Nature Conservancy, MT Lidar
312019288

Lidar Report

January, 2020

EXECUTIVE SUMMARY

The Nature Conservancy (TNC) contracted with The Sanborn Map Company, Inc. (Sanborn) to provide remote sensing services for Montana in the form of lidar. Utilizing a multi-return system, Light Detection and Ranging (Lidar) detects 3-dimensional positions and attributes to form a point cloud. The high accuracy airborne system is integrated with both Global Navigation Satellite System (GNSS) and an Inertial Measure Unit (IMU) for accurate position and orientation. Acquisition of the project area's ~69.5mi² was completed on October 25th, 2019.

The Leica TerrainMapper was used to collect data for the aerial survey campaign. The sensor is attached to the aircraft's underside and emits rapid laser pulses that are used to calculate ranges between the aircraft and subsequent terrain below. The Airborne Lidar System (ALS) is boresighted by completing multiple passes over a known ground surface before the project acquisition. During data processing, the system calibration parameters are updated and used during post-processing of the lidar point cloud.

Differential GNSS unit in aircraft sampled positions at 2Hz or higher frequency. Lidar data was only acquired when GNSS PDOP is ≤4 and at least 6 satellites are in view. Collection conditions were for leaf-off vegetation. The atmosphere was free of clouds and fog between the aircraft and ground. The ground was free of snow and extensive flooding or any other type of inundation

The contents of this report summarize the methods used to establish the base station coordinates, perform the lidar data acquisition and processing as well as the results of these methods.

CONTENTS

1.0 INTRODUCTION

This document contains the technical write-up of the lidar campaign, including system calibration techniques, and the collection and processing of the lidar data.

1.1 Contact Information

Questions regarding the technical aspects of this report should be addressed to:

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1.2 Purpose of Lidar Acquisition

The objective of this project is to collect accurate measurements of the bare-earth surface as well as above ground features to be provided as geometric inputs for surface and/or change modeling as is relates survey assessments.

1.3 Project Location

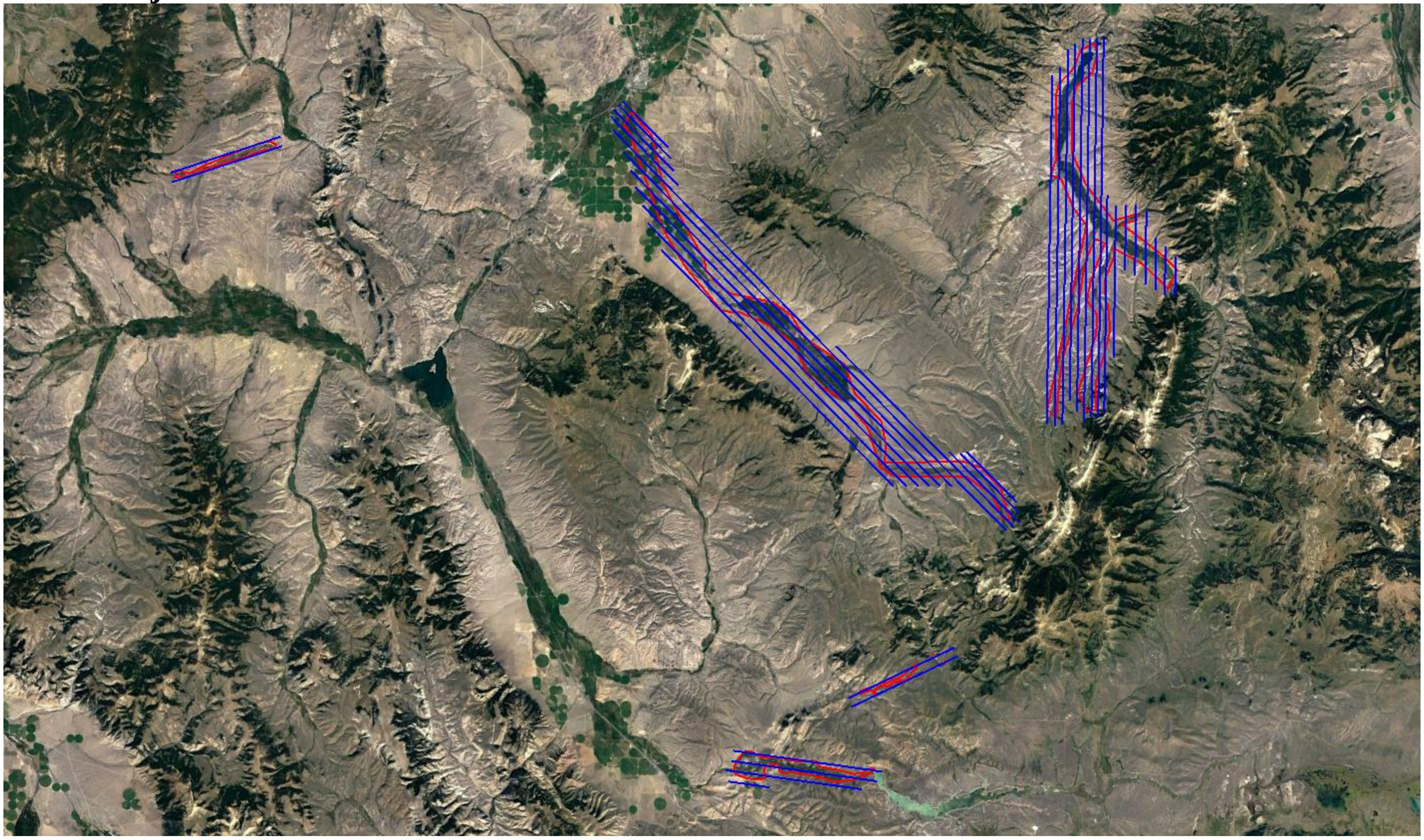

Figure 1: AOI and Trajectories As-Flown

2.0 ACQUISITION

2.1 Introduction

This section outlines the lidar system, flight reporting and data acquisition methodology used during the collection of the Montana lidar campaign. Although Sanborn conducts all lidar missions with the same rigorous and strict procedures and processes, all lidar collections are unique.

2.2 Acquisition Parameters

Sanborn specifically defined the collection parameters to accomplish the desired project specifications. **Table 1** shows the planned acquisition parameters utilized for this aerial survey with the sensor(s) installed.

Planned Acquisition Parameters	
Sensor	Leica TerrainMapper
Aircraft	N603ET - CESSNA TU205F
Flying Height (AGL)	1764
Air Speed (kts)	145
Field of View (degrees)	40
Overlap (%)	20
Pulse Rate (kHz)	1251.4
Scan Rate (Hz)	150
Laser Footprint (m)	0.42
Mode (PIA)	Gateless
Point Spacing (m)	0.35
Point Density (pls/m²)	8.29
Swath Width (m)	1284

Table 1: Lidar Acquisition Parameters

2.3 Field Work Procedures

Sanborn's standard procedure before every mission is to perform pre-flight checks to ensure correct operation of all systems. All cables were checked and the sensor head glass was cleaned. A three minute static session was conducted on the ground with the engines running prior to take-off in order to establish fine-alignment of the IMU and to resolve GNSS ambiguities.

The project acquisition consisted of four (4) mission(s). During the data collection, the operator recorded information on log sheets which includes weather conditions, lidar operation parameters, flight line statistics and PDOP.

Preliminary data processing was performed in the field immediately following the missions for quality control of GNSS data and to ensure sufficient coverage of the project AOI. Any problematic data could then be re-flown immediately as required. Final data processing was completed in the Colorado Springs, CO office. **Table 2** below shows the flight acquisition metrics for the entire collection. **Table 3** contains the base station names and locations in operation during acquisition. Base station coordinates are provided in NAD83 (2011), Geographic Coordinate System, Ellipsoid, Meters.

Date	Sensor	Serial #	Tail #	MissionID	PDOP	Start (UTC)	End (UTC)
10/24/2019	Leica TerrainMapper	TM91520	N603ET	20191024A	1.0	16:47:24	17:28:36
10/24/2019	Leica TerrainMapper	TM91520	N603ET	20191024B	1.0	17:33:18	18:31:31
10/25/2019	Leica TerrainMapper	TM91520	N603ET	20191025A	1.0	15:29:09	20:32:33
10/25/2019	Leica TerrainMapper	TM91520	N603ET	20191025B	1.0	21:00:24	0:39:20

Table 2: Collection Date Time by Mission

Designation	Type	PID	Latitude (N)	Longitude (W)	Elevation
DILLPORT	NGS	QY0663	45 15 17.05644	112 33 3.58996	1579.232

Table 3: GNSS Reference Station Coordinates

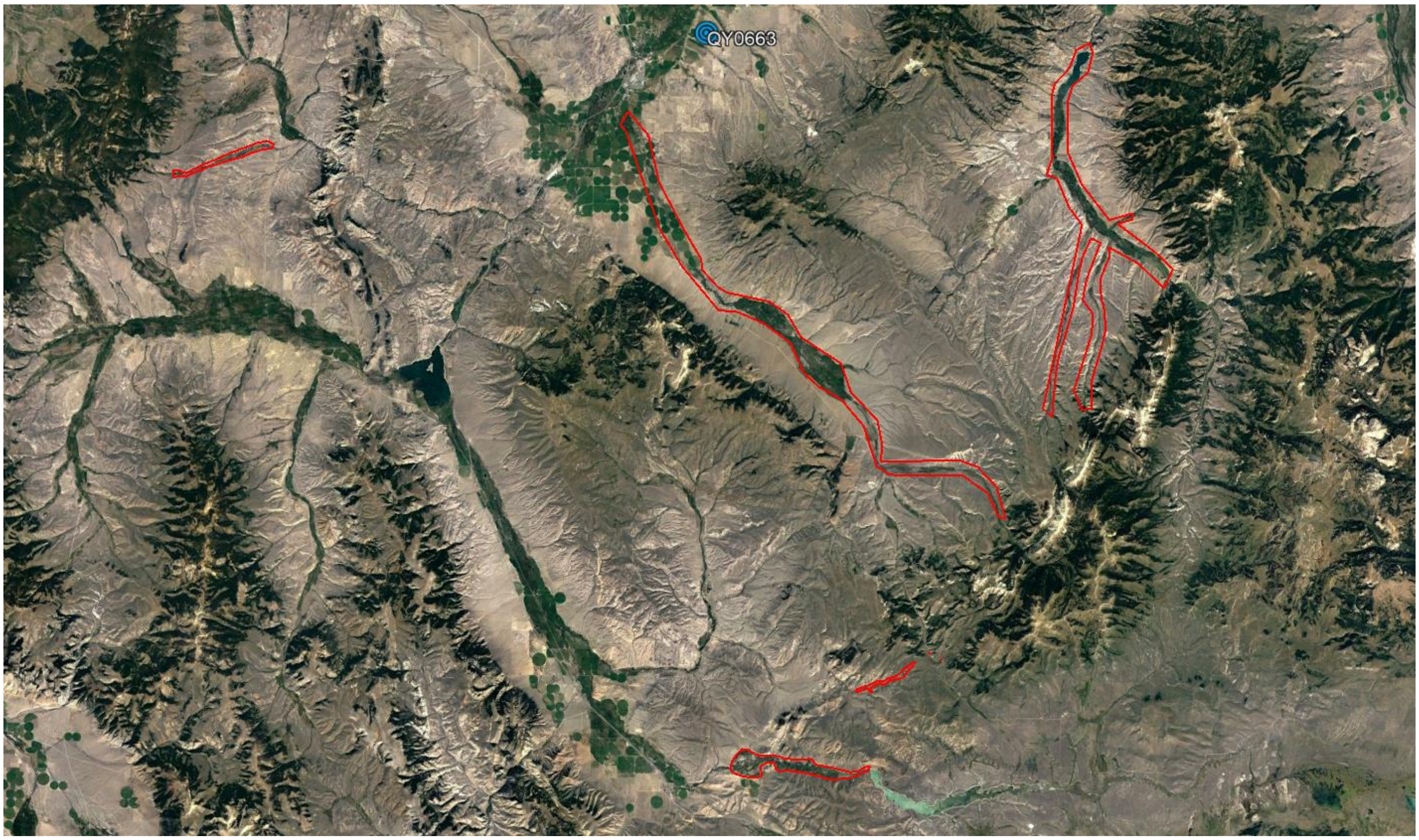

Figure 2: GNSS Reference Stations

3.0 PROCESSING

3.1 Introduction

The GNSS/IMU data was post-processed using Waypoint Inertial Explorer software to create Smoothed Best Estimate Trajectory (SBET) file(s). The SBET was then combined with the laser range measurements in Leica HxMapsoftware to produce the 3-dimensional coordinates resulting in an accurate set of Raw Point Cloud (RPC) mass points. These raw swath (*.las) files are output in WGS84, UTM, Ellipsoid, Meters and transformed to the project Coordinate Reference System (CRS) upon ingest into GeoCue before project wide lidar matching.

The Leica HxMap pre-processing software created raw swath files with all return values. This multi-return information was processed and classified to obtain the required feature for delivery. All lidar data is processed using the ASPRS binary LAS format version 1.4. **Table 4** illustrates the achieved point cloud statistics.

Category	Value
Aggregate Total Points	3,476,994,140
Aggregate Nominal Pulse Spacing (m)	0.25
Aggregate Nominal Pulse Density (pls/m²)	15.4
Aggregate Nominal Pulse Spacing (ft)	0.84
Aggregate Nominal Pulse Density (pls/ft²)	1.4

Table 4: Point Cloud Statistics

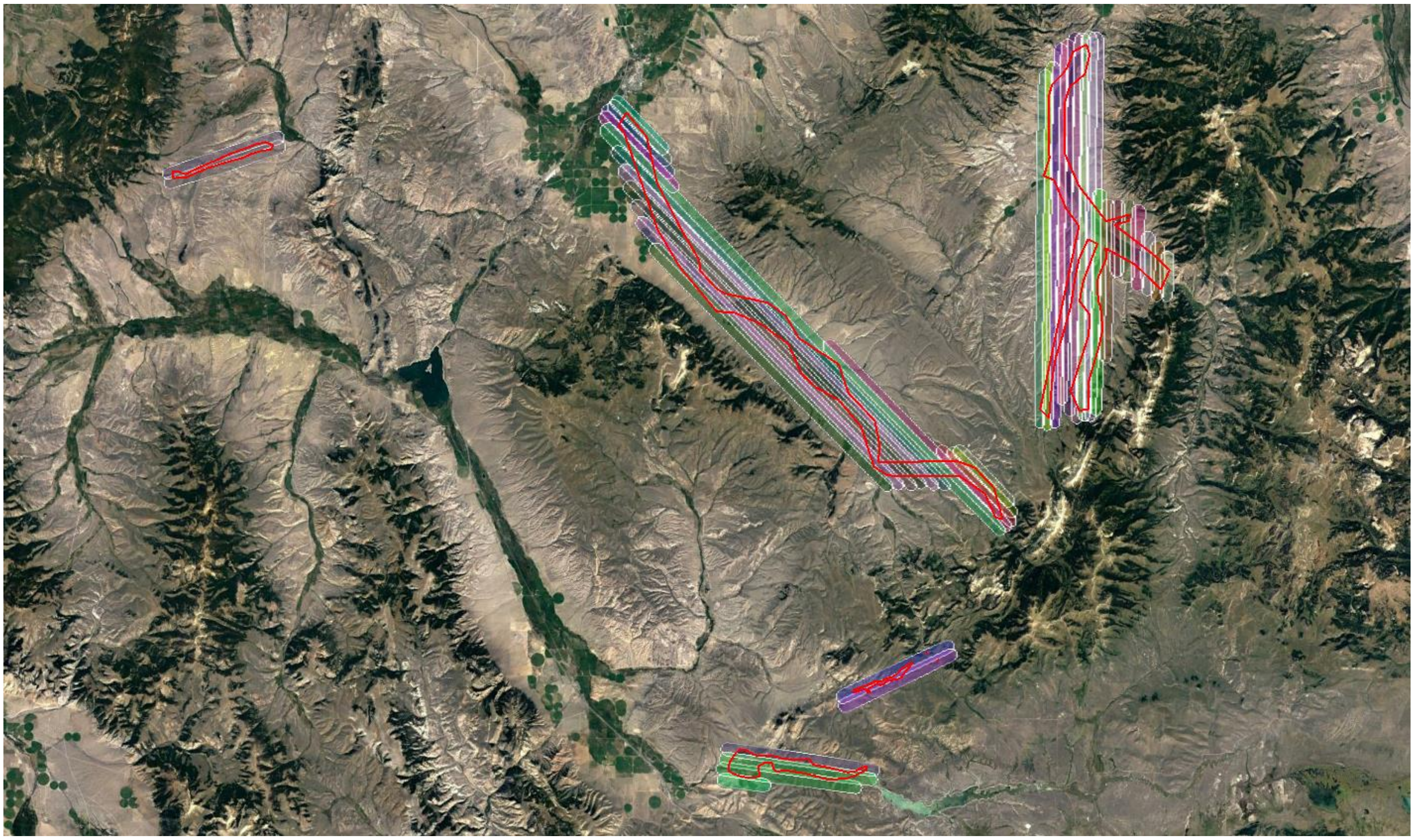

Figure 3: Raw Point Cloud Coverage

3.2 Coordinate Reference System

Horizontal Datum: North American Datum of 1983 (2011)
Projection: State Plane Montana (FIPS 2500)
Vertical Datum: North American Vertical Datum of 1988
Geoid Model: Geoid12B
Units: International Feet

3.3 Lidar Matching

Sanborn uses Leica HxMap software and the latest boresight values to combine the processed SBET with the laser scan files to produce the lidar point cloud. The data is processed by mission and/or block and is output in ASPRS LASv1.4 Point Data Record Format (PDRF) 6 with 16bit linearly scaled intensities to the nearest 0.001 3D position. Each mission is produced in WGS84, UTM, Ellipsoid, Meters and transformed to the project CRS upon import into GeoCue.

Each mission in imported into GeoCue where each individual flight line is assigned a unique flight line number. The SBET is cut per mission into TerraScan Trajectory files based on flight line number and timestamp to be utilized during the lidar natching process. The project area(s) are broken into logical blocks based on AOIs or predetermined delivery blocks and the individual flight lines are populated into lidar matching tile grids. These lidar matching tile grids are prepared for scanner, line, mission, block and eventual project wide lidar matching routines by first running point cloud filters to identify ground and building features to be used during any TerraMatch processes.

After successful point cloud filters have been run on the lidar matching dataset TerraMatch is used to extract Tie Line Observations. TerraMatch Tie Lines are 3D vectors extracted from the lidar point cloud intended to reduce the overwhelming data size to a more manageable amount. Each Tie Line is extracted using a series of parameters designed to identify features such a flat or sloping ground or roofline apexes that geospatially correlates to the same observation of an overlapping flight line. These observed 3D vectors are then utilized across multiple solution iterations to reduce the average offset from line to line, mission to mission, and block to block. TerraMatch Solutions are calculated to adjust Roll, Heading, Pitch, Mirror Scale, X, Y and Z in combination to reduce the Root Mean Square Deviation (RMSDr and RMSDz). These solutions are calculated, applied, and reviewed throughout the lidar matching process.

Sanborn takes advantage of both visual and statistical validation methodologies to review and ensure overlap consistency of the lidar data meets and/or exceeds project specifications. Differential Elevation (dZ) rasters are color ramp (Dark Green, Green, Yellow, Orange, Red) based visual representations produced to identify vertical offsets between flight lines. The dZ rasters are reviewed in their entirety for flight lines and areas that exceed the required RMSDz. Furthermore, an additional set of TerraMatch Tie Lines are produced after solutions are applied and a Tie Line Report is produced to assess the X. Y. and Z offset averages and magnitudes for the whole project including each line individually. This visual and statistical review guarantees the relative accuracy of the lidar dataset. **Table 5** outlines the relative accuracy requirements of the project. **Tables 6 – 9** are the relative accuracies achieved.

Category	Value
Smooth Surface Repeatability (ft)	≤0.197
Swath overlap difference, RMSDz (ft)	≤0.262
Swath overlap difference, Maximum (ft)	±0.525

Table 5: Relative Accuracy Requirements

No Data	0ft to 0.131ft	0.131ft to 0.262ft	0.262ft to 0.393ft	0.393ft to 0.524ft	> 0.524ft

Figure 4: dZ Rasters

Line	X	Y	Z	Line	X	Y	Z	Line	X	Y	Z
1	0.048	0.040	0.010	**14**	0.052	0.063	0.008	**31**	-	-	0.007
2	0.047	0.044	0.011	**15**	0.011	0.014	0.009	**32**	-	-	0.006
3	0.042	0.036	0.011	**16**	0.030	0.024	0.010	**34**	0.003	0.001	0.008
4	0.031	0.023	0.011	**17**	0.073	0.024	0.008	**35**	0.004	0.001	0.008
5	0.036	0.017	0.007	**18**	0.079	0.004	0.011	**36**	-	-	0.008
6	0.038	0.010	0.010	**19**	0.030	0.105	0.012	**38**	-	-	0.011
7	0.079	0.062	0.012	**20**	0.017	0.057	0.011	**40**	0.030	0.028	0.009
8	0.079	0.068	0.012	**24**	-	-	0.011	**41**	0.054	0.030	0.008
9	0.029	0.042	0.013	**25**	-	-	0.012	**42**	0.027	0.018	0.009
10	0.028	0.052	0.016	**26**	-	-	0.011	**43**	0.000	0.021	0.009
11	0.026	0.071	0.013	**27**	-	-	0.007	**44**	0.054	0.050	0.010
12	0.089	0.085	0.013	**28**	-	-	0.009	**45**	0.055	0.051	0.008
13	0.076	0.061	0.012	**29**	-	-	0.009	**46**	-	-	0.009

Table 6: Average Magnitudes by Line (Feet)

Category	X	Y	Z
Average Magnitude	0.044	0.039	0.010
RMS Values	0.067	0.059	0.015
Maximum Values	0.380	0.288	0.278
Observation Weight	1012.0	1012.0	522716.0

Table 7: Internal Observation Statistics (Feet)

Category	Mismatch
Average 3D Mismatch	0.01005
Average XY Mismatch	0.06658
Average Z Mismatch	0.00994

Table 8: Overall Relative Accuracy (Feet)

Category	Observations
Section Lines	184,717
Roof Lines	487

Table 9: Vector Observations

3.4 Lidar Classification

Lidar filtering was accomplished using GeoCue with TerraSolid processing and modeling software. The filtering process reclassifies all the data into classes within the point cloud classification scheme. Once the data is classified, the entire dataset is reviewed and manually edited for anomalies that are outside the required guidelines of the product specification or contract requirements. This can include, but is not limited to, classifying bridges, structures, filling culverts, and manually analyzing the bare-earth surface by classifying features that belong in non-extraneous classification codes. **Table 10** outlines the point classes leveraged in the lidar dataset.

Code	Description	Definition
1	Unclassified	Processed, but unclassified
2	Ground	Bare-earth surface
7	Low Noise	Erroneous returns below bare-earth surface
9	Water	Hydrologically identified water surface points
17	Bridge Decks	Structure carrying a means of transit of higher
18	High Noise	Erroneous atmospheric returns above bare-earth
20	Ignored Ground	Bare-earth points near breaklines excluded from
Flag	Overlap	Overage points lying within overlapping areas of two or more swaths
Flag	Withheld	Outliers, blunders, noise points, geometrically unreliable points near the extreme edge of the swath

Table 10: Lidar Classification Scheme

3.5 Accuracy Assessment

The lidar dataset was evaluated using a total of twenty-five (25) check points (20 NVA + 5 VVA). The end result provided a vertical accuracy that fell within project specifications. Please see the **Attachment A** for the full Vertical Accuracy Report and the project *Metadata* for an in-depth accuracy assessment. **Table 11** outlines the absolute accuracy requirements of the project. **Table 12** shows high level statistics and mean errors for the area processed by Sanborn.

Category	Value
RMSEz (ft)	≤0.328
@ 95-percent confidence level (ft)	≤0.984

Table 11: Absolute Accuracy Requirements

Broad Land Cover Type	# of Points	RMSEz	95% Confidence Level	95th Percentile
NVA of Point Cloud	20	0.129	0.252	
NVA of Bare Earth	20	0.128	0.251	
NVA of DEM	20	0.132	0.258	
VVA of Bare Earth	5	0.146		0.216
VVA of DEM	5	0.144		0.209

Table 12: Vertical Accuracy Assessment of Check Points (Feet)

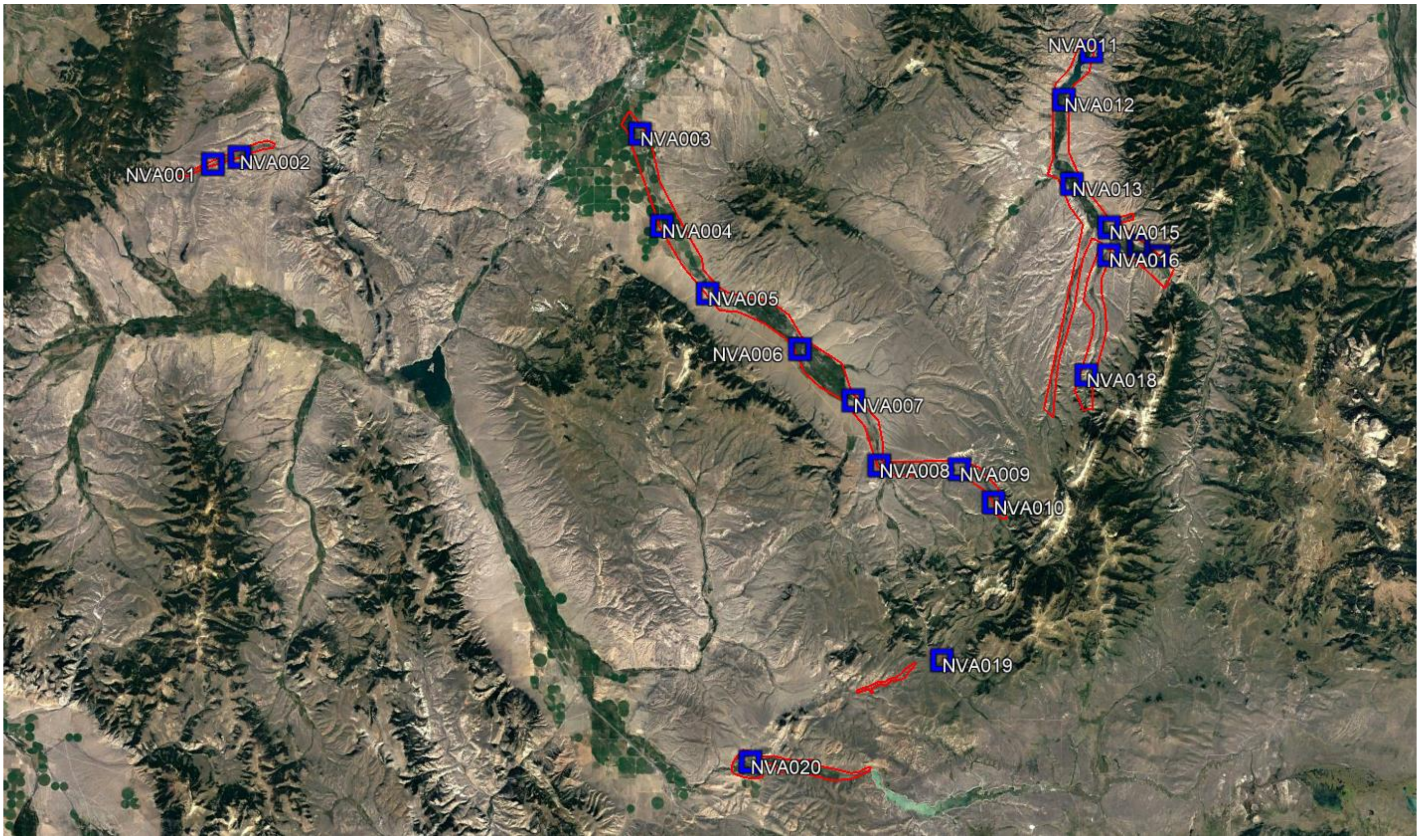

Figure 5: Non-vegetated Check Point Distribution

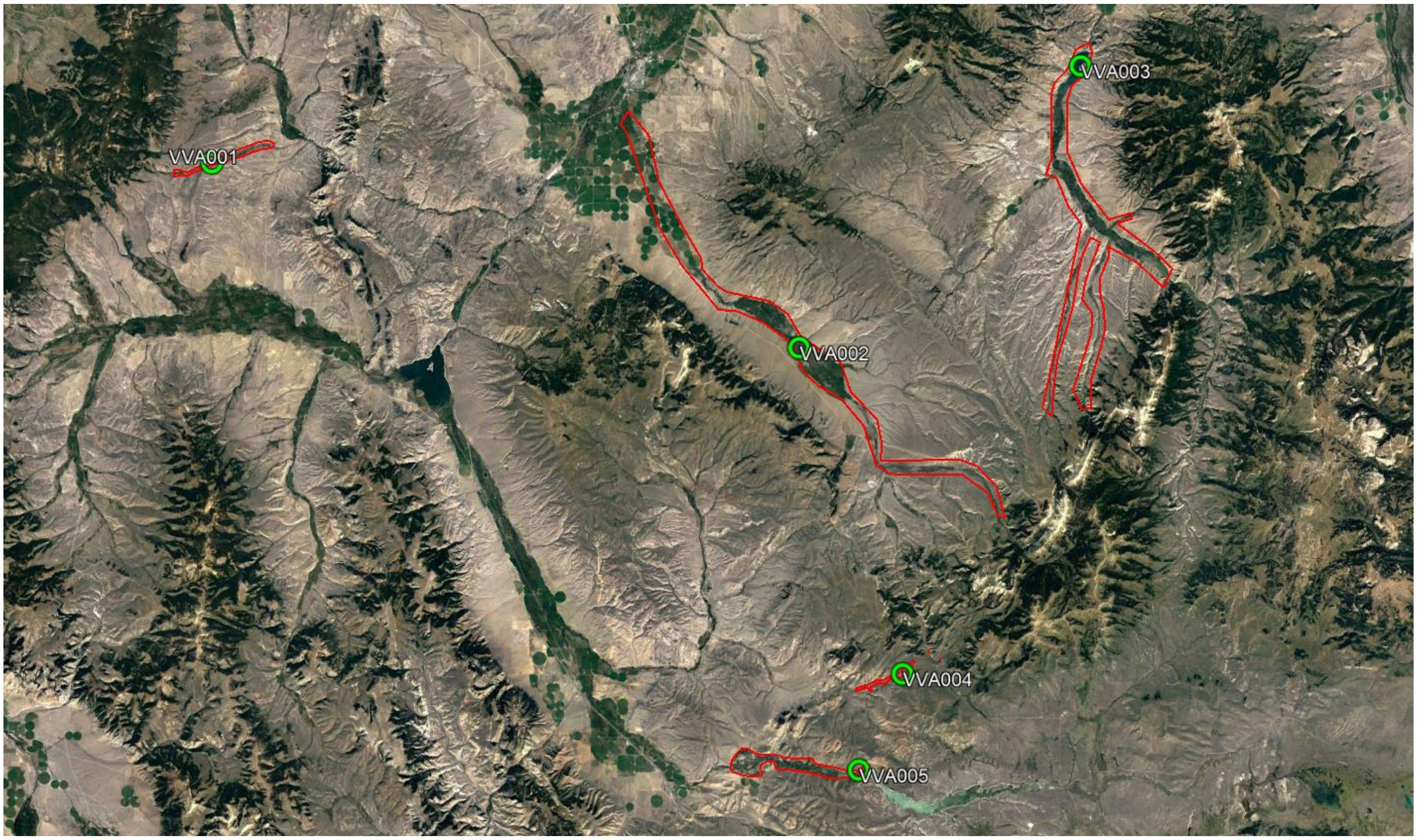

Figure 6: Vegetated Check Point Distribution

4.0 PRODUCT GENERATION

Once the lidar surface was finalized and manually QC'd for anomalies, the required deliverables were then generated and/or organized. The following products were generated using the final coordinate system as defined in the contract, and provided in section 4.0 of this report.

Raw Point Cloud
The Raw Point Cloud, containing all returns, is delivered in LASv1.4 (*.las) format and meets project specifications. The Raw Point Cloud is delivered as one file per swath and one swath per file containing names by Source File ID.

Classified Point Cloud
The Classified Point Cloud, containing all returns, is delivered in LASv1.4 (*.las) format and meets project specifications. The Classified Point Cloud containing names referencing the tile index.

Bare-Earth Digital Terrain Model
32-bit Esri Grid 1 ft elevation rasters were created from the bare-earth points in the processed lidar dataset. Each pixel contains an elevation value interpolated from the lidar.

Intensity Rasters
8-bit GeoTIFF (*.tif) 1 ft intensity rasters were created from the first-return points in the processed lidar dataset.

Other Deliverables
Vertical Accuracy Report
Metadata

A final QC process was undertaken to validate all deliverables for the project. Prior to release of data for delivery, Sanborn's Quality control/quality assurance department reviews the data and then releases it for delivery.