AIRBORNE LIDAR PROJECT REPORT

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CINCINNATI, OH NGA LIDAR

DELIVERY ORDER #0002

Woolpert Project Number: 74866
March 2015

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SECTION 1: OVERVIEW

TASK ORDER NAME: NGA LIDAR, CINCINNATI, OH

WOOLPERT PROJECT #74866

This report contains a comprehensive outline of the airborne LiDAR data acquisition for Cincinnati, OH. The project area was approximately 950 square kilometers. The LiDAR was processed to meet the Nominal Post Spacing (NPS) requirement of 1.0 meter. The NPS assessment is made against single swath, first return data located within the geometrically usable center portion (typically ~90%) of each swath.

The data was collected using a Leica ALS70 500 kHz Multiple Pulses in Air (MPiA) LiDAR sensor. This sensor collects up to four returns per pulse, as well as intensity data for the first three returns. If a fourth return was captured, the system does not record an associated intensity value. The aerial LiDAR was collected at the following sensor specifications:

Post Spacing (Minimum):	3.28 ft / 1.0 m
AGL (Above Ground Level) average flying height:	7,577 ft / 2,309 m
Average Ground Speed:	150 knots / 173 mph
Field of View (full):	40 degrees
Pulse Rate:	237 kHz
Scan Rate:	35.6 Hz
Side Lap (Minimum):	25 %

LiDAR data was produced in Universal Transverse Mercator (UTM) Zone 16N, WGS84. Coordinate positions were specified in units of meters. The vertical datum used for the project was referenced to NAVD 1988, meters, GEOID12A.

SECTION 2: ACQUISITION

The LiDAR data was acquired with a Leica ALS70 500 kHz Multiple Pulses in Air (MPiA) LiDAR sensor system, on board a Cessna aircraft. The ALS70 LiDAR system, developed by Leica Geosystems of Heerbrugg, Switzerland, includes the simultaneous first, intermediate and last pulse data capture module, the extended altitude range module, and the target signal intensity capture module. The system software is operated on an OC50 Operation Controller aboard the aircraft.

The ALS70 500 kHz Multiple Pulses in Air (MPiA) LiDAR System has the following specifications:

Table 2.1 ALS70 LiDAR System Specifications

Specification	
Operating Altitude	200 – 3,500 meters
Scan Angle	0 to 75° (variable)
Swath Width	0 to 1.5 X altitude (variable)
Scan Frequency	0 – 200 Hz (variable based on scan angle)
Maximum Pulse Rate	500 kHz (Effective)
Range Resolution	Better than 1 cm
Elevation Accuracy	7 - 16 cm single shot (one standard deviation)
Horizontal Accuracy	5 – 38 cm (one standard deviation)
Number of Returns per Pulse	7 (infinite)
Number of Intensities	3 (first, second, third)
Intensity Digitization	8 bit intensity + 8 bit AGC (Automatic Gain Control) level
MPiA (Multiple Pulses in Air)	8 bits @ 1nsec interval @ 50kHz
Laser Beam Divergence	0.22 mrad @ $1/e^2$ (~0.15 mrad @ 1/e)
Laser Classification	Class IV laser product (FDA CFR 21)
Eye Safe Range	400m single shot depending on laser repetition rate
Roll Stabilization	Automatic adaptive, range = 75 degrees minus current FOV
Power Requirements	28 VDC @ 25A
Operating Temperature	0-40°C
Humidity	0-95% non-condensing
Supported GNSS Receivers	Ashtech Z12, Trimble 7400, Novatel Millenium

Prior to mobilizing to the project site, Woolpert flight crews coordinated with the necessary Air Traffic Control personnel to ensure airspace access.

The LiDAR data was collected in five missions to ensure consistent ground conditions across the project area.

An initial quality control process was performed immediately on the LiDAR data to review the data coverage, airborne GPS data, and trajectory solution. Any gaps found in the LiDAR data were relayed to the flight crew, and the area was re-flown.

Table 2.2 Airborne LiDAR Acquisition Flight Summary

Airborne LiDAR Acquisition Flight Summary			
Date of Mission	Lines Flown	Mission Time (UTC) Wheels Up/ Wheels Down	Mission Time (Local = EDT) Wheels Up/ Wheels Down
March 12, 2015	1-8	14:21-16:32	10:21 AM-12:32 PM
March 15, 2015	9	14:04-14:31	10:04 AM-02:31 PM
March 15, 2015	10	14:49-20:10	02:49 PM-04:10 PM
March 15, 2015	11-31	23:00-03:40	06:00 PM-10:40 PM
March 25, 2015	32-50	17:44-20:36	01:44 PM-03:36 PM

After the initial reviews of the LiDAR data following the March 15th collection, it was determine that the water had exceeded their banks along the Ohio River within the Cincinnati, OH collection area, and supplemental LiDAR flight lines would have to be flown once the water level receded to normal levels. Polygons were created around all flooded areas and new supplemental LiDAR flight lines (flight lines 32 to 50) were flight planned and provided to our flight team. The LiDAR data was re-captured on March 25, 2015. All LiDAR data was thoroughly evaluated and deemed accepted.

SECTION 3: LIDAR DATA PROCESSING

APPLICATIONS AND WORK FLOW OVERVIEW

1. Resolved kinematic corrections for three subsystems: inertial measurement unit (IMU), sensor orientation information and airborne GPS data. Developed a blending post-processed aircraft position with attitude data using Kalman filtering technology or the smoothed best estimate trajectory (SBET).
   Software: Novatel Inertial Explorer 8.50.4320

2. Calculated laser point position by associating the SBET position to each laser point return time, scan angle, intensity, etc. Created raw laser point cloud data for the entire survey in LAS format. Automated line-to-line calibrations were then performed for system attitude parameters (pitch, roll, heading), mirror flex (scale) and GPS/IMU drift.
   Software: Leica Cloud Pro v 1.2.1, Proprietary Software, TerraMatch v. 14.007.

3. Imported processed LAS point cloud data into project tiles. Resulting data were classified as ground and non-ground points with additional filters created to meet the project classification specifications. Statistical absolute accuracy was assessed via direct comparisons of ground classified points to ground RTK survey data. Based on the statistical analysis, the LiDAR data was then adjusted in relation to the survey ground control.
   Software: TerraScan v.14.024.

4. The LAS files were evaluated through a series of QA/QC steps to eliminate remaining artifacts and small undulations from the ground class.
   Software: TerraScan v.14.024.

GLOBAL NAVIGATION SATELLITE SYSTEM (GNSS)-INERTIAL MEASUREMENT UNIT (IMU) TRAJECTORY PROCESSING

EQUIPMENT

Flight navigation during the LiDAR data acquisition mission is performed using IGI CCNS (Computer Controlled Navigation System). The pilots are skilled at maintaining their planned trajectory, while holding the aircraft steady and level. If atmospheric conditions are such that the trajectory, ground speed, roll, pitch and/or heading cannot be properly maintained, the mission is aborted until suitable conditions occur.

The aircraft are all configured with a NovAtel Millennium 12-channel, L1/L2 dual frequency Global Navigation Satellite System (GNSS) receivers collecting at 2 Hz.

All Woolpert aerial sensors are equipped with a Litton LN200 series Inertial Measurement Unit (IMU), operating at 200 Hz.

The Continuously Operating Reference Station (CORS) station used during the LiDAR acquisition mission is listed on the next page:

Table 3.1: GNSS Base Station

Station	Latitude	Longitude	Ellipsoid Height (L1 Phase Center)
Name	(DMS)	(DMS)	(Meters)
KYTF_CORS	N 39° 02’ 40.92840”	W -84° 34’ 36.88359”	229.250
LEBA_CORS	N 39° 25’ 49.78839”	W -84° 16’ 59.28357”	225.533

DATA PROCESSING

All airborne GNSS and IMU data was post-processed and quality controlled using Applanix MMS software. GNSS data was processed at a 1 and 2 Hz data capture rate and the IMU data was processed at 200 Hz.

TRAJECTORY QUALITY

The GNSS Trajectory, along with high quality IMU data are key factors in determining the overall positional accuracy of the final sensor data. See **Figure 3.1** for the flight trajectory.

Flight Trajectory

Figure 3.1: Representative Graph from Day07415: N111SD

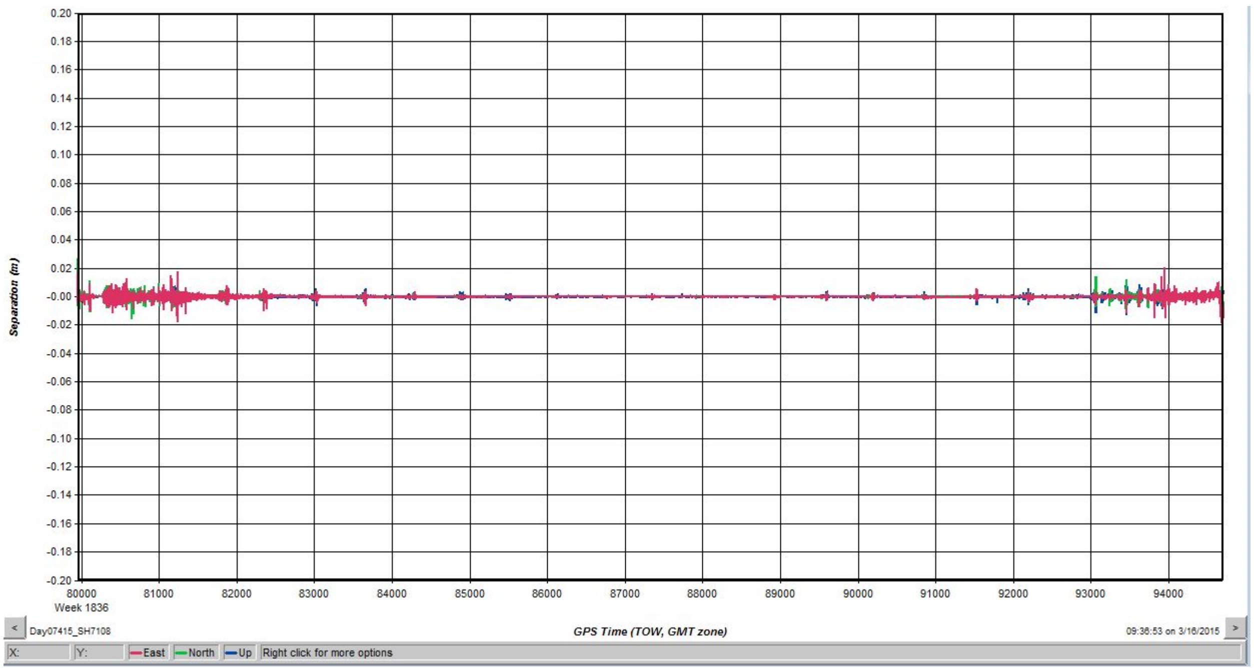
Within the trajectory processing, there are many factors that affect the overall quality, but the most indicative are the Combined Separation, the Estimated Positional Accuracy, and the Positional Dilution of Precision (PDOP).

Combined Separation

The Combined Separation is a measure of the difference between the forward run and the backward run solution of the trajectory. The Kalman filter is processed in both directions to remove the combined directional anomalies. In general, when these two solutions match closely, an optimally accurate reliable solution is achieved.

Woolpert's goal is to maintain a Combined Separation Difference of less than ten (10) centimeters. In most cases we achieve results below this threshold. See **Figure 3.2** for the combined separation graph.

Figure 3.2: Representative Graph from Day07415: N111SD

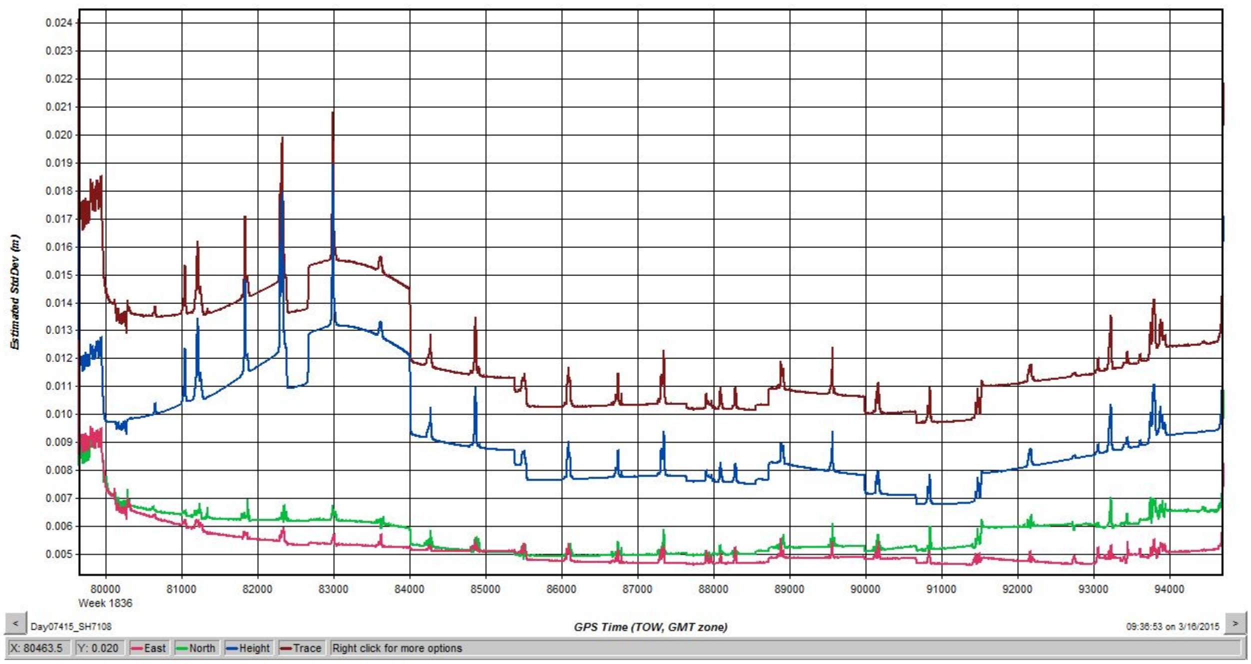


Estimated Positional Accuracy

The Estimated Positional Accuracy plots the standard deviations of the east, north, and vertical directions along a time scale of the trajectory. It illustrates loss of satellite lock issues, as well as issues arising from long baselines, noise, and/or other atmospheric interference.

Woolpert's goal is to maintain an Estimated Positional Accuracy of less than ten (10) centimeters, often achieving results well below this threshold.

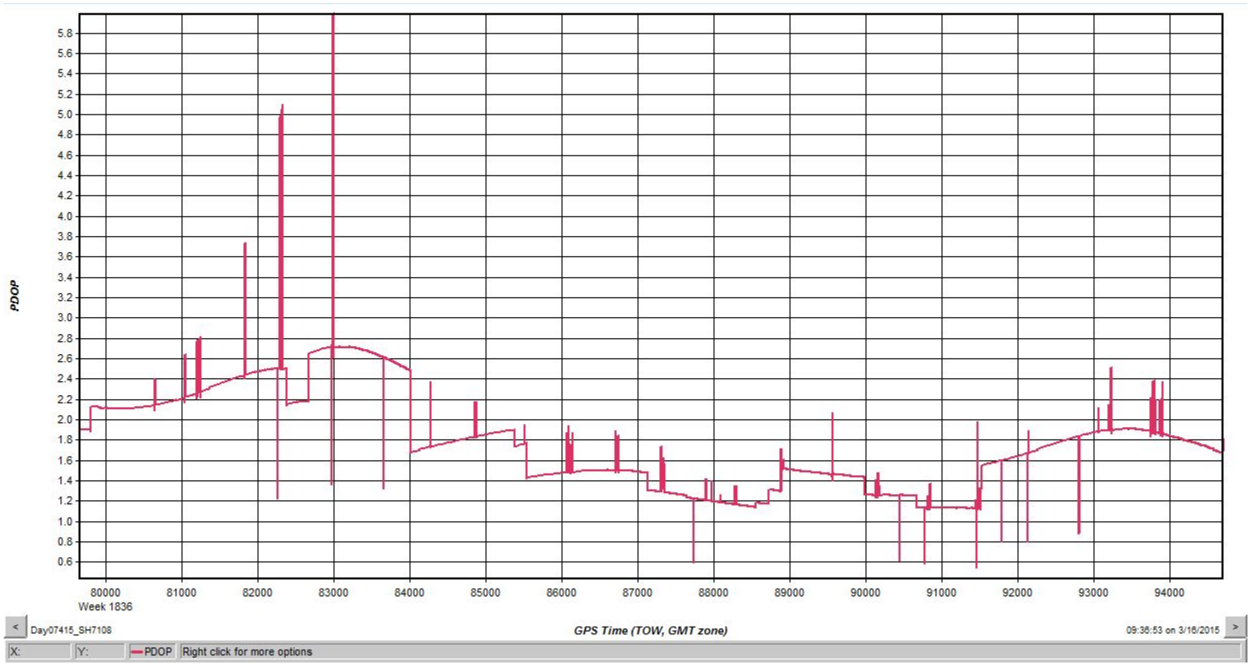
Figure 3.3: Representative Graph from Day07415: N111SD



Positional Dilution of Precision (PDOP)

The PDOP measures the precision of the GPS solution in regards to the geometry of the satellites acquired and used for the solution. Woolpert's goal is to maintain an average PDOP value below 3.0. Brief periods of PDOP over 3.0 are acceptable due to the calibration and control process if other metrics are within specification. See **Figure 3.4** for the PDOP Graph.

Figure 3.4 Representative Graph from Day07415: N111SD



LIDAR DATA PROCESSING AND FEATURE EXTRACTION

When the sensor calibration, data acquisition, and GPS processing phases were complete, the formal data reduction processes by Woolpert LiDAR specialists included:

- Processed individual flight lines to derive a "Point Cloud". Matched overlapping flight lines, generated statistics for evaluation comparisons, and made the necessary adjustments to remove any residual systematic error.

- Calibrated LAS files were imported into project tiles and initially filtered to create a ground and non-ground class. Then additional classes are filtered as necessary to meet client specified classes.

- Once all project data was imported and classified, survey ground control data was imported and calculated for an accuracy assessment. As a QA/QC measure, Woolpert has developed a routine to generate accuracy statistical reports by comparison among LiDAR points, ground control, and TINs. The LiDAR is adjusted accordingly to meet or exceed the vertical accuracy requirements.

- The LiDAR data in LAS format was reviewed using a series of proprietary QA/QC procedures to ensure it fulfills the project requirements.

- The LiDAR LAS files for this project have been classified into the Default (Class 1), Ground (Class 2), Noise (Class 7), and Vegetation (Class 5) classifications.

- Final deliverable data was derived from the adjusted classified LiDAR data.

- Automated Feature Extraction: Using proprietary Leidos software the raw LiDAR and bare earth model were processed to extract and attribute building and vegetation features. Automated extraction was followed by detailed Q/C to verify completeness and accuracy of extraction. Final QA/QC features were attributed with geometrically derived attributes based on feature extents, reflective surface DEM and bare earth DEM.

SECTION 4: FINAL ACCURACY ASSESSMENT

FINAL VERTICAL ACCURACY ASSESSMENT

The vertical accuracy statistics were calculated by comparison of the LiDAR bare earth points to the ground surveyed QA/QC points.

Table 4.1: Overall Vertical Accuracy Statistics

Average error	0.016	meters
Minimum error	-0.103	meters
Maximum error	0.119	meters
Average magnitude	0.050	meters
Root mean square	0.063	meters
Standard deviation	0.062	meters

Table 4.2: QA/QC FVA Bare Earth Open Terrain Analysis UTM 16N, WGS84 Meters

Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Laser Elevation (meters)	Dz (meters)
2	701377.736	4327086.500	257.273	257.250	-0.023
3	708239.095	4323784.925	250.443	250.500	0.057
10	723424.958	4332761.377	144.246	144.250	0.004
14	716607.924	4338806.189	162.423	162.320	-0.103
15	715192.578	4334744.309	243.663	243.630	-0.033
16	711978.545	4337947.912	166.735	166.740	0.005
21	703672.819	4330454.897	245.049	245.000	-0.049
23	725950.114	4324046.808	150.184	150.200	0.016
24	727311.630	4329103.557	219.934	219.990	0.056
26	726536.801	4345624.654	256.915	257.010	0.095
28	722181.332	4351209.092	177.156	177.220	0.064
33	715281.456	4345529.109	252.141	252.260	0.119
35	713675.895	4352693.950	258.258	258.370	0.112
39	705068.178	4343009.553	251.507	251.460	-0.047
40	704521.354	4341280.565	259.766	259.760	-0.006
41	702238.375	4340804.620	216.179	216.180	0.001
42	701972.345	4331619.727	251.341	251.370	0.029
44	700708.138	4337949.591	214.353	214.300	-0.053
46	721092.625	4322997.490	258.107	258.210	0.103
50	704452.713	4337913.368	269.794	269.760	-0.034

VERTICAL ACCURACY CONCLUSIONS

LAS Swath Fundamental Vertical Accuracy (FVA) Tested 0.123 meters fundamental vertical accuracy at a 95 percent confidence level, derived according to NSSDA, in open terrain using 0.063 meters (RMSEz) x 1.96000 as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation Program (NDEP)/ASPRS Guidelines, Tested against the TIN.

Bare-Earth DEM Fundamental Vertical Accuracy (FVA) Tested 0.128 meters fundamental vertical accuracy at a 95 percent confidence level, derived according to NSSDA, in open terrain using 0.065 meters (RMSEz) x 1.96000 as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation Program (NDEP)/ASPRS Guidelines and tested against the DEM.

Table 4.3: QA/QC SVA Urban Analysis UTM 16N, WGS84 Meters

Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Laser Elevation (meters)	Dz (meters)
1	702546.268	4323574.017	256.709	256.620	-0.089
3	708239.095	4323784.925	250.443	250.390	-0.053
4	711107.428	4329172.503	148.821	148.680	-0.141
5	713245.368	4323741.104	166.366	166.360	-0.006
7	721647.986	4329252.748	149.345	149.340	-0.005
8	718198.328	4331840.758	166.422	166.400	-0.022
12	724309.898	4338871.488	181.647	181.660	0.013
13	719718.164	4334823.900	225.680	225.640	-0.040
17	713031.490	4332605.125	149.894	149.840	-0.054
18	707240.098	4338845.186	272.324	272.230	-0.094
19	708353.862	4333427.669	253.236	253.300	0.064
20	703687.652	4335249.940	249.027	248.940	-0.087
24	727311.630	4329103.557	219.934	219.950	0.016
25	729236.446	4340056.488	260.542	260.650	0.108
27	725413.530	4351780.265	228.573	228.540	-0.033
31	719587.130	4340430.968	183.228	183.250	0.022
32	714205.038	4340655.260	201.397	201.380	-0.017
36	711688.341	4344431.029	248.541	248.430	-0.111
37	710815.184	4339843.713	230.533	230.490	-0.043
38	708360.118	4342171.682	260.611	260.570	-0.041
43	700116.311	4333072.569	153.136	153.090	-0.046
45	698879.356	4343310.739	154.168	154.080	-0.088
47	724448.366	4343175.371	257.962	258.000	0.038
48	717256.781	4343384.461	178.503	178.490	-0.013

VERTICAL ACCURACY CONCLUSIONS

Urban Land Cover Classification Supplemental Vertical Accuracy (SVA) Tested 0.134 meters supplemental vertical accuracy at the 95th percentile in the Urban supplemental class reported using National Digital Elevation Program (NDEP)/ASPRS Guidelines and tested against the DEM. Urban Errors larger than 95th percentile include:
Point 4, Easting 711107.428, Northing 4329172.503, Z-Error 0.141 meters

VERTICAL ACCURACY CONCLUSIONS

Consolidated Vertical Accuracy (CVA) Tested 0.134 meters consolidated vertical accuracy at the 95th percentile level; reported using National Digital Elevation Program (NDEP)/ASPRS Guidelines and tested against the DEM. CVA is based on the 95th percentile error in all land cover categories combined. CVA errors larger than 95th percentile include:
Point 4, Easting 711107.428, Northing 4329172.503, Z-Error 0.141 meters
Point 35, Easting 713675.895, Northing 4352693.950, Z-Error 0.152 meters

Approved By:			
Title	Name	Signature	Date
Associate Member LiDAR Specialist Certified Photogrammetrist #1281	Qian Xiao		April 1, 2015

SECTION 5: FINAL DELIVERABLES

FINAL DELIVERABLES

The final deliverables are listed below:

- Two sets of LiDAR data reflective surface data in 1.0 meter IMG format.
- Two sets of LiDAR data bare earth data in 1.0 meter IMG format.
- Two sets of LiDAR data last return data in 1.0 meter IMG format.
- Two sets of LiDAR data intensity data in 1.0 meter IMG.
- LAS classified point cloud files in tile format in 2,000 meter x 2,000 meter overlapping tiles.
- Feature extracted data from LiDAR collection to include 3-D buildings, 2-D building footprints, tree points, and forest polygons.
- FGDC compliant metadata provided per deliverable product file and as project level file.
- Project History Folder

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