AIRBORNE LIDAR PROJECT REPORT

KNOXVILLE, TN NGA LIDAR

DELIVERY ORDER #0002

Woolpert Project Number: 74866
January 2015

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SECTION 1: OVERVIEW

TASK ORDER NAME: NGA LIDAR

WOOLPERT PROJECT #74866

This report contains a comprehensive outline of the airborne LiDAR data acquisition for Knoxville, TN. The project area was approximately 445 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:	7,800 ft / 2,377 m
Average Ground Speed:	150 knots / 173 mph
Field of View (full):	40 degrees
Pulse Rate:	230 kHz
Scan Rate:	34.4 Hz
Side Lap (Minimum):	25 %

LiDAR data was produced in Universal Transverse Mercator (UTM) Zone 17N, 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.

Woolpert survey crews were onsite, operating a Global Navigation Satellite System (GNSS) Base Station for the airborne GPS support.

The LiDAR data was collected in one mission 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
October 24, 2014	1-21	15:30-19:13	11:30 AM-03:13 PM

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: ALS Post Processing Software v.2.74, 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.

Woolpert survey crews were onsite, operating a Global Navigation Satellite System (GNSS) Base Station for the ground control at NGS PID FB3476. The base 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)
NGS PID FB3476 Base	N 35° 51' 27.26863"	W -83° 31' 30.74609"	271.378

DATA PROCESSING

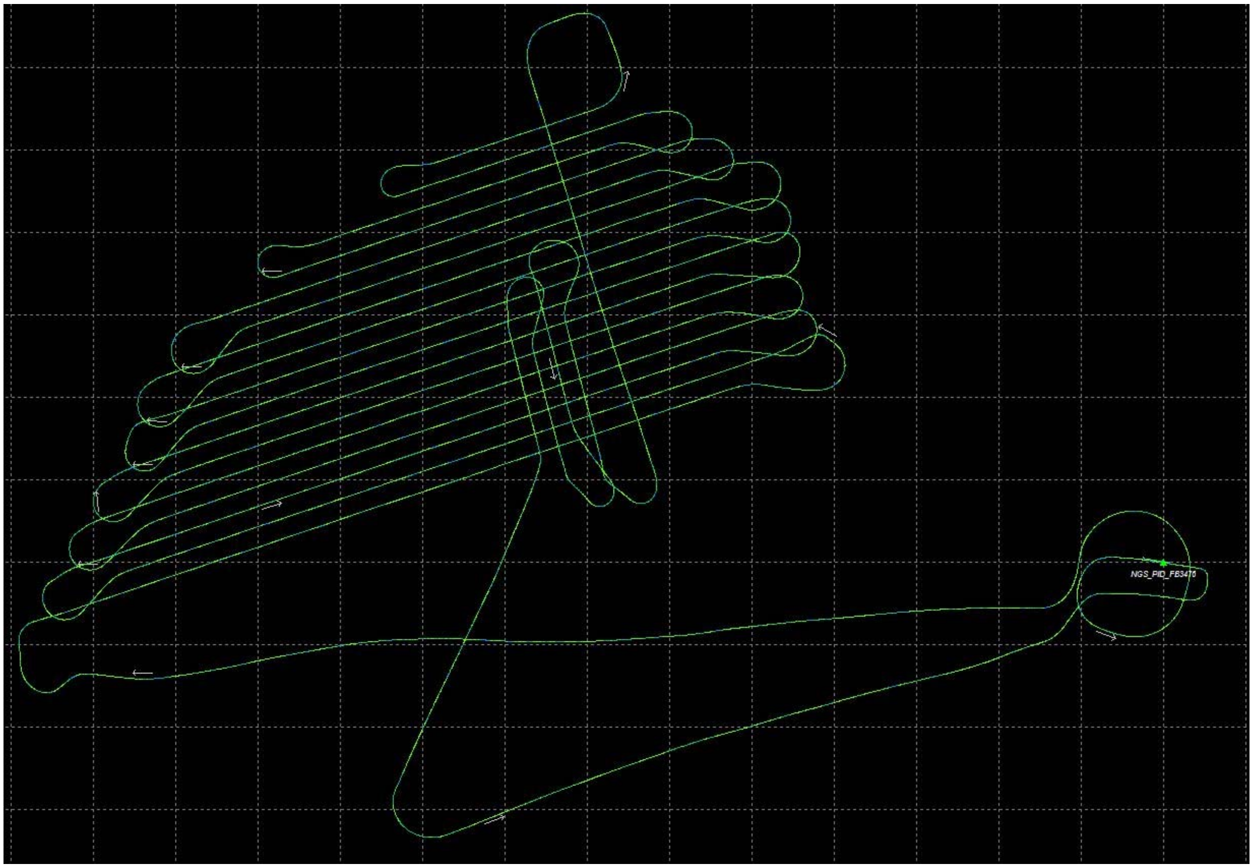
All airborne GNSS and IMU data was post-processed and quality controlled using Applanix MMS software. GNSS data was processed at a 1 and 2 Hz data capture rate and the IMU data was processed at 200 Hz.

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 Day29714: N111SD



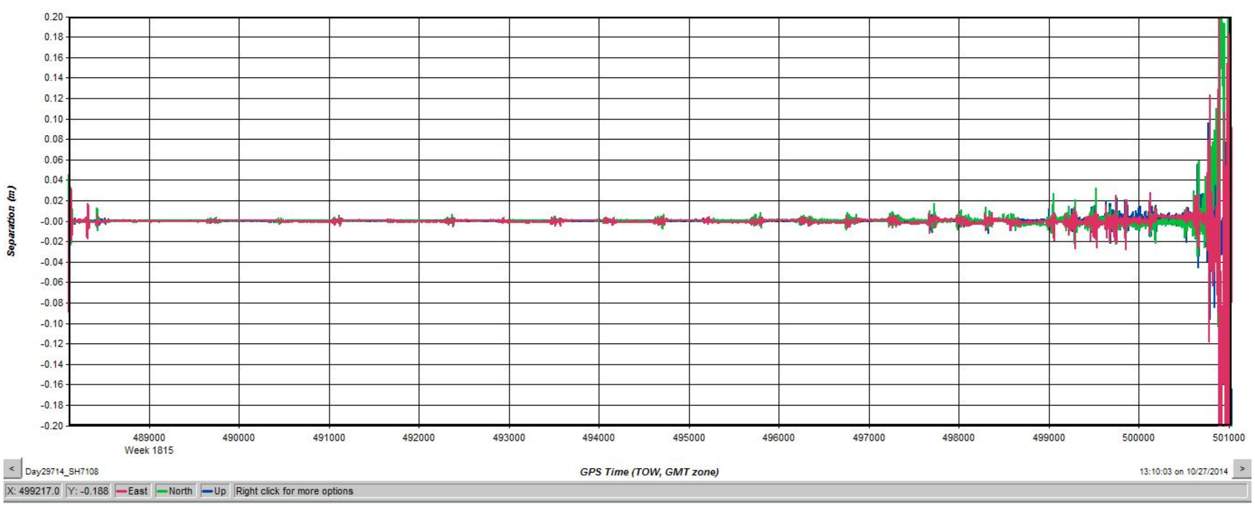
Within the trajectory processing, there are many factors that affect the overall quality, but the most indicative are the Combined Separation, the Estimated Positional Accuracy, and the Positional Dilution of Precision (PDOP).

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 Day29714: N111SD

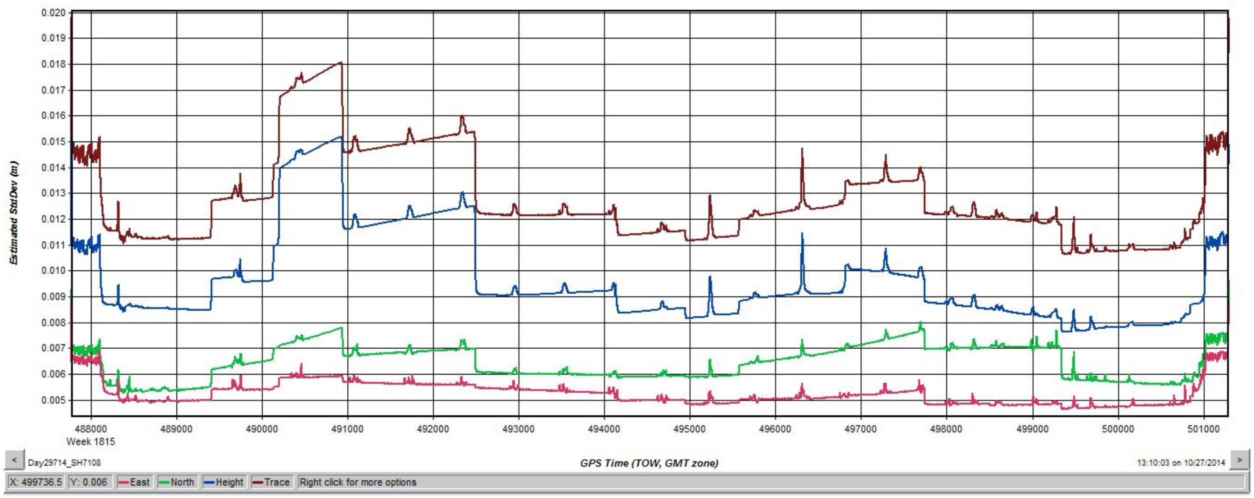


Estimated Positional Accuracy

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.

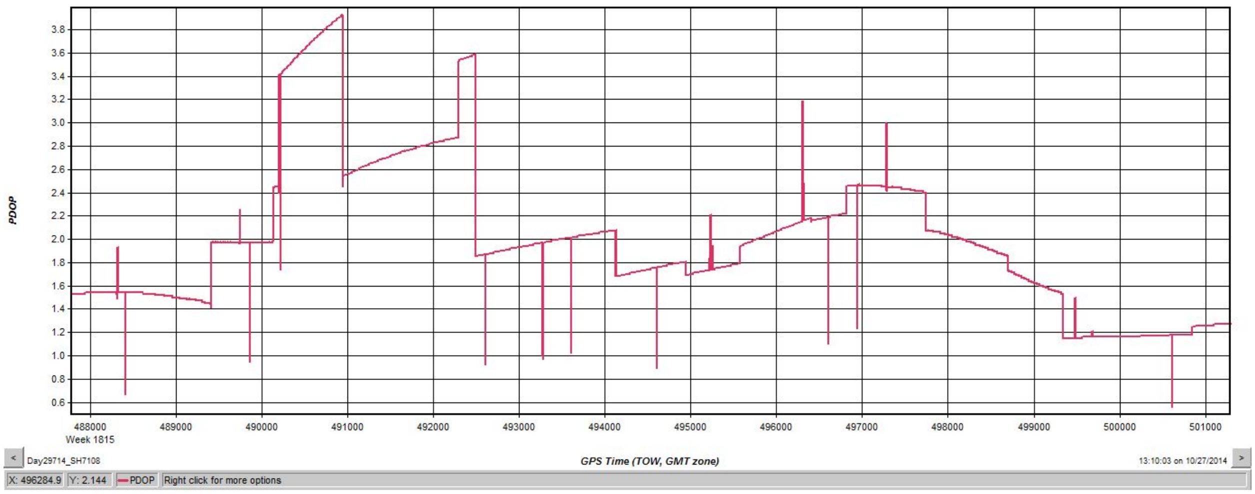
Figure 3.3: Representative Graph from Day29714: N111SD



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 Day29714: 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	0.003	meters
Minimum error	-0.127	meters
Maximum error	0.073	meters
Average magnitude	0.042	meters
Root mean square	0.053	meters
Standard deviation	0.054	meters

Table 4.2: QA/QC FVA Bare Earth Open Terrain Analysis UTM 17N, WGS84 Meters

Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Laser Elevation (meters)	Dz (meters)
NOX006	240139.666	3986616.471	291.845	291.890	0.045
NOX007	242143.961	3985088.970	250.720	250.730	0.010
NOX008	244036.464	3981881.180	259.877	259.750	-0.127
NOX009	239851.444	3982362.149	269.369	269.320	-0.049
NOX013	231210.813	3981995.695	278.411	278.430	0.019
NOX014	233323.504	3980696.559	249.206	249.160	-0.046
NOX016	235802.402	3997884.615	325.426	325.420	-0.006
NOX018	236699.486	3993433.208	346.347	346.390	0.043
NOX021	237259.151	3989573.927	302.444	302.510	0.066
NOX024	237695.507	3985804.604	274.177	274.180	0.003
NOX026	234376.927	3984955.742	278.239	278.190	-0.049
NOX032	225225.288	3989560.738	307.230	307.300	0.070
NOX034	229678.386	3985889.762	312.697	312.770	0.073
NOX036	222722.958	3986710.682	335.199	335.270	0.071
NOX040	218724.356	3983193.948	298.611	298.630	0.019
NOX049	215656.616	3976542.930	274.407	274.440	0.033
NOX050	221584.383	3978292.385	284.690	284.670	-0.020
NOX051	220984.973	3980843.722	291.434	291.460	0.026
NOX056	226577.651	3979045.790	284.244	284.240	-0.004
NOX058	222866.363	3976326.309	269.658	269.640	-0.018
NOX060	230369.664	3979457.568	258.181	258.090	-0.091

VERTICAL ACCURACY CONCLUSIONS

LAS Swath Fundamental Vertical Accuracy (FVA) Tested 0.104 meters fundamental vertical accuracy at a 95 percent confidence level, derived according to NSSDA, in open terrain using 0.053 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 0.093 meters fundamental vertical accuracy at a 95 percent confidence level, derived according to NSSDA, in open terrain using 0.047 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 17N, WGS84 Meters

Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Laser Elevation (meters)	Dz (meters)
NOX001	240101.695	3994336.058	307.946	307.930	-0.016
NOX003	241793.760	3989639.894	280.785	280.730	-0.055
NOX010	237850.729	3980909.392	269.314	269.210	-0.104
NOX017	234402.136	3997019.287	323.552	323.550	-0.002
NOX020	236442.733	3992264.982	307.421	307.370	-0.051
NOX025	237159.116	3984243.355	272.062	271.960	-0.102
NOX027	233492.747	3986114.597	284.990	284.930	-0.060
NOX028	233790.753	3989419.409	314.350	314.290	-0.060
NOX029	230379.770	3993266.028	302.777	302.680	-0.097
NOX031	222600.159	3990250.834	354.596	354.550	-0.046
NOX035	228663.838	3987280.740	317.701	317.660	-0.041
NOX038	220197.954	3988000.206	310.081	310.080	-0.001
NOX039	219413.798	3985758.745	302.104	302.090	-0.014
NOX041	216703.613	3981811.872	315.166	315.120	-0.046
NOX043	215381.046	3978625.932	277.513	277.450	-0.063
NOX044	217404.250	3979115.160	300.861	300.830	-0.031
NOX045	213975.035	3974576.900	286.754	286.630	-0.124
NOX046	211544.880	3971874.745	292.396	292.300	-0.096
NOX048	217447.683	3974117.031	252.502	252.300	-0.202
NOX052	221496.353	3984283.257	317.751	317.740	-0.011
NOX053	224735.819	3985122.401	317.805	317.780	-0.025
NOX054	224780.146	3981957.439	315.919	315.840	-0.079
NOX055	226687.879	3982744.329	340.079	340.010	-0.069
NOX059	226109.225	3976717.323	273.063	272.930	-0.133

VERTICAL ACCURACY CONCLUSIONS

Urban Land Cover Classification Supplemental Vertical Accuracy (SVA) Tested 0.185 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 NOX048, Easting 217447.683, Northing 3974117.031, Z-Error 0.202 meters

VERTICAL ACCURACY CONCLUSIONS

Consolidated Vertical Accuracy (CVA) Tested 0.130 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 NOX048, Easting 217447.683, Northing 3974117.031, Z-Error 0.202 meters
Point NOX059, Easting 226109.225, Northing 3976717.323, Z-Error 0.133 meters

Approved By:			
Title	Name	Signature	Date
Associate Member LiDAR Specialist Certified Photogrammetrist #1281	Qian Xiao		January 20, 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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