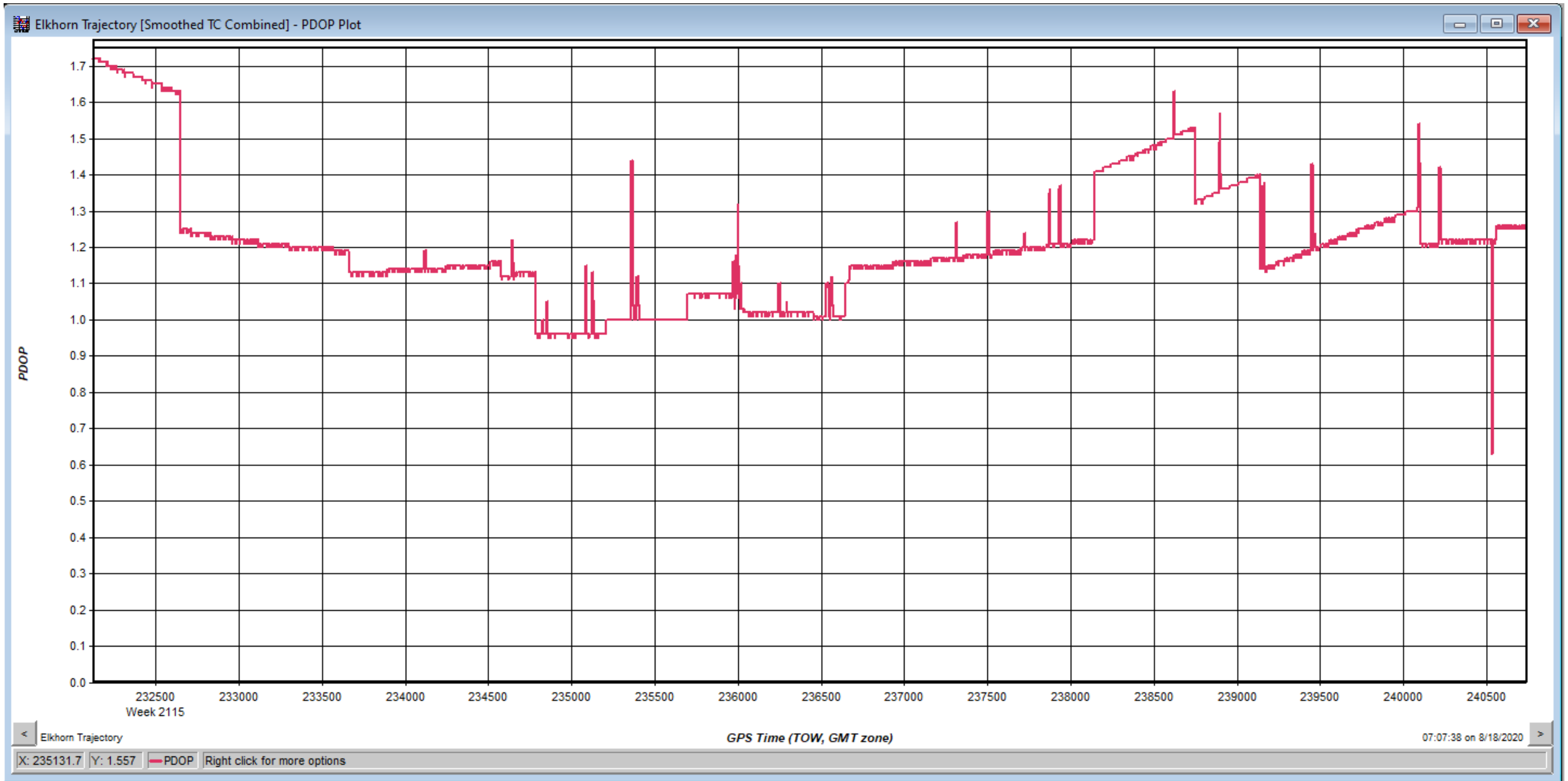

Figure 5. PDOP observed during data collection flight.

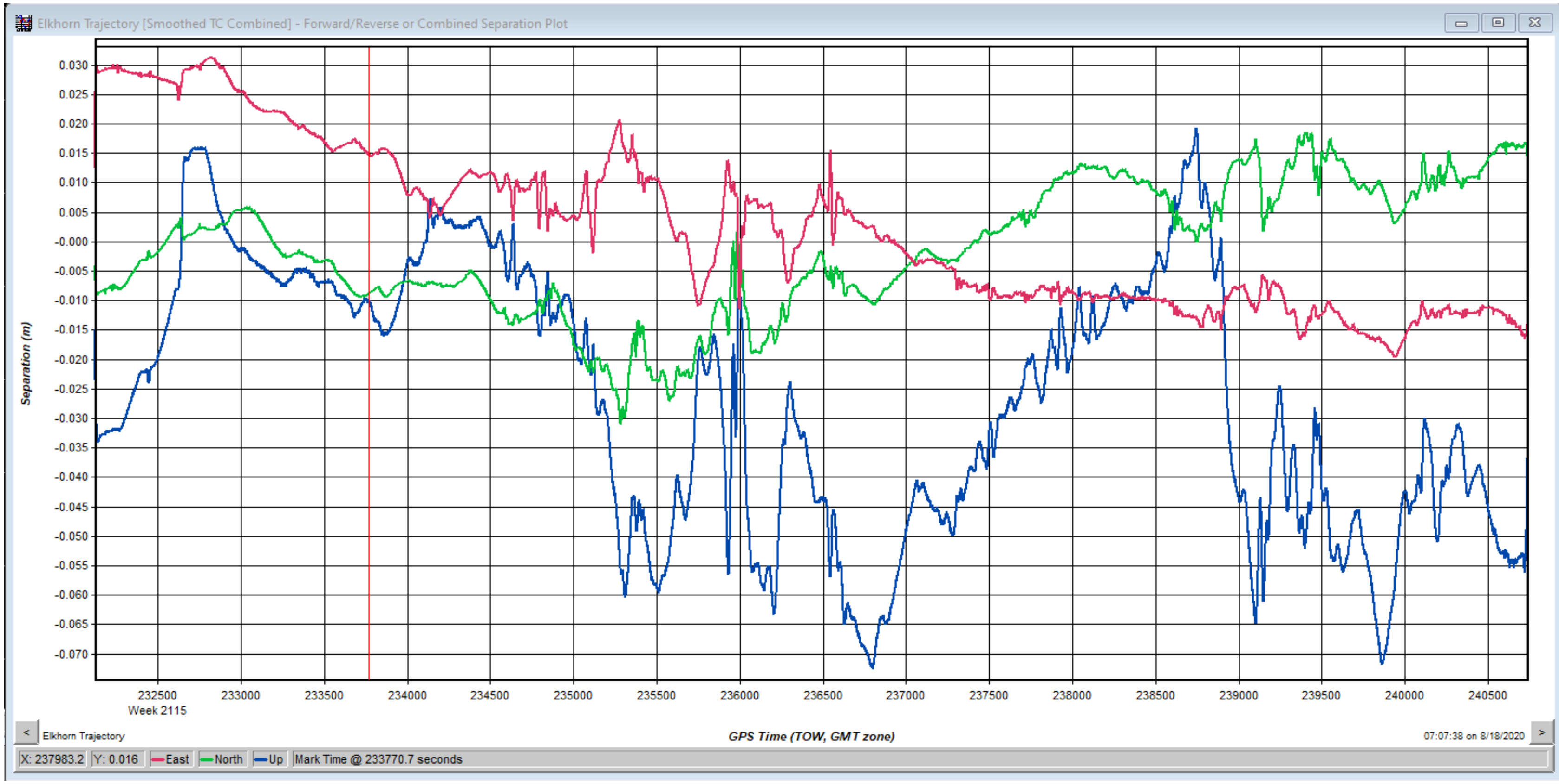

Figure 6. Linear separation between GNSS and INS trajectories. Red, green, and blue show easting, northing, and elevation separations, respectively.

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LiDAR Point Cloud Processing

After processing finalized trajectories for each data acquisition flight in Inertial Explorer, the final trajectories, refined attitude data, and raw LiDAR returns are combined in Leica Geosystems HxMap 2.7.0 to generate laser point positions in 3D space. The Hyperion 2 LiDAR sensor provides multiple returns from each laser pulse. This ensures a high likelihood of obtaining a return from the ground in each pulse, even in densely vegetated areas.

These point clouds and the finalized trajectories are used in the Terra Solid Mapping Suite to rectify point clouds from different flight lines, classify the point clouds, and obtain a ground solution of the unified cloud for surface generation. Point clouds from each data trajectory (corresponding to the different data collection flightlines) are rectified with each other by comparing areas of overlap between the clouds. A series of algorithms is used to find common geometry between the clouds, determine the geometric transformations required to fit the clouds together, and apply appropriate transformations. Iterative applications of this process eventually yield a single unified cloud with high internal (relative) accuracy. Once this unified cloud is created, a grounding algorithm is applied to classify ground points and model keypoints across the project area. Additional classification routines may be used in a similar manner to generate additional classes. Grounding and classification algorithms are customized for each project based on the terrain, vegetation, and other features. The technician may utilize a variety of standard and custom routines to rectify and classify point clouds.

After auto-generated ground and model keypoints classes are obtained, point clouds are reviewed by a technician to remove anomalies and artifacts still present. During this cleaning stage, the technician also verifies that the final point cloud is consistent and complete with no unexpected voids. Finally, a randomly generated subset of the truthing points is imported to compare to a surface interpolated from the model key points. A uniform vertical shift is applied to bring the point cloud into better alignment with the subset of truthing points. This improves global accuracy. As a final quality check, the remaining truthing points are imported and a statistics report is generated to evaluate how well the control-shifted point cloud aligns with these remaining points. The points used for the uniform vertical shift and final quality check are provided in the CSV files included with this submission. Results of the quality check are provided below.

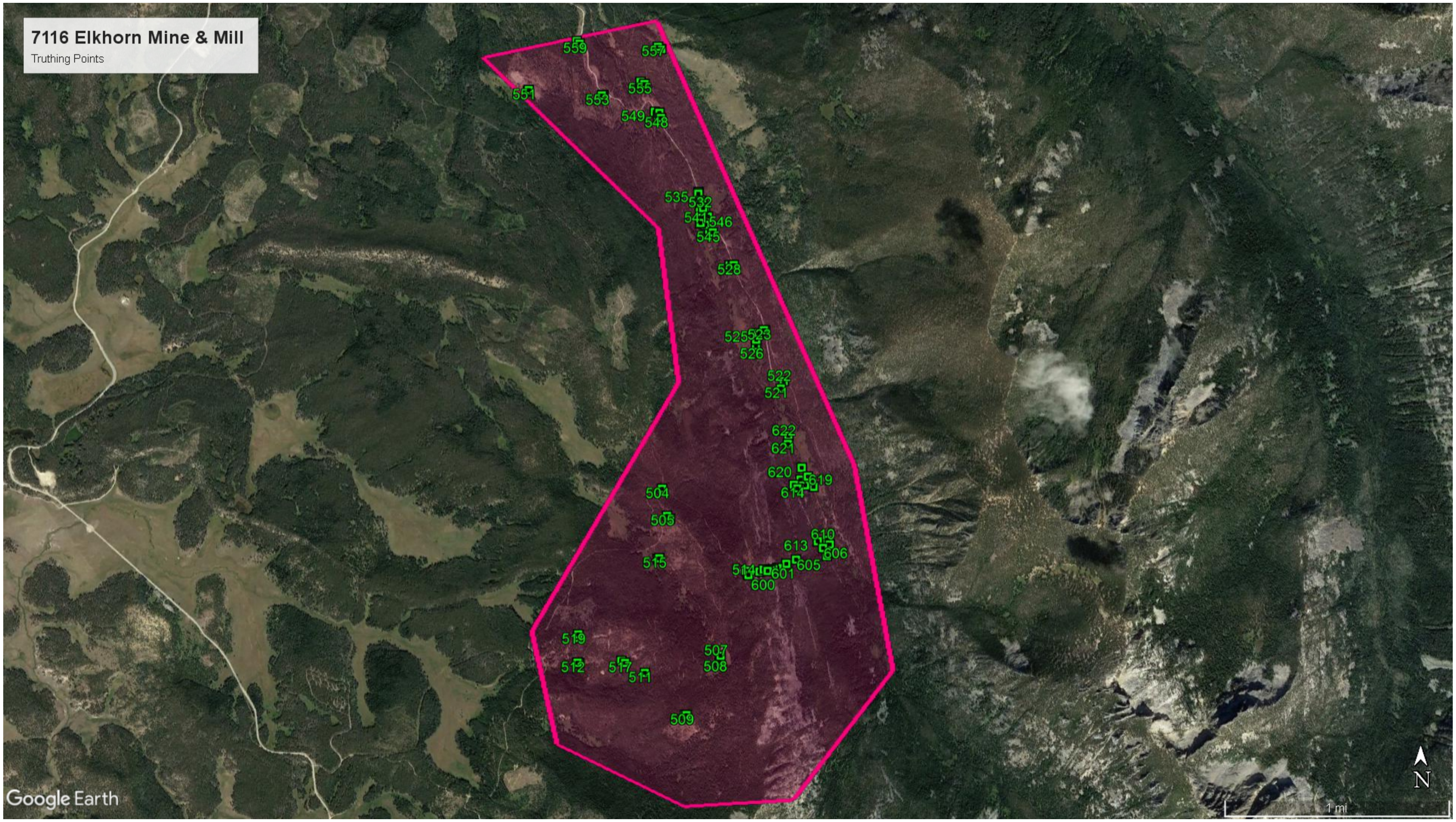

Figure 7. Distribution of all truthing shots across LiDAR acquisition area.

Final Point Cloud Quality Reports

Parameter	Value	
General Point Cloud Information		
Total Number of Points (all classes)	1,193,273,896	100%
Ground Points Quantity	381,432,237	32.0%
Model Keypoints Quantity	13,303,298	1.1%
Default (unclassified) Points Quantity	798,538,361	66.9%
Average Total Point Density Across Project *(all classes)* *[ppsm = points per square meter]*	149.5 ppsm	
Average Surface Point Density Across Project *(ground + model key points)* *[ppsm = points per square meter]*	49.5 ppsm	
Project Truthing Information	***Vertical Units: U.S. Survey Feet***	
Vertical Accuracy Class Tested	19.6cm (USGS LBS QL1 NVA)	
Elevation Delta Calculation Method	Interpolated from TIN surface	
LiDAR Classifications Included	Model Key Points	
Total Quantity of Truthing Points	83	
Quantity of Truthing Points used for Final Quality Report	18	
Final Quality Report	***Vertical Units: U.S. Survey Feet***	
Average Vertical Error	-0.079	
Maximum (highest) Vertical Error	+0.256	
Minimum (lowest) Vertical Error	-0.384	
Average Magnitude Vertical Error	±0.181	
Vertical Accuracy RMSE(z)	±0.218	
Standard Deviation of Vertical Error	±0.203	
Vertical Accuracy NSSDA (95% Confidence)	0.426	

Table 3. Statistics on Elkhorn Mine and Mill LiDAR point cloud, truthing shots, and results of the final point cloud quality report.

Truthing Points used for Final Quality Report

Point Number	Northing	Easting	GNSS Z (U.S. Survey Feet)	LiDAR Z (U.S. Survey Feet)	Dz (U.S. Survey Feet)
501	472294.91	1059450.29	8169.61	8169.75	+0.14
506	473639.84	1057692.49	8303.12	8303.38	+0.26
510	469046.56	1057830.21	8641.25	8641.37	+0.12
516	472718.51	1057361.81	8223.53	8223.78	+0.25
522	476728.75	1060499.87	7389.33	7389.29	-0.04
525	477873.25	1059950.80	7333.37	7333.10	-0.27
529	479477.84	1059429.30	7334.72	7334.69	-0.04
549	480625.44	1058768.30	7297.55	7297.53	-0.02
552	483760.82	1054814.22	7402.54	7402.16	-0.38
556	483858.28	1057461.52	7252.87	7252.99	+0.12
557	484660.01	1057904.65	7413.95	7413.67	-0.28
558	484603.70	1057979.59	7411.04	7411.06	+0.02
560	484878.30	1056009.21	7267.16	7267.01	-0.15
601	472331.46	1059990.98	8052.34	8052.04	-0.30
603	472379.08	1060156.43	7978.02	7977.70	-0.32
605	472553.82	1060600.95	7852.67	7852.49	-0.18
608	472715.54	1061379.42	7506.90	7506.55	-0.35
611	472935.90	1061250.40	7514.62	7514.63	+0.01

Table 4. All points used to calculate final quality check statistics.