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Pierce County, WA Lidar 2020
312020323

Lidar Report

November, 2020

EXECUTIVE SUMMARY

Pierce County, WA (Pierce) contracted with The Sanborn Map Company, Inc. (Sanborn) to provide remote sensing services 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 ~884mi² was completed on June 3rd, 2020.

The Riegl VQ-780ii and VQ-1560ii were 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:

Shawn Benham, PMP
Vice President of Programs
The Sanborn Map Company, Inc.
1935 Jamboree Drive, Suite 100
Colorado Springs, CO 80920
(719) 502-1296
sbenham@sanborn.com

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

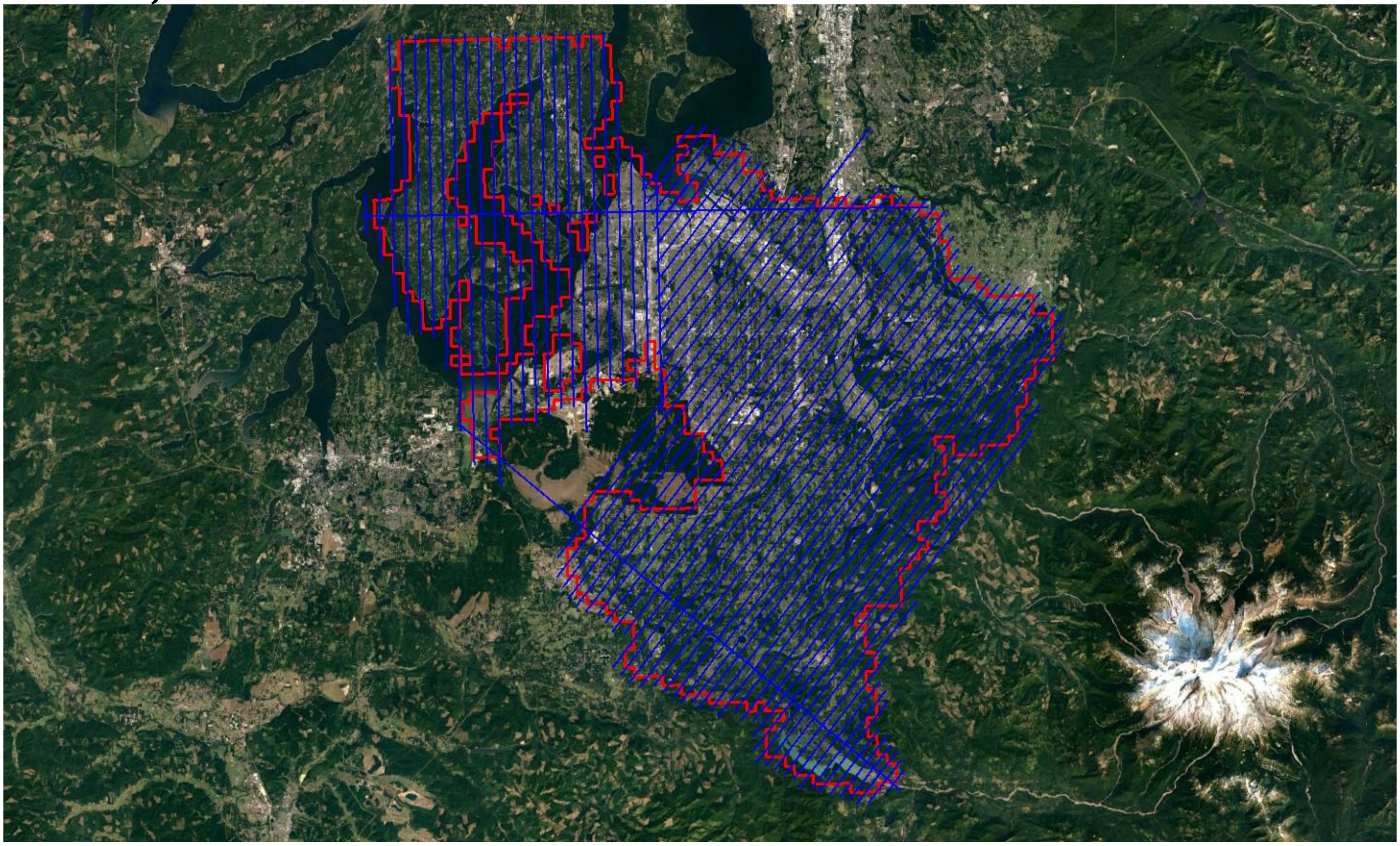


Figure 1: AOI and Trajectories As-Flown

2.0 ACQUISITION

2.1 Introduction

This section outlines the lidar system, flight reporting and data acquisition methodology used during the collection of the Pierce County 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.

Acquisition Parameters			
Sensor	Riegl VQ-1560ii	Riegl VQ-780ii	Riegl VQ-780ii
Aircraft	C-FFSL - Piper PA-31	C-FFFC Piper PA-31	C-FFFC Piper PA-31
Flying Height (AGL) (m)	1550	915	1400
Air Speed (kts)	160	140	140
Field of View (degrees)	58	60	60
Overlap (%)	30	30	100
Pulse Rate (kHz)	2000	1200	1000
Scan Rate (Hz)	345	228	199
Laser Footprint (m)	0.39	0.35	0.35
Multi-Pulse	Yes	Yes	Yes
Point Spacing (m)	0.32	0.31	0.25
Point Density (pls/m²)	9.3	10.5	16
Swath Width (m)	1737	1057	1155

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)
4/10/2020	Riegl VQ-1560ii	S2224050	C-FFSL	20200410A	2.2	18:20:00	01:03:00
4/13/2020	Riegl VQ-1560ii	S2224050	C-FFSL	20200413A	1.5	17:35:00	00:31:00
4/14/2020	Riegl VQ-1560ii	S2224050	C-FFSL	20200414A	1.3	16:41:00	21:33:00
6/3/2020	Riegl VQ-780ii	S2223883	C-FFFC	20200603A	1.4	23:46:00	0:49:00

Table 2: Collection Date Time by Mission

Designation	Type	PID	Latitude (N)	Longitude (W)	Elevation
CPXF	CORS	AJ7202	46 50 24.29151	122 15 23.40720	533.975
GRMD	CORS	DJ4303	46 47 43.73504	123 01 21.28886	31.083
HAHD	CORS	DN5822	47 17 26.86772	121 47 17.03837	854.322
P420	CORS	DG8344	46 35 18.95255	122 51 58.73331	74.461
P432	CORS	DG8347	46 37 22.26501	121 40 59.56701	319.262
SMAI	CORS	DL2071	47 31 24.84355	122 20 42.14745	113.784
SSHO	CORS	DJ9210	47 40 56.26370	122 18 54.53169	74.455
TWHL	CORS	AJ7208	47 00 57.24443	122 55 22.29042	107.630
ZSE1	CORS	DF4068	47 17 13.16182	122 11 18.07700	82.021

Table 3: GNSS Reference Station Coordinates

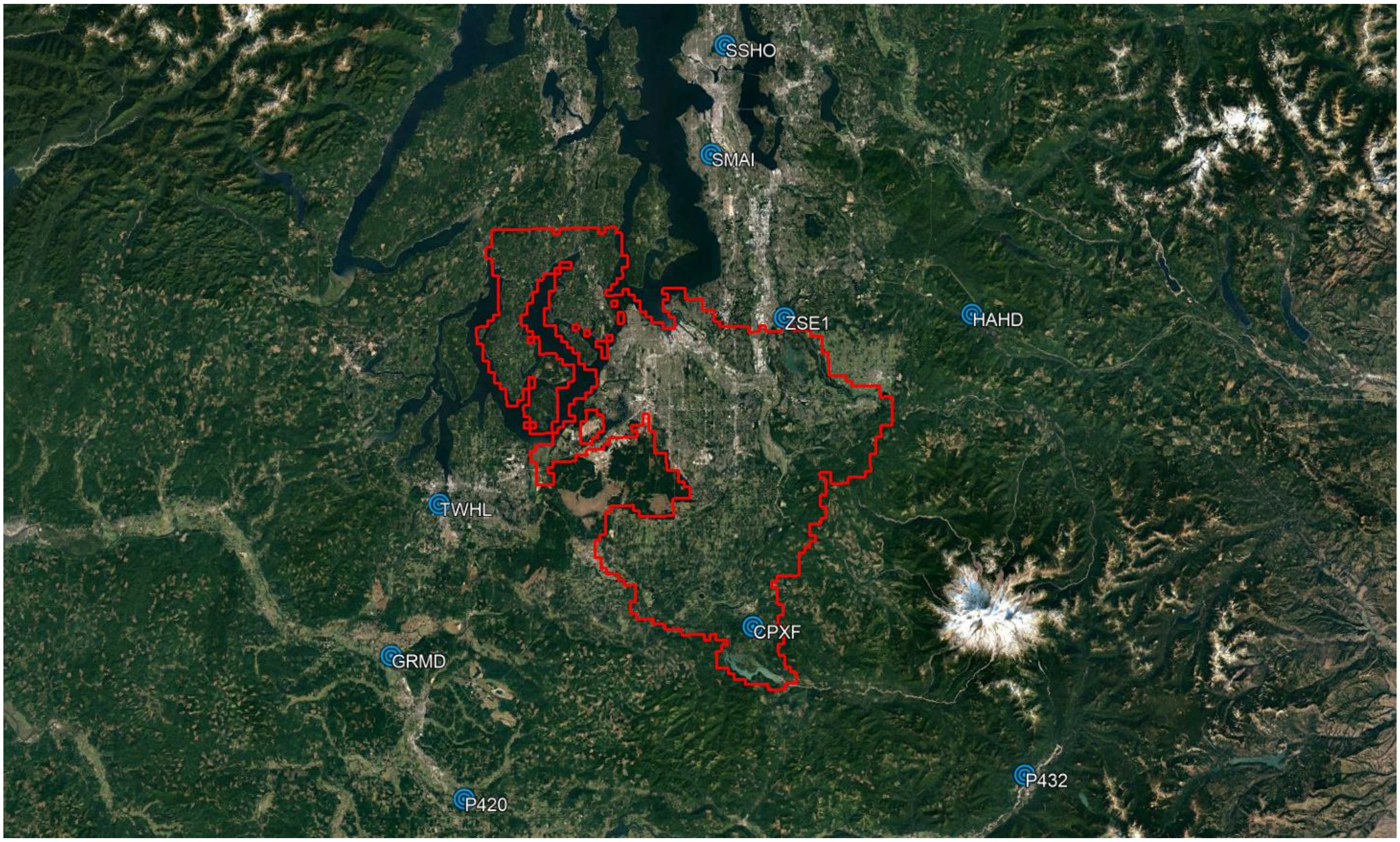


Figure 2: GNSS Reference Stations

3.0 PROCESSING

3.1 Introduction

The GNSS/IMU data was post-processed using Applanix POSPac MMS software to create Smoothed Best Estimate Trajectory (SBET) file(s). The SBET was then combined with the laser range measurements in Riegl RiPROCESS software 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 Riegl RiPROCESS 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	59,348,004,619
Aggregate Nominal Pulse Spacing (m)	0.26
Aggregate Nominal Pulse Density (pls/m²)	15.1
Aggregate Nominal Pulse Spacing (ft)	0.84
Aggregate Nominal Pulse Density (pls/ft²)	1.4

Table 4: Point Cloud Statistics

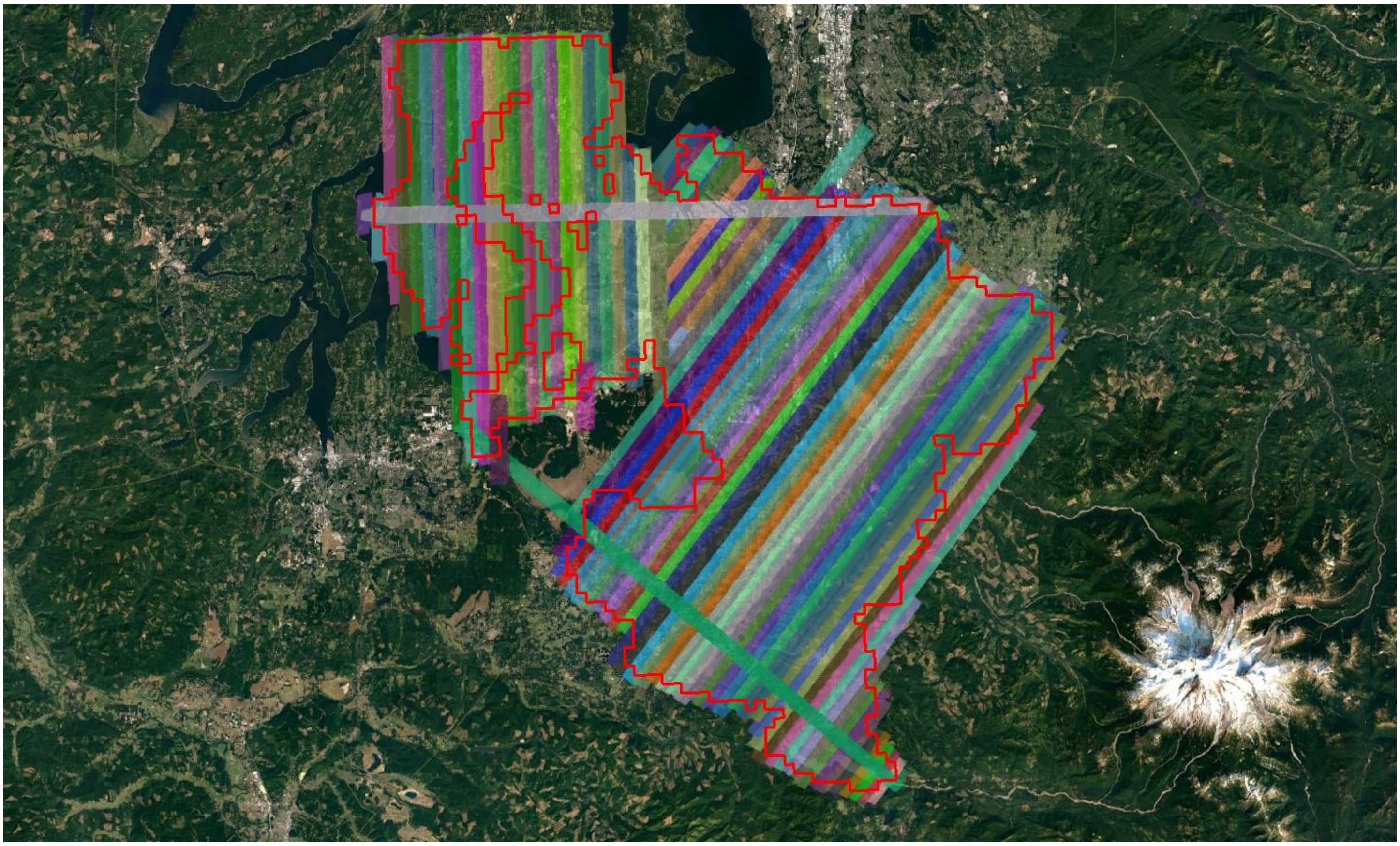


Figure 3: Raw Point Cloud Coverage

3.2 Coordinate Reference System

Horizontal Datum: North American Datum of 1983 (HARN)
Projection: State Plane Washington South (FIPS 2602)
Vertical Datum: North American Vertical Datum of 1988
Geoid Model: Geoid12B
Units: U.S. Survey Feet

3.3 Lidar Matching

Sanborn uses Riegl RiPROCESS 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.

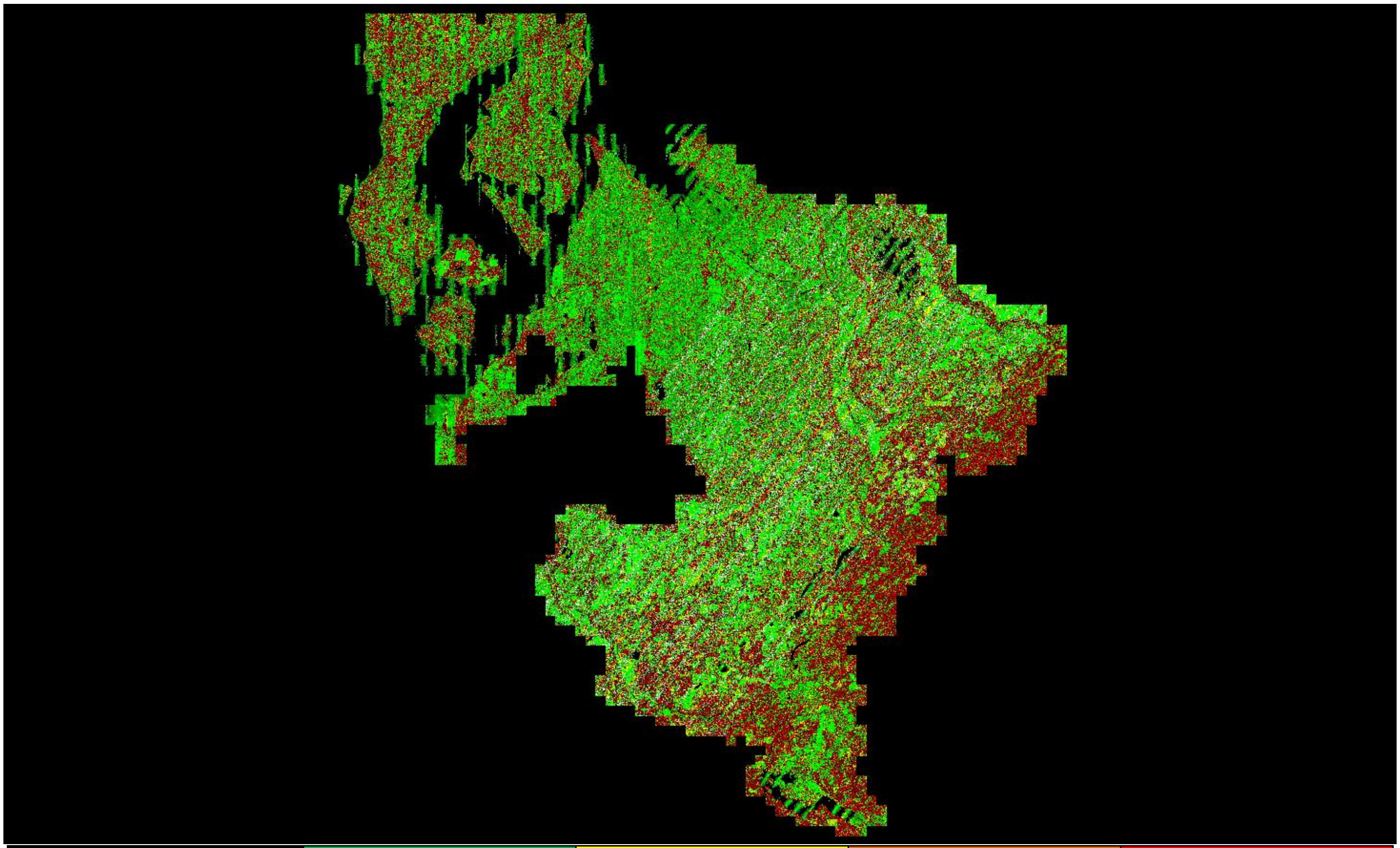
Each mission is imported into GeoCue where each individual flight line is assigned a unique Source ID number. The SBET is cut per swath into TerraScan Trajectory files based on Source ID number and timestamp; these are utilized during the lidar matching process. The project area(s) are broken into logical 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 number. 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 correlate to the same observation of an overlapping flight line.

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. Height Separation Rasters modulated by Intensity are representative of the interswath alignment and provide a holistic qualitative look at the positional quality of the point cloud. The dZ rasters are reviewed in their entirety for flight lines and areas that exceed the required RMSDz. Furthermore, the set of TerraMatch Tie Lines are used to produce a Tie Line Report to statistically 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 (m)	Value (ft)
Smooth Surface Repeatability	≤0.060	≤0.197
Swath overlap difference, RMSDz	≤0.080	≤0.262

Table 5: Relative Accuracy Requirements



No Data	< 0.08m	0.08m to 0.16m	0.16m to 0.24m	> 0.24m
No Data	< 0.262ft	0.262ft to 0.524ft	0.524ft to 0.786ft	> 0.786ft

Figure 4: Height Separation Rasters

Line	X	Y	Z	Line	X	Y	Z	Line	X	Y	Z
1	-	-	0.021	**61**	0.041	0.033	0.021	**141**	0.039	0.047	0.044
2	-	-	0.022	**62**	0.024	0.030	0.020	**142**	0.042	0.044	0.041
3	0.077	0.028	0.023	**63**	0.023	0.026	0.060	**143**	0.041	0.058	0.053
4	0.064	0.030	0.038	**64**	0.022	0.025	0.044	**144**	0.041	0.040	0.050
5	0.076	0.030	0.036	**65**	0.020	0.024	0.028	**145**	0.037	0.066	0.038
6	0.074	0.039	0.048	**66**	0.021	0.026	0.019	**146**	0.051	0.047	0.037
7	0.034	0.034	0.022	**67**	0.033	0.029	0.032	**147**	0.082	0.088	0.039
8	0.028	0.026	0.031	**68**	0.046	0.034	0.025	**148**	0.067	0.063	0.041
9	0.031	0.030	0.033	**69**	0.021	0.021	0.025	**201**	0.063	0.080	0.048
10	0.020	0.020	0.018	**70**	0.019	0.022	0.031	**202**	0.044	0.057	0.025
11	0.027	0.032	0.017	**71**	0.020	0.021	0.020	**203**	0.044	0.063	0.055
12	0.024	0.028	0.020	**72**	0.018	0.023	0.018	**204**	0.039	0.067	0.045
13	0.030	0.027	0.028	**73**	0.017	0.021	0.019	**205**	0.048	0.031	0.022
14	0.029	0.027	0.029	**74**	0.024	0.024	0.018	**206**	0.029	0.047	0.025
15	0.021	0.031	0.016	**75**	0.016	0.021	0.018	**207**	0.038	0.057	0.036
16	0.020	0.028	0.014	**76**	0.024	0.025	0.026	**208**	0.021	0.018	0.038
17	0.024	0.036	0.033	**77**	0.027	0.022	0.030	**209**	0.147	0.143	0.113
18	0.023	0.032	0.041	**78**	0.034	0.026	0.024	**210**	0.138	0.120	0.106
19	0.037	0.032	0.016	**79**	0.033	0.039	0.028	**211**	0.085	0.090	0.069
20	0.023	0.031	0.013	**80**	0.087	0.048	0.052	**212**	0.072	0.106	0.076

21	0.026	0.038	0.022	**101**	0.033	0.067	0.025	**213**	0.092	0.119	0.038
22	0.019	0.032	0.025	**102**	0.042	0.036	0.028	**214**	0.109	0.117	0.047
23	0.027	0.032	0.019	**103**	0.031	0.034	0.019	**215**	0.121	0.079	0.060
24	0.018	0.024	0.018	**104**	0.031	0.029	0.019	**216**	0.052	0.047	0.038
25	0.021	0.047	0.028	**105**	0.033	0.052	0.036	**217**	0.043	0.034	0.023
26	0.025	0.031	0.031	**106**	0.035	0.035	0.024	**218**	0.053	0.051	0.022
27	0.051	0.044	0.019	**107**	0.079	0.049	0.021	**219**	0.049	0.052	0.041
28	0.036	0.034	0.017	**108**	0.060	0.044	0.024	**220**	0.033	0.041	0.027
29	0.033	0.032	0.014	**109**	0.043	0.051	0.023	**221**	0.042	0.050	0.020
30	0.026	0.029	0.012	**110**	0.043	0.035	0.023	**222**	0.049	0.055	0.018
31	0.041	0.038	0.014	**111**	0.048	0.038	0.036	**223**	0.040	0.054	0.023
32	0.037	0.035	0.016	**112**	0.042	0.034	0.038	**224**	0.041	0.047	0.022
33	0.027	0.054	0.020	**113**	0.072	0.061	0.028	**225**	0.059	0.075	0.025
34	0.029	0.054	0.020	**114**	0.049	0.050	0.027	**226**	0.043	0.053	0.027
35	0.067	0.062	0.029	**115**	0.047	0.038	0.068	**227**	0.074	0.051	0.062
36	0.064	0.060	0.032	**116**	0.046	0.036	0.063	**228**	0.031	0.038	0.049
37	0.059	0.040	0.035	**117**	0.046	0.058	0.049	**229**	0.039	0.031	0.028
38	0.067	0.046	0.032	**118**	0.044	0.044	0.042	**230**	0.029	0.029	0.026
39	0.056	0.038	0.036	**119**	0.044	0.045	0.084	**231**	0.037	0.027	0.045
40	0.036	0.032	0.027	**120**	0.047	0.045	0.075	**232**	0.023	0.025	0.042
41	0.029	0.035	0.021	**121**	0.043	0.071	0.061	**233**	0.025	0.025	0.022
42	0.056	0.045	0.019	**122**	0.041	0.038	0.055	**234**	0.027	0.027	0.024
43	0.027	0.030	0.030	**123**	0.036	0.041	0.085	**235**	0.023	0.025	0.043
44	0.043	0.032	0.020	**124**	0.042	0.036	0.079	**236**	0.026	0.035	0.044
45	0.057	0.040	0.020	**125**	0.036	0.050	0.065	**237**	0.050	0.057	0.033
46	0.041	0.036	0.024	**126**	0.040	0.043	0.061	**238**	0.049	0.049	0.042
47	0.032	0.031	0.044	**127**	0.034	0.043	0.096	**239**	0.036	0.037	0.026
48	0.062	0.046	0.029	**128**	0.039	0.040	0.089	**240**	0.038	0.039	0.036
49	0.042	0.036	0.023	**129**	0.050	0.079	0.056	**301**	0.116	0.091	0.068
50	0.037	0.034	0.035	**130**	0.047	0.046	0.052	**302**	0.098	0.075	0.051
51	0.048	0.050	0.046	**131**	0.034	0.040	0.072	**303**	0.114	0.096	0.044
52	0.040	0.046	0.028	**132**	0.037	0.037	0.066	**304**	0.149	0.127	0.038
53	0.045	0.046	0.040	**133**	0.045	0.066	0.046	**305**	0.127	0.130	0.041
54	0.036	0.041	0.028	**134**	0.048	0.056	0.043	**306**	0.111	0.132	0.045
55	0.039	0.043	0.055	**135**	0.055	0.050	0.063	**307**	0.069	0.085	0.059
56	0.029	0.034	0.032	**136**	0.054	0.052	0.060	**308**	0.068	0.095	0.037
57	0.026	0.032	0.029	**137**	0.036	0.067	0.043	**309**	0.087	0.096	0.036
58	0.028	0.031	0.023	**138**	0.039	0.051	0.041	**310**	0.080	0.081	0.030
59	0.022	0.027	0.039	**139**	0.029	0.039	0.064				
60	0.031	0.029	0.025	**140**	0.033	0.034	0.062				

Table 6: Average Magnitudes by Line (Feet)

Category	X	Y	Z
Average Magnitude	0.033	0.033	0.032
RMS Values	0.060	0.061	0.046
Maximum Values	0.564	0.621	0.498
Observation Weight	931389.0	931389.0	1395626.0

Table 7: Internal Observation Statistics (Feet)

Category	Mismatch
Average 3D Mismatch	0.06041
Average XY Mismatch	0.05907
Average Z Mismatch	0.03194

Table 8: Overall Relative Accuracy (Feet)

Category	Observations
Section Lines	199,588
Roof Lines	332,703

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
21	Snow	Unavoidable snow or snow pack
22	Temporal Exclusion	Nonfavored data in intertidal zones
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 one hundred and one (101) check points (56 NVA + 45 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 (m)	Value (ft)
RMSEz	≤0.100	≤0.328
@ 95-Percent Confidence Level	≤0.196	≤0.643
@ 95^{th} Percentile	≤0.300	≤0.984

Table 11: Absolute Accuracy Requirements

Broad Land Cover Type	# of Points	RMSEz	95% Confidence Level	95th Percentile
NVA of Point Cloud	56	0.124	0.243	
NVA of Bare Earth	56	0.145	0.284	
NVA of DEM	56	0.144	0.282	
VVA of Bare Earth	45	0.163		0.257
VVA of DEM	45	0.163		0.251

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

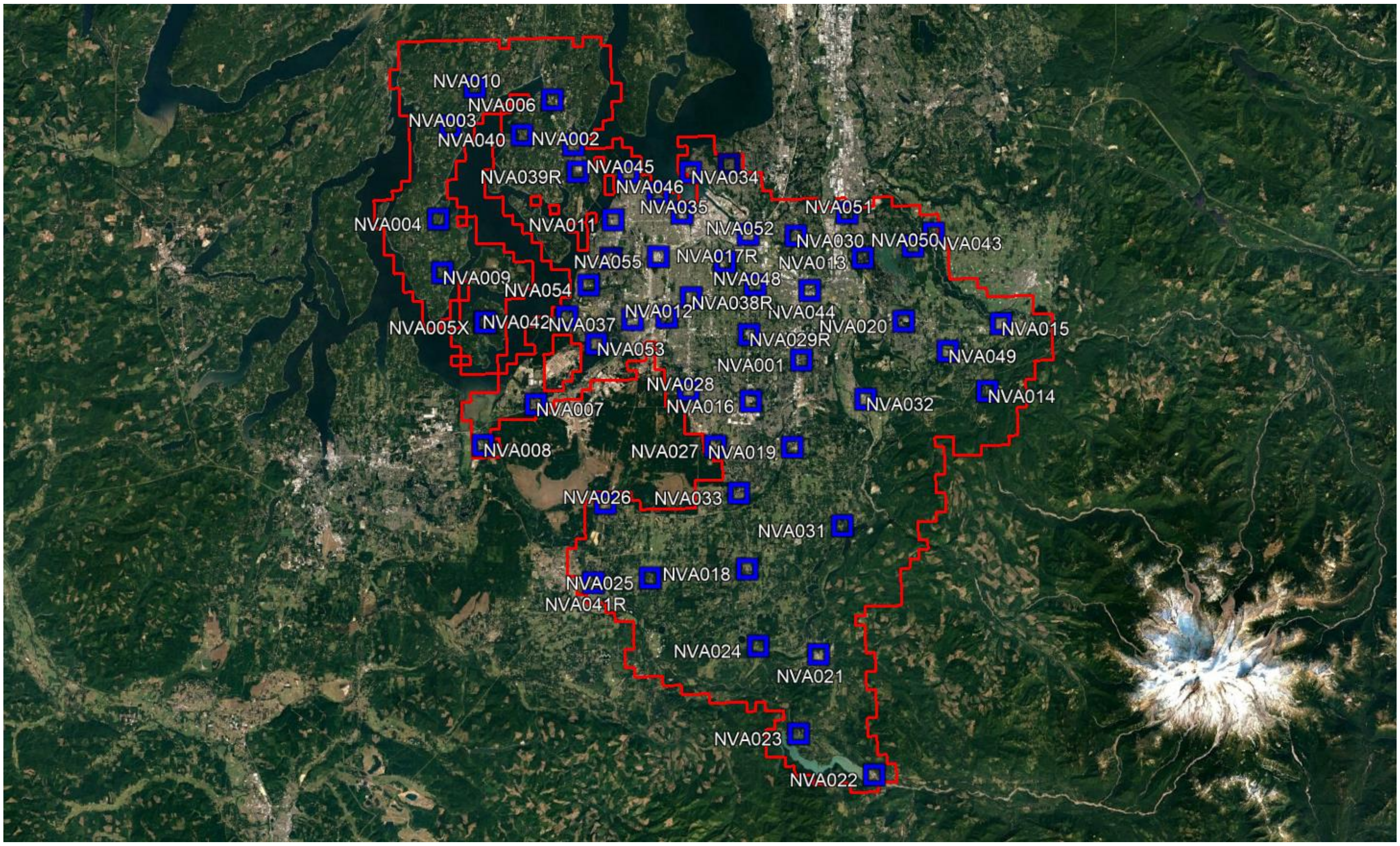


Figure 5: Non-vegetated Check Point Distribution

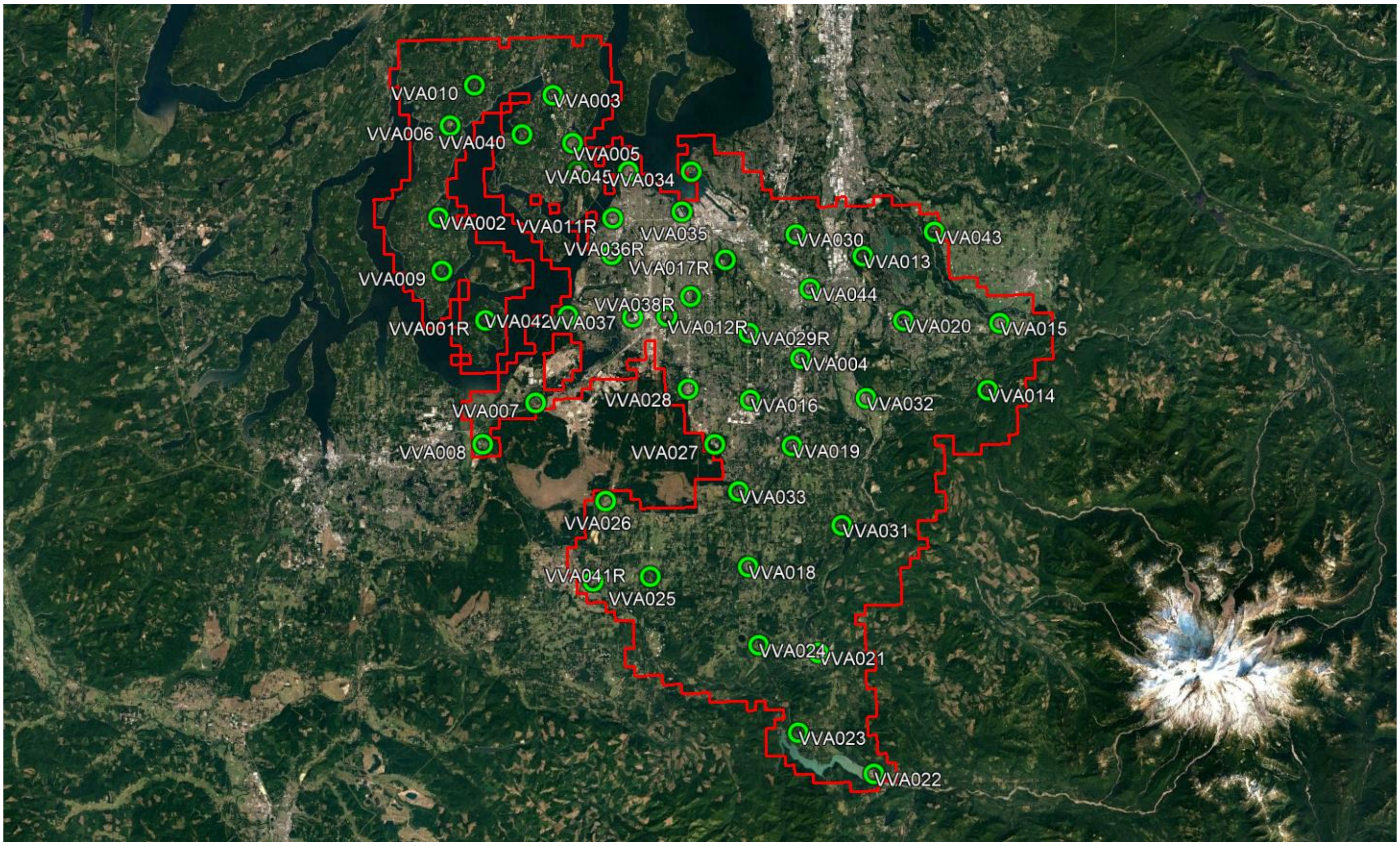


Figure 6: Vegetated Check Point Distribution

4.0 PRODUCT GENERATION

The following products were generated using the final coordinate system as defined in the contract:

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 contains file names referencing the tile index.

Bare-Earth Digital Elevation Model
32-bit GeoTIFF (*.tif) elevation rasters were created from the bare-earth points in the processed lidar dataset and hydro-flattened breaklines. Each pixel contains an elevation.

First-Return Digital Surface Model
32-bit GeoTIFF (*.tif) elevation rasters were created from the first-return points in the processed lidar dataset. All overlap classes were ignored during this process. Each pixel contains an elevation.

First-Return Intensity Images
8-bit GeoTIFF (*.tiff) intensity rasters were created from the first-return points in the processed lidar dataset. All overlap classes were ignored during this process.

Swath Separation Images
24-bit GeoTIFF (*.tif) height separation rasters modulated by intensity were created from the last-return points in the processed lidar dataset.

Swath Polygons
Polygons features representing either the convex or concave hull of swaths, where each record is an individual swath or channel within a swath. Delivered in Esri (*.shp) format.

Other Deliverables
Breaklines
Metadata
Vertical Accuracy Report

A final quality assurance 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.