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NJ NW New Jersey 6 County Lidar 2017 B17

USGS Contract: G16PC00051

Lidar Report

December, 2018

EXECUTIVE SUMMARY

The U.S. Geological Survey (USGS) contracted with The Sanborn Map Company, Inc. (Sanborn) to provide remote sensing services for 6 New Jersey counties 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 ~2,358mi² was completed on May 1st, 2018.

The Leica ALS70 - HP and Optech Galaxy were used to collect data for the aerial survey campaign. The sensors are attached to the aircraft's underside and emit rapid laser pulses that are used to calculate ranges between the aircraft and subsequent terrain below. The Airborne Lidar Systems (ALS) are boresighted by completing multiple passes over a known ground surface before the project acquisition. During data processing, the 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

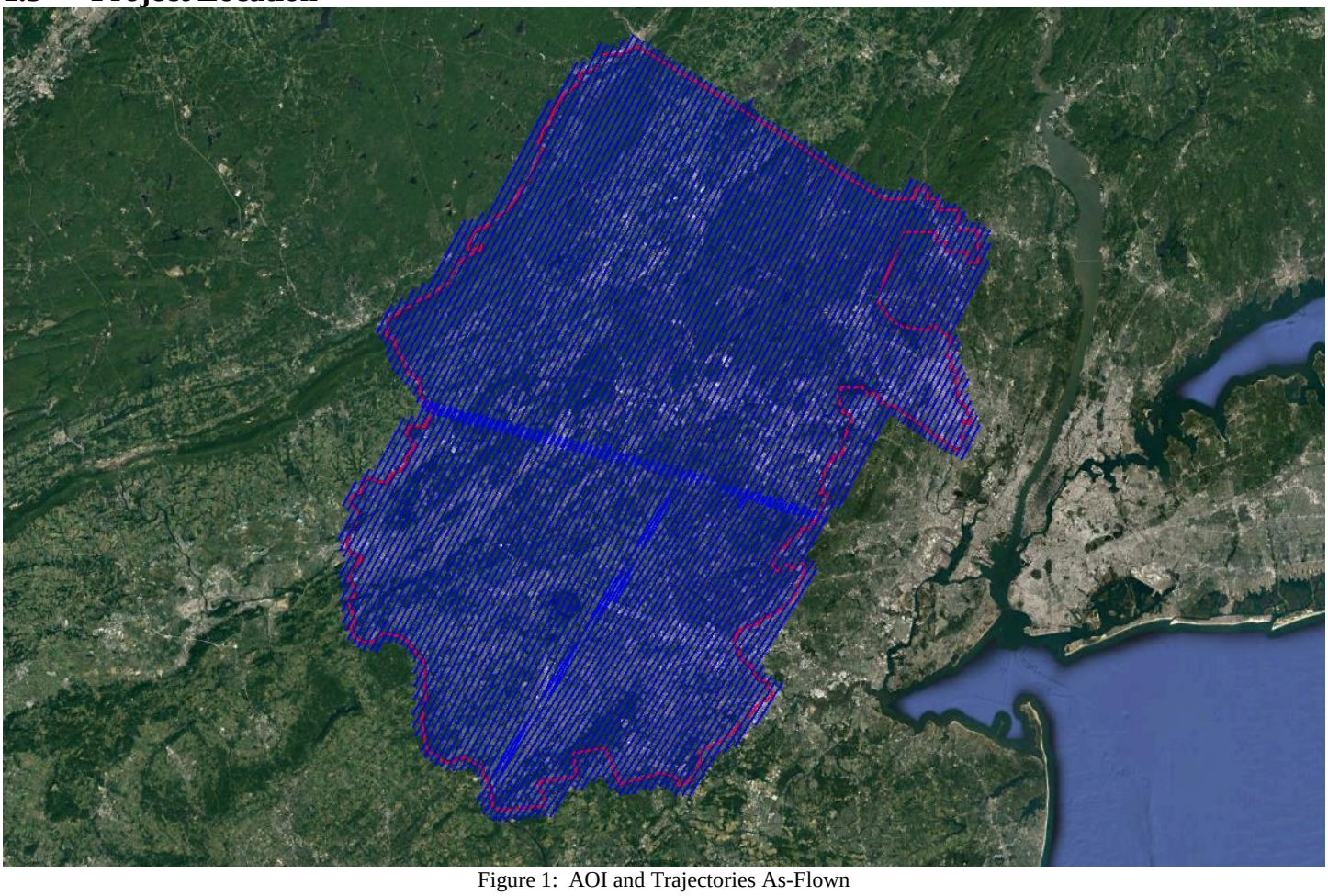


Figure 1: AOI and Trajectories As-Flown

2.0 ACQUISITION

2.1 Introduction

This section outlines the lidar system, flight reporting and data acquisition methodology used during the collection of the Presque Isle County 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. **Tables 1** and **2** shows the planned acquisition parameters utilized by Sanborn for this aerial survey with the sensor(s) installed.

Planned Acquisition Parameters	
Sensor	Leica ALS70 - HP
Aircraft	N940U – AERO COMMANDER 680W
Flying Height (AGL)	2350m
Air Speed (kts)	140
Field of View (degrees)	30
Overlap (%)	23
Pulse Rate (kHz)	240.0
Scan Rate (Hz)	55.8
Laser Footprint (m)	0.53
Mode (PIA)	Multi-Pulse
Point Spacing (m)	0.61
Point Density (pls/m²)	2.4
Swath Width (m)	1259

Table 1: Lidar Acquisition Parameters

Planned Acquisition Parameters	
Sensor	Optech Galaxy
Aircraft	N210AX – CESSNA T210N
Flying Height (AGL)	1500m
Air Speed (kts)	150
Field of View (degrees)	42
Overlap (%)	20
Pulse Rate (kHz)	250.0
Scan Rate (Hz)	61.0
Laser Footprint (m)	0.33
Mode (PIA)	Multi-Pulse
Point Spacing (m)	0.60
Point Density (pls/m²)	2.5
Swath Width (m)	1225

Table 2: 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 five 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 sixteen (16) missions. During the data collection, the operator recorded information on log sheets which includes weather conditions, lidar operation parameters, flight line statistics and PDOP. Near the end of each mission, GNSS ambiguities are again resolved by flying within ten kilometers of the base stations to aid in post-processing.

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 3** below shows the flight acquisition metrics for the entire collection. **Table 4** 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)
4/15/2017	Leica ALS70 - HP	SN7233	N940U	20170415 A	1.2	05:03:45	09:45:51
4/16/2017	Leica ALS70 - HP	SN7233	N940U	20170415 A	1.2	04:56:46	09:35:52
2/28/2018	Optech Galaxy	5060391	N210AX	20180228_1	1.2	15:44:00	18:51:00
2/28/2018	Optech Galaxy	5060391	N210AX	20180228_2	1.0	20:54:00	21:06:00
4/5/2018	Optech Galaxy	5060391	N210AX	20180405_1	1.0	23:00:00	01:58:00
4/7/2018	Optech Galaxy	5060391	N210AX	20180407_1	1.0	14:15:00	18:01:00
4/7/2018	Optech Galaxy	5060391	N210AX	20180407_2	1.1	19:08:00	20:53:00
4/9/2018	Optech Galaxy	5060391	N210AX	20180409_1	1.3	06:29:00	09:03:00
4/9/2018	Optech Galaxy	5060391	N210AX	20180409_2	1.1	09:35:00	12:45:00
4/9/2018	Optech Galaxy	5060391	N210AX	20180409_3	1.0	15:09:00	16:18:00
4/12/2018	Optech Galaxy	5060391	N210AX	20180412_1	1.1	10:55:00	12:30:00
4/13/2018	Optech Galaxy	5060391	N210AX	20180413_1	1.0	08:12:00	11:13:00
4/13/2018	Optech Galaxy	5060391	N210AX	20180413_2	1.0	13:55:00	15:33:00
4/14/2018	Optech Galaxy	5060391	N210AX	20180414_1	1.1	10:11:00	13:47:00
4/24/2018	Optech Galaxy	5060391	N210AX	20180424_1	1.2	13:35:00	14:20:00
4/26/2018	Optech Galaxy	5060391	N210AX	20180426_1	1.0	01:34:00	05:50:00

Table 3: Collection Date Time by Mission

Designation	Type	PID	Latitude (N)	Longitude (W)	Elevation
LAMT	CORS	AJ4872	41 00 16.23300	073 54 32.05717	90.181
LUMT	CORS	DL6296	40 36 05.77930	075 21 27.14671	250.091
NJDY	CORS	DH3766	40 22 52.07372	074 27 56.30160	4.283
NJHC	CORS	DK4430	40 30 05.80472	074 54 04.01548	95.918
NJI2	CORS	AJ3348	40 44 29.30548	074 10 39.72656	17.917
NJMT	CORS	DH3768	40 47 47.35003	074 28 59.33955	101.119
NJSC	CORS	DK4432	41 03 31.67656	074 45 09.42967	172.957
NJTP	CORS	DI3830	40 32 25.84153	074 28 04.13508	0.374
NJTR	CORS	DG7014	40 15 27.46254	074 47 48.07181	41.271
NJWC	CORS	DK7751	40 48 03.07209	075 04 52.53027	79.803
PAMS	CORS	DJ8947	40 59 44.02490	075 15 03.83591	193.832

Table 4: GNSS Reference Station Coordinates

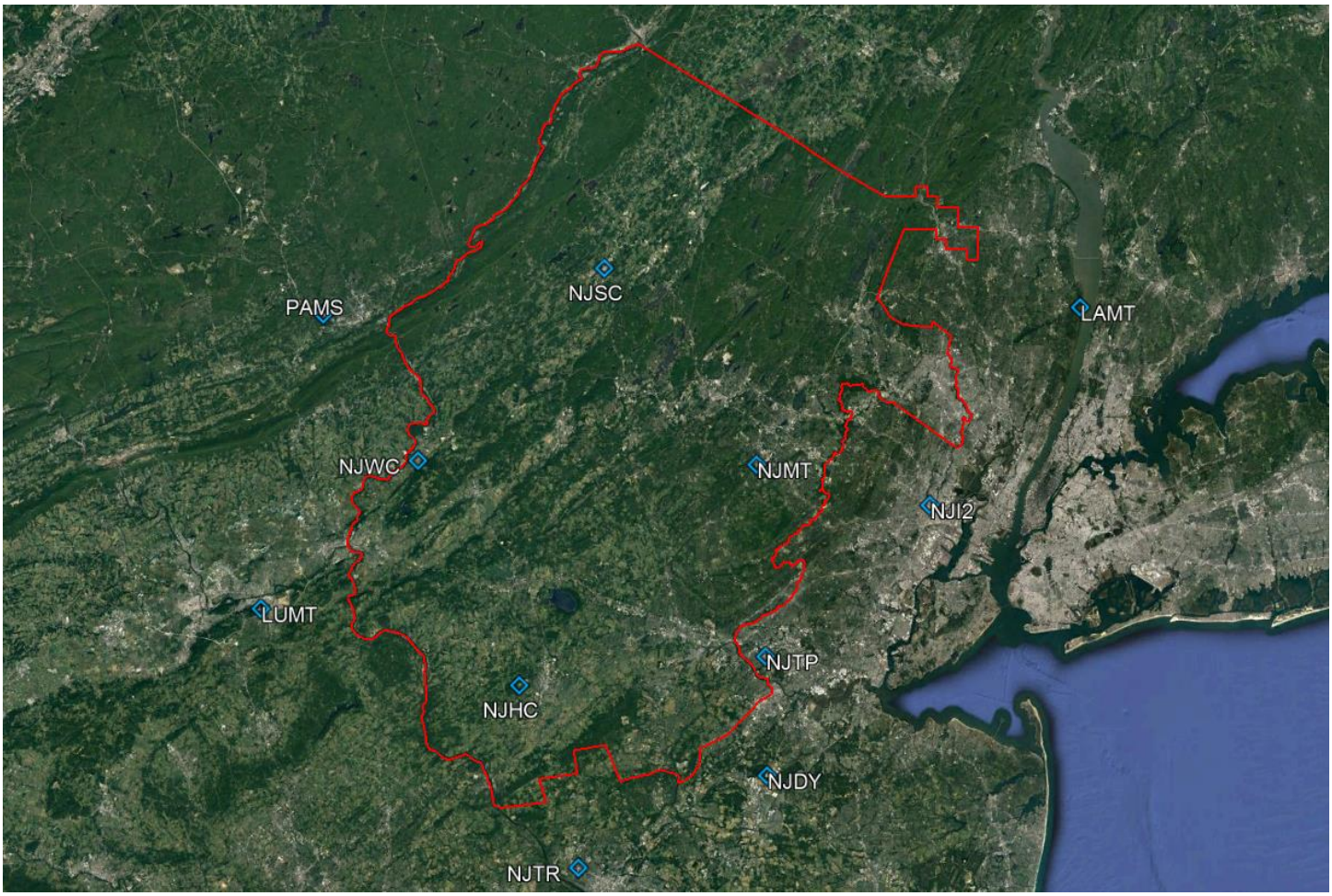


Figure 2: GNSS Reference Stations

3.0 PROCESSING

3.1 Introduction

The ABGNSS/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 CloudPro 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 calibration.

The Leica CloudPro 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 5** illustrates the achieved point cloud statistics.

Category	Value
Aggregate Total Points	30,097,024,116
Aggregate Nominal Pulse Spacing (m)	0.47
Aggregate Nominal Pulse Density (pls/m²)	4.5
Aggregate Nominal Pulse Spacing (ft)	1.55
Aggregate Nominal Pulse Density (pls/ft²)	0.4

Table 5: Point Cloud Statistics

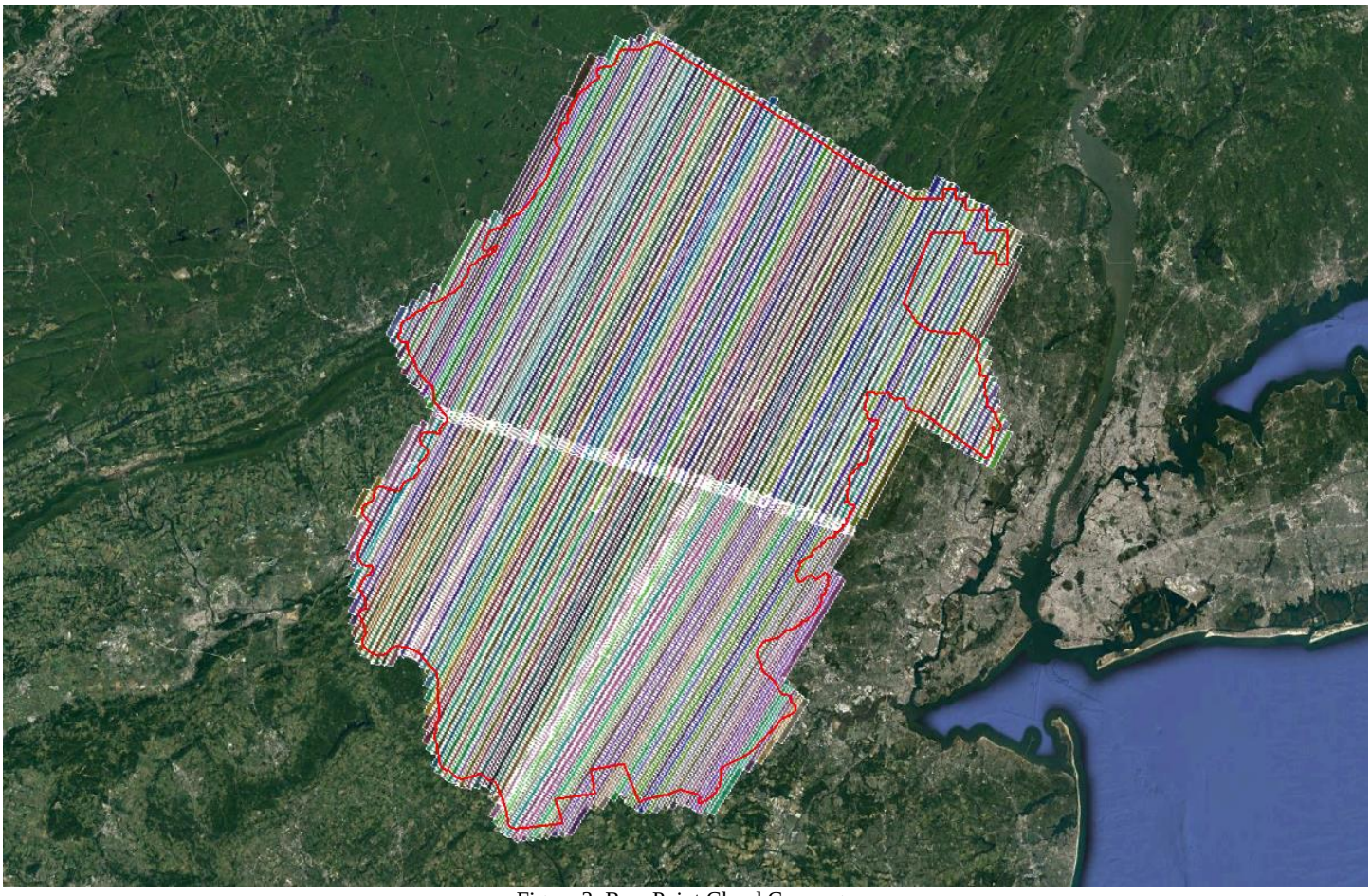


Figure 3: Raw Point Cloud Coverage

3.2 Coordinate Reference System

Horizontal Datum: North American Datum of 1983 (2011)
Projection: State Plane New Jersey (FIPS 2900)
Vertical Datum: North American Vertical Datum of 1988
Geoid Model: Geoid12B
Units: U.S. Survey Feet

3.3 Calibration

Sanborn uses Leica CloudPro 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 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.

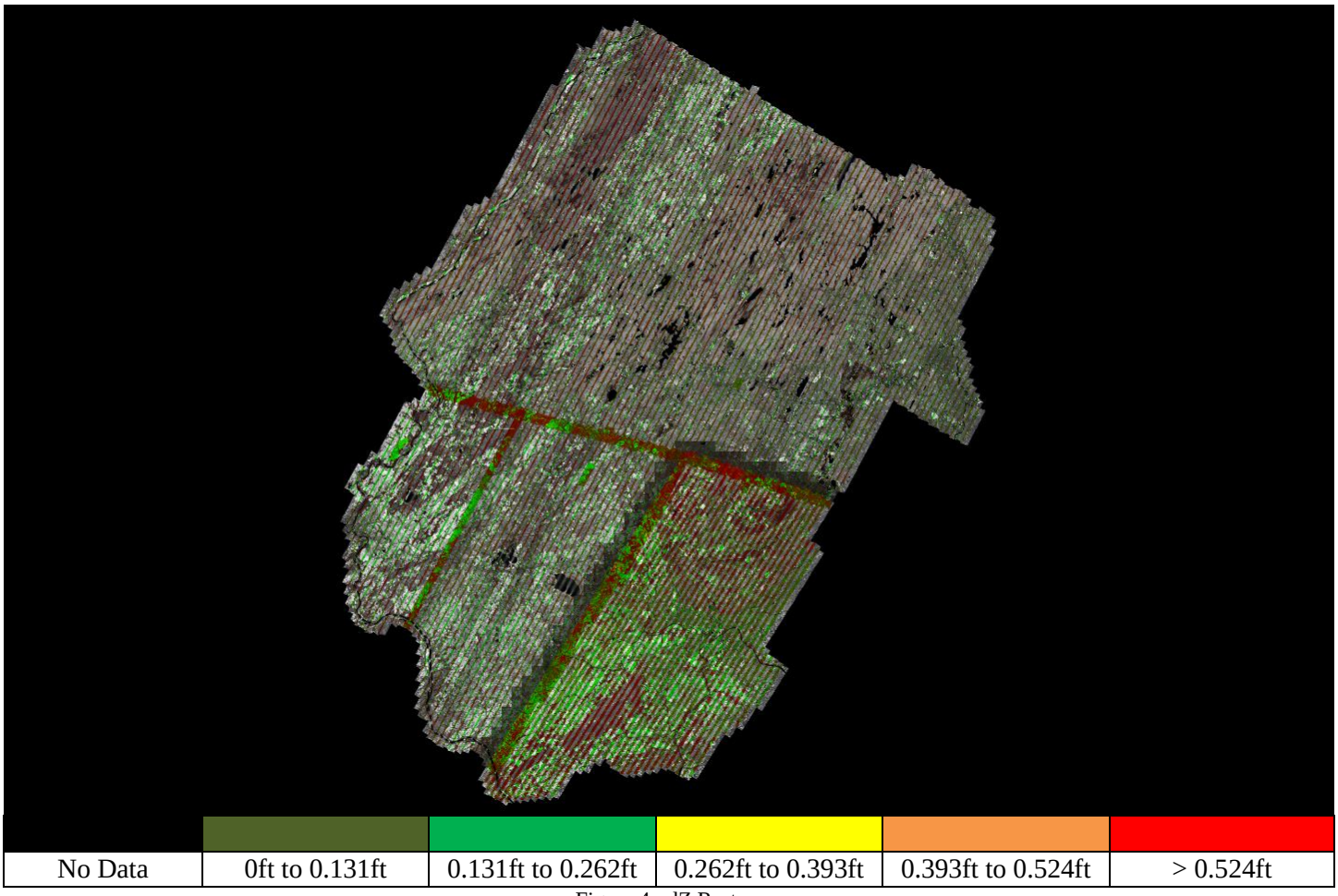
Each mission in imported into GeoCue where each individual flight line is assigned a unique flight line number. The SBET is cut per mission into TerraScan Trajectory files based on flight line number and timestamp to be utilized during the calibration process. The project area(s) are broken into logical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

After successful point cloud filters have been run on the calibration dataset TerraMatch is used to extract Tie Line Observations. TerraMatch Tie Lines are 3D vectors extracted from the lidar points 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 collected 3D vectors are then utilized across multiple 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, X, Y and Z in combination to reduce the Root Mean Square Deviation (RMSDr and RMSDz). These solutions are calculated, applied, and checked throughout the calibration 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 corrections are applied and a Tie Line Report is produced to assess the X. Y. and Z offset averages for each line and the project. This visual and statistical review guarantees the relative accuracy of the lidar dataset. **Table 6** outlines the relative accuracy requirements of the project. **Tables 7 – 10** 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 6: 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	0.172	0.208	0.032	**266**	0.158	0.161	0.041	**456**	0.114	0.132	0.073
2	0.114	0.127	0.031	**267**	0.170	0.178	0.042	**457**	0.138	0.139	0.116
3	0.153	0.193	0.032	**268**	0.193	0.224	0.040	**458**	0.105	0.090	0.080
4	0.133	0.169	0.030	**269**	0.309	0.336	0.048	**459**	0.073	0.070	0.032
5	0.092	0.114	0.037	**270**	0.140	0.140	0.056	**460**	0.129	0.133	0.035
6	0.123	0.148	0.055	**300**	0.121	0.112	0.049	**461**	0.136	0.104	0.042
7	0.084	0.091	0.050	**301**	0.233	0.242	0.066	**500**	0.138	0.085	0.049
8	0.114	0.125	0.046	**302**	0.161	0.169	0.064	**501**	0.090	0.101	0.045
9	0.110	0.140	0.033	**303**	0.205	0.221	0.061	**502**	0.159	0.149	0.058
10	0.097	0.133	0.036	**304**	0.205	0.213	0.051	**503**	0.214	0.187	0.062
11	0.091	0.135	0.037	**305**	0.177	0.171	0.041	**505**	0.096	0.102	0.048
12	0.094	0.138	0.037	**306**	0.181	0.168	0.043	**506**	0.100	0.106	0.051
13	0.081	0.123	0.035	**307**	0.127	0.130	0.040	**550**	0.129	0.131	0.055
14	0.133	0.217	0.045	**308**	0.127	0.121	0.035	**551**	0.128	0.141	0.054
15	0.071	0.125	0.034	**309**	0.111	0.101	0.047	**552**	0.127	0.155	0.044
16	0.075	0.134	0.038	**310**	0.127	0.169	0.064	**553**	0.126	0.143	0.048
17	0.085	0.158	0.036	**311**	0.126	0.171	0.038	**600**	0.142	0.129	0.064
18	0.079	0.140	0.034	**312**	0.105	0.133	0.035	**601**	0.093	0.091	0.046
19	0.073	0.089	0.034	**314**	0.103	0.128	0.027	**602**	0.079	0.080	0.038
20	0.147	0.181	0.039	**315**	0.118	0.134	0.032	**603**	0.079	0.076	0.042

50	0.392	0.395	0.043	**316**	0.129	0.146	0.055	**604**	0.084	0.096	0.068
51	0.422	0.365	0.042	**317**	0.151	0.167	0.090	**605**	0.144	0.133	0.126
52	0.404	0.346	0.049	**318**	0.113	0.130	0.084	**606**	0.089	0.073	0.059
53	0.421	0.370	0.046	**319**	0.154	0.155	0.079	**607**	0.095	0.070	0.047
54	0.500	0.476	0.042	**350**	0.178	0.161	0.066	**608**	0.116	0.096	0.044
55	0.464	0.397	0.039	**351**	0.163	0.145	0.058	**609**	0.180	0.153	0.050
56	0.482	0.435	0.040	**352**	0.149	0.148	0.053	**610**	0.263	0.190	0.051
57	0.495	0.451	0.044	**353**	0.158	0.146	0.055	**650**	0.171	0.166	0.071
58	0.477	0.449	0.044	**354**	0.202	0.183	0.055	**653**	0.070	0.074	0.092
59	0.530	0.456	0.047	**355**	0.210	0.191	0.079	**654**	0.085	0.075	0.105
60	0.458	0.419	0.047	**356**	0.256	0.218	0.063	**655**	0.056	0.057	0.050
61	0.487	0.419	0.048	**357**	0.235	0.213	0.063	**700**	0.101	0.102	0.049
62	0.391	0.321	0.050	**401**	0.087	0.080	0.083	**701**	0.140	0.126	0.056
63	0.501	0.378	0.049	**402**	0.164	0.188	0.058	**702**	0.104	0.114	0.051
101	0.222	0.198	0.048	**403**	0.331	0.320	0.039	**703**	0.067	0.061	0.044
102	0.183	0.162	0.052	**404**	0.256	0.220	0.052	**704**	0.087	0.087	0.041
103	0.163	0.157	0.049	**405**	0.243	0.221	0.055	**705**	0.097	0.095	0.056
104	0.194	0.196	0.037	**406**	0.189	0.179	0.042	**706**	0.124	0.109	0.058
105	0.170	0.157	0.046	**407**	0.193	0.222	0.043	**707**	0.090	0.094	0.064
106	0.164	0.131	0.040	**408**	0.173	0.194	0.039	**708**	0.204	0.200	0.082
107	0.168	0.162	0.041	**409**	0.174	0.161	0.039	**709**	0.115	0.087	0.069
108	0.207	0.193	0.056	**410**	0.189	0.178	0.042	**710**	0.113	0.090	0.059
109	0.176	0.197	0.071	**411**	0.197	0.158	0.033	**711**	0.101	0.095	0.055
150	0.200	0.177	0.071	**412**	0.151	0.123	0.039	**712**	0.120	0.104	0.068
250	0.095	0.084	0.059	**413**	0.178	0.142	0.039	**713**	0.097	0.089	0.088
251	0.388	0.306	0.057	**414**	0.211	0.175	0.039	**714**	0.083	0.083	0.073
252	0.104	0.097	0.048	**415**	0.258	0.213	0.058	**750**	0.137	0.100	0.095
253	0.200	0.179	0.051	**416**	0.176	0.138	0.050	**800**	0.138	0.136	0.090
254	0.207	0.189	0.052	**417**	0.162	0.118	0.042	**801**	0.116	0.114	0.093
255	0.137	0.114	0.038	**418**	0.176	0.132	0.038	**802**	0.086	0.115	0.064
256	0.231	0.209	0.051	**419**	0.178	0.137	0.043	**803**	0.097	0.143	0.048
257	0.188	0.170	0.049	**420**	0.136	0.110	0.051	**804**	0.096	0.123	0.051
258	0.172	0.146	0.038	**421**	0.150	0.127	0.059	**805**	0.081	0.069	0.045
259	0.176	0.156	0.044	**422**	0.231	0.186	0.087	**806**	0.083	0.084	0.042
260	0.177	0.162	0.046	**450**	0.168	0.151	0.065	**807**	0.086	0.098	0.048
261	0.206	0.170	0.046	**451**	0.130	0.124	0.043	**808**	0.096	0.090	0.058
262	0.195	0.171	0.047	**452**	0.145	0.139	0.039	**809**	0.105	0.087	0.059
263	0.145	0.143	0.047	**453**	0.137	0.138	0.046	**810**	0.093	0.095	0.076
264	0.167	0.178	0.043	**454**	0.133	0.117	0.053	**813**	0.092	0.097	0.069
265	0.136	0.132	0.040	**455**	0.106	0.096	0.052				

Table 7: Average Magnitudes by Line (Feet)

Category	X	Y	Z
Average Magnitude	0.173	0.169	0.049
RMS Values	0.281	0.256	0.075
Maximum Values	2.368	2.415	11.760
Observation Weight	417087.0	417087.0	1023451.0

Table 8: Internal Observation Statistics (Feet)

Category	Mismatch
Average 3D Mismatch	0.14402
Average XY Mismatch	0.26874
Average Z Mismatch	0.04940

Table 9: Overall Relative Accuracy (Feet)

Category	Observations
Section Lines	286,943
Roof Lines	204,830

Table 10: 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 with in the point cloud file based 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, removing bridges, structures, filling culverts, and manually analyzing the bare-earth surface by classifying features that belong in non-extraneous classification codes. **Table 11** 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 elevation
18	High Noise	Erroneous atmospheric returns above bare-earth surface
20	Ignored Ground	Bare-earth points near breaklines excluded from DEM
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 11: Lidar Classification Scheme

3.5 Accuracy Assessment

The lidar dataset was evaluated using a total of one hundred forty (140) check points (79 NVA + 61 VVA). The end result provided an RMSEz 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 12** outlines the absolute accuracy requirements of the project. **Table 13** shows high level statistics and mean errors for the area processed by Sanborn.

Category	Value
RMSEz (ft)	≤0.328
@ 95% Confidence Level (ft)	≤0.643
95th Percentile (ft)	≤0.984

Table 12: Absolute Accuracy Requirements

Broad Land Cover Type	# of Points	RMSEz	95% Confidence Level	95th Percentile
NVA of Point Cloud	79	0.262	0.513	
NVA of Bare Earth	79	0.259	0.508	
NVA of DEM	79	0.257	0.503	
VVA of Bare Earth	61	0.216		0.373
VVA of DEM	61	0.209		0.354

Table 13: Vertical Accuracy Assessment of Check Points (Feet)

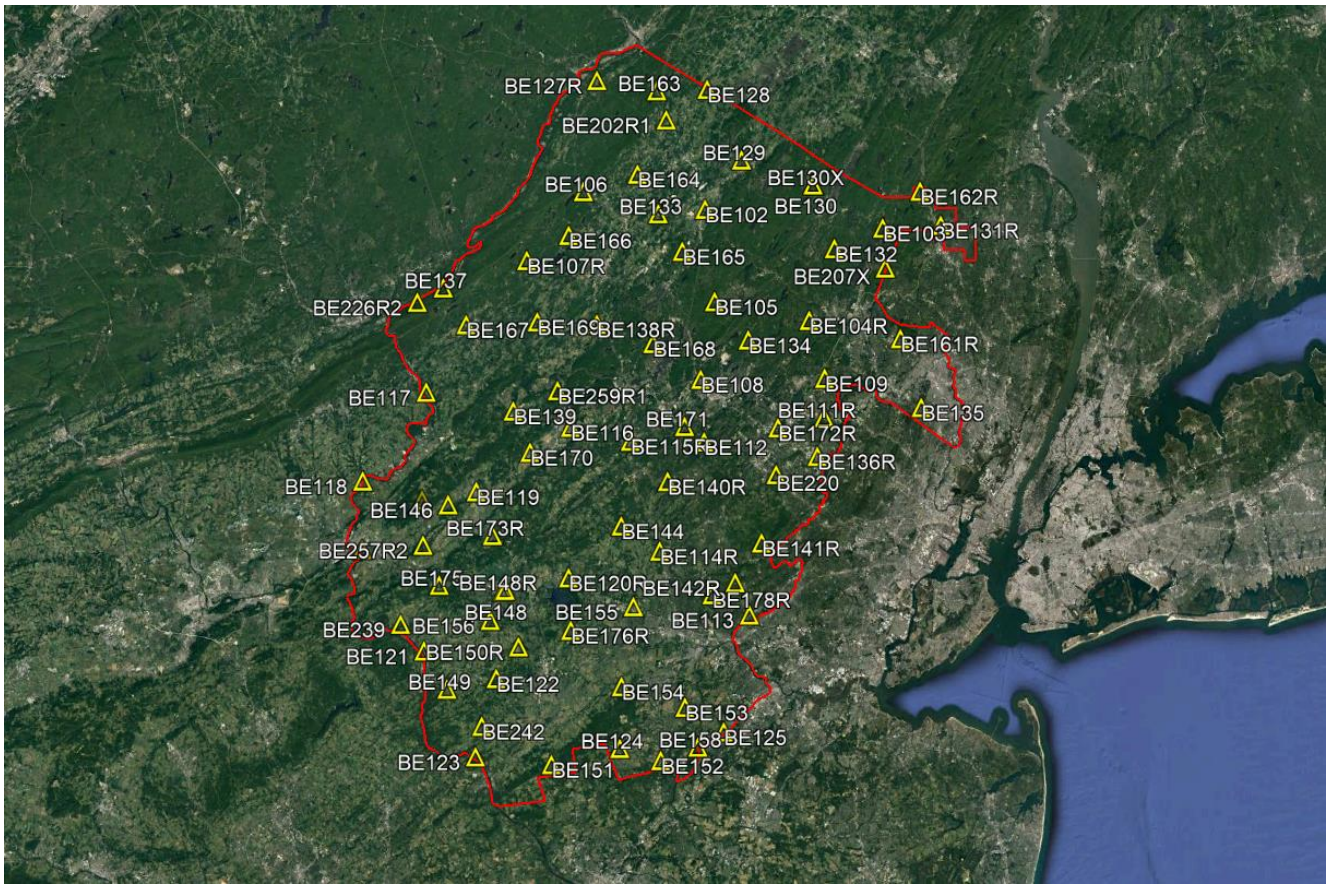


Figure 5: Non-vegetated Check Point Distribution

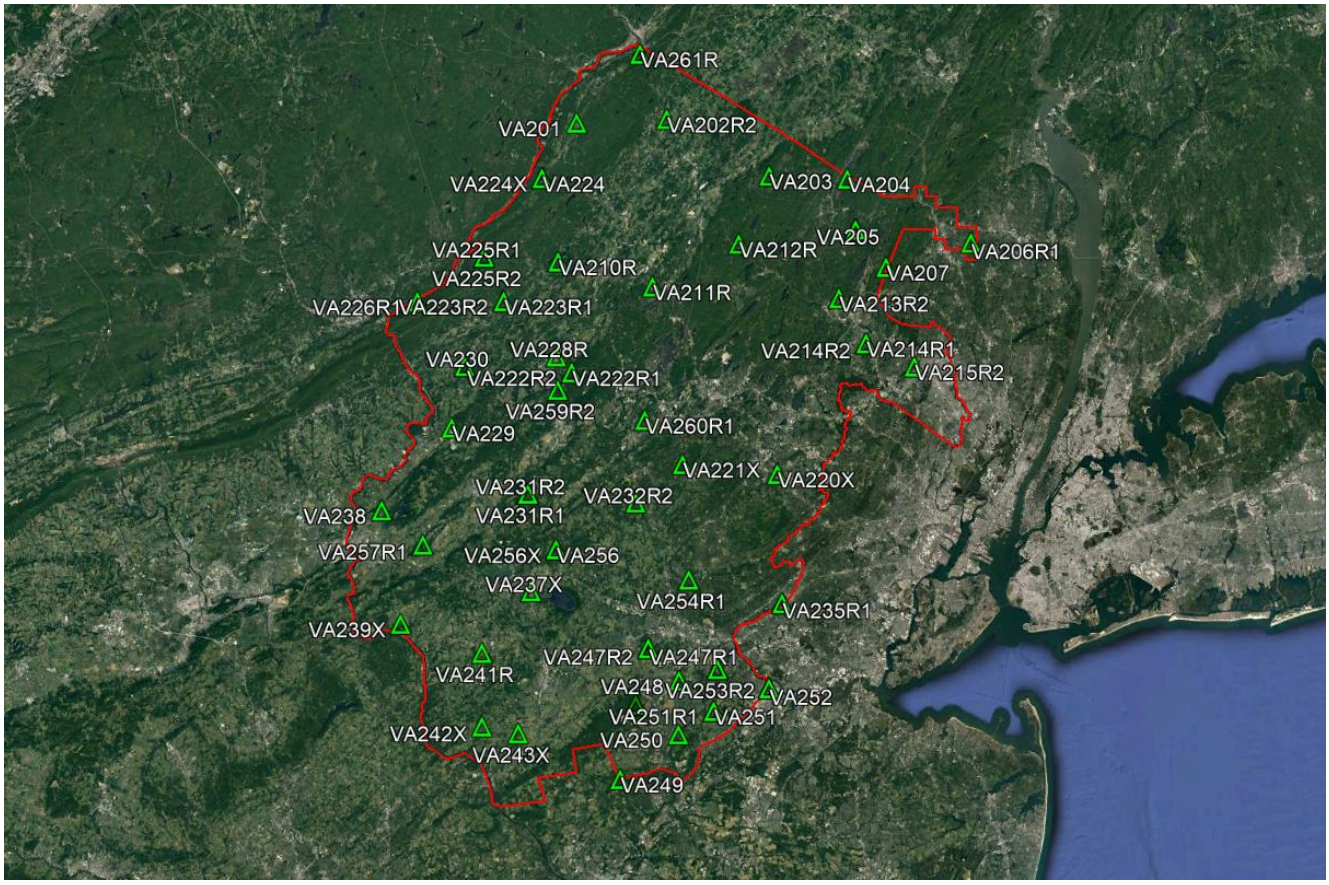


Figure 6: Vegetated Check Point Distribution

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.

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 Terrain Model
32-bit ERDAS Imagine (*.img) 2 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.

Breaklines
Esri Geodatabase (*.gdb) containing all hydro-flattened and additional bridge and/or supporting 3D breaklines.

Intensity Rasters
8-bit ERDAS Imagine (*.img) 2 ft intensity rasters were created from the first-return points in the processed lidar dataset.

Other Deliverables
Vertical Accuracy Report
Supporting Shapefiles
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.