AIRBORNE LIDAR TASK ORDER REPORT

OSMRE TENNESSEE LIDAR TASK ORDER

UNITED STATES GEOLOGICAL SURVEY (USGS)

CONTRACT NUMBER: G10PC00057

TASK ORDER NUMBER: G11PD00240

Woolpert Project Number: 71278
May 2011

DESIGN | GEOSPATIAL | INFRASTRUCTURE

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For:

United States Geological Survey
(USGS)
National Geospatial Technical Operations Center
(NGTOC)
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SECTION 1: OVERVIEW

TASK ORDER NAME: OSMRE OFFICE OF SURFACE MINING RECLAMATION AND ENFORCEMENT TENNESEE LIDAR TASK ORDER

WOOLPERT PROJECT #71278

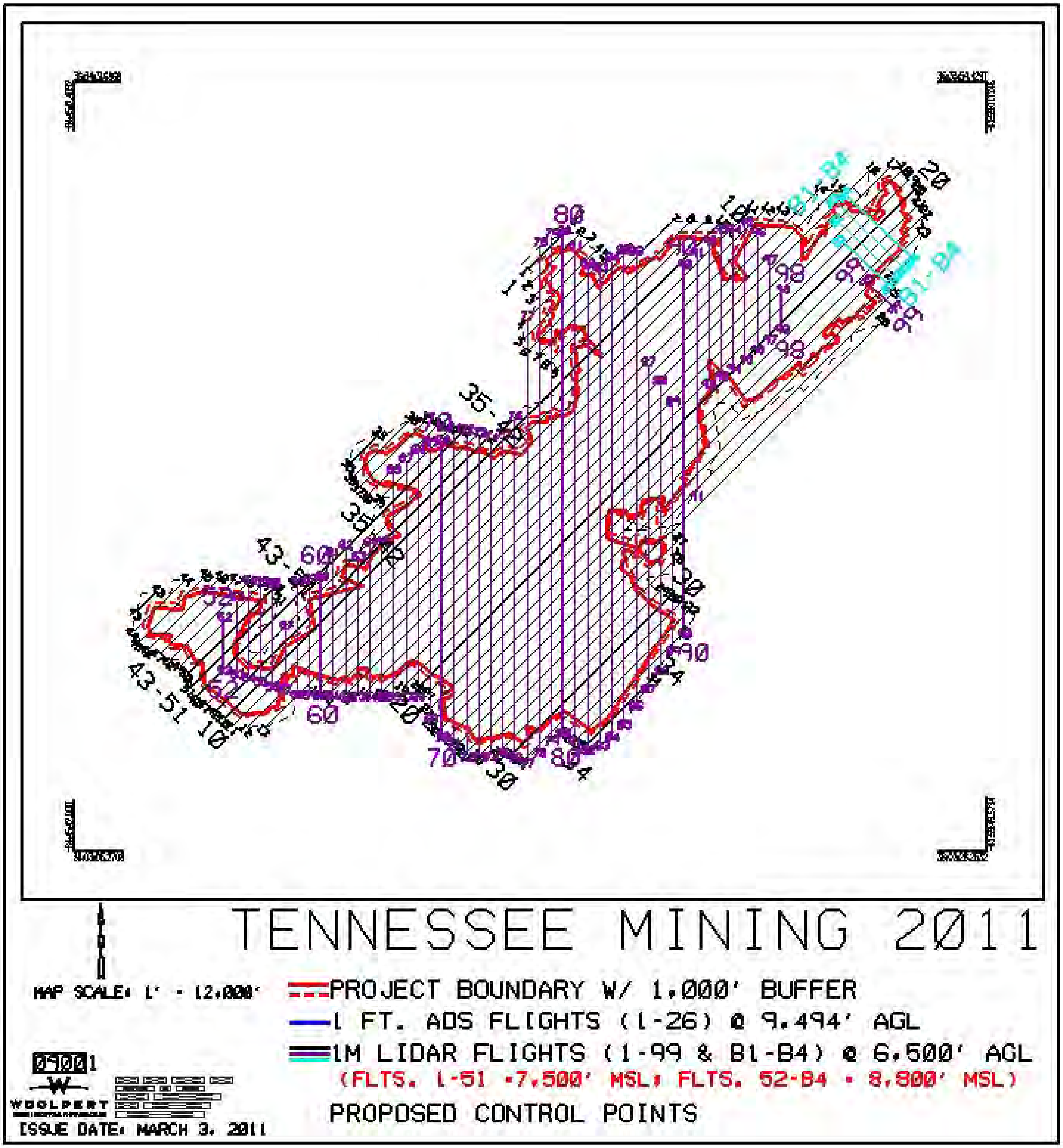
This report contains a comprehensive outline of the airborne LiDAR data acquisition consisting of a 300 square mile area with an additional minimum buffer of 100 meters that is approximately 30 miles northwest of Knoxville, TN; Contract Number G10PC00057; Task Order Number G11PD00240, for the United States Geological Survey (USGS). The LiDAR was collected and processed to meet a maximum Nominal Post Spacing (NPS) 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. In addition, breaklines defining waterbodies and streams were used to hydrologically flatten the DEM surface. This surface will be inserted into the 1/9 arc-second (3-meter) National Elevation Database.

The data was collected using a Leica ALS50-II 150 kHz Multiple Pulses in Air (MPiA) LiDAR sensor installed in a shock isolator sled mount. The ALS50-II 150 kHz sensor collects up to four returns (echo) per pulse, recording attributes such as time stamp and 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:	6,500 ft / 1,981.2 m
MSL (Mean Sea Level) average flying height:	8,800 ft / 2,682 m
Average Ground Speed:	130 knots / 149 mph
Field of View (full):	40 degrees
Pulse Rate:	115.6 kHz
Scan Rate:	46.8 Hz
Side Lap (Minimum):	25%

LiDAR data was processed and projected in Tennessee State Plane (zone 4100), North American Datum of 1983 (NAD83) in units of survey feet. The vertical datum used for the task order was referenced to NAVD 1988, survey feet, Geoid09.

Figure 1.1 Task Order and LiDAR Flight Layout



SECTION 2: ACQUISITION

The LiDAR data was acquired with a Leica ALS50-II 150 kHz Multiple Pulses in Air (MPiA) LiDAR sensor system, on board a Cessna 404. The ALS50-II 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 ALS50-II 150 kHz Multiple Pulses in Air (MPiA) LiDAR System has the following specifications:

Table 2.1 ALS50-II LiDAR System Specifications

Specification	
Operating Altitude	200 - 6,000 meters
Scan Angle	0 to 75° (variable)
Swath Width	0 to 1.5 X altitude (variable)
Scan Frequency	0 – 90 Hz (variable based on scan angle)
Maximum Pulse Rate	150 kHz
Range Resolution	Better than 1 cm
Elevation Accuracy	8 – 24 cm single shot (one standard deviation)
Horizontal Accuracy	7 – 64 cm (one standard deviation)
Number of Returns per Pulse	4 (first, second, third, last)
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 task order 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 at the McGhee-Tyson Airport FBO (KTYS) for the airborne GPS support.

The LiDAR data was collected in seven (6) separate missions, flown as close together as the weather permitted, to ensure consistent ground conditions across the task order 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.

Figure 2.1 LiDAR Flight Diagram

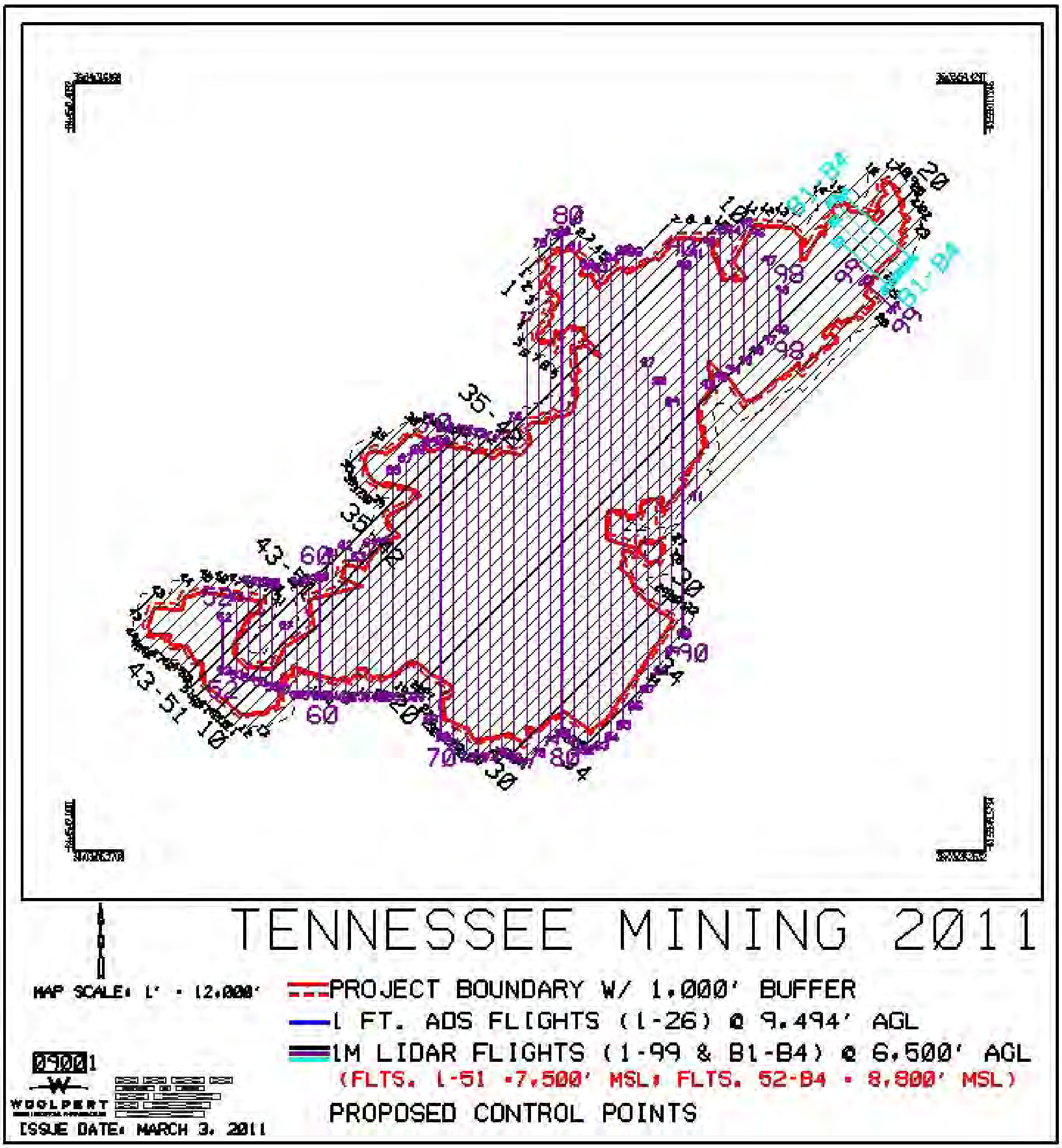


Table 2.2 Airborne LiDAR Acquisition Flight Summary

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 07, 2011 – S/N 46	b1-b4, 87-99	21:12 - 00:01	04:12 PM - 7:01 PM
March 03, 2011 – S/N 46	1-4, 52-54	20:24 - 22:04	3:24 PM – 5:04 PM
March 16, 2011 – S/N 77	5-20, 35-42, 43-51	23:13 - 05:15	07:13 PM - 11:15 PM
March 17, 2011 – S/N 77	22-34, 52-59, 82,22-28, 60-65, 87-98	14:42 - 21:25	10:42 AM - 02:25 PM
April 04, 2011 – S/N 46	66-74	12:40 - 14:55	08:40 AM - 10:55 PM
April 03, 2011 – S/N 46	21, 26-28, 68-86	12:18 - 17:05	08:18 AM - 01:05 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: POSPac Software v. 5.3, IPAS Pro v.1.3.

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.2.70, Proprietary Software, TerraMatch v. 10.04.

3. Imported processed .LAS point cloud data into the task order tiles. Resulting data were classified as ground and non-ground points with additional filters created to meet the task order 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 to reduce the vertical bias when compared to the survey ground control.
   Software: TerraScan v.10.018.

4. The .LAS files were evaluated through a series of manual QA/QC steps to eliminate remaining artifacts and small undulations from the ground class.
   Software: TerraScan v.10.018.

5. All water bodies greater than two acres and all rivers with a nominal 100 foot width or larger were hydro-flattened using Woolpert's proprietary software.
   Software: TerraScan v.10.018, TerraModeler v.10.006, ArcMap 9.3.1, Proprietary Software.

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 highly 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.

A base-station unit was mobilized for each acquisition mission, and was operated by a member of the Woolpert survey crew. Each base-station setup consisted of one Trimble 4000 – 5000 series dual frequency receiver, one Trimble Compact L1/L2 dual frequency antenna, one 2-meter fixed-height tripod, and essential battery power and cabling. Ground planes were used on the base-station antennas. Data was collected at 1 or 2 Hz.

Woolpert survey crews were onsite, operating a Global Navigation Satellite System (GNSS) Base Station at the Knoxville, TN airport (TYS) for the airborne GPS support. The GNSS base station operated during the LiDAR acquisition missions is listed below:

Table 3.1: GNSS Base Station

Station	Latitude	Longitude	Ellipsoid Height (L1 Phase Center)
Name	(DMS)	(DMS)	(Meters)
Pin @ KTYS	N 35° 48' 35.05"	W 83° 59' 05.83"	255.0

DATA PROCESSING

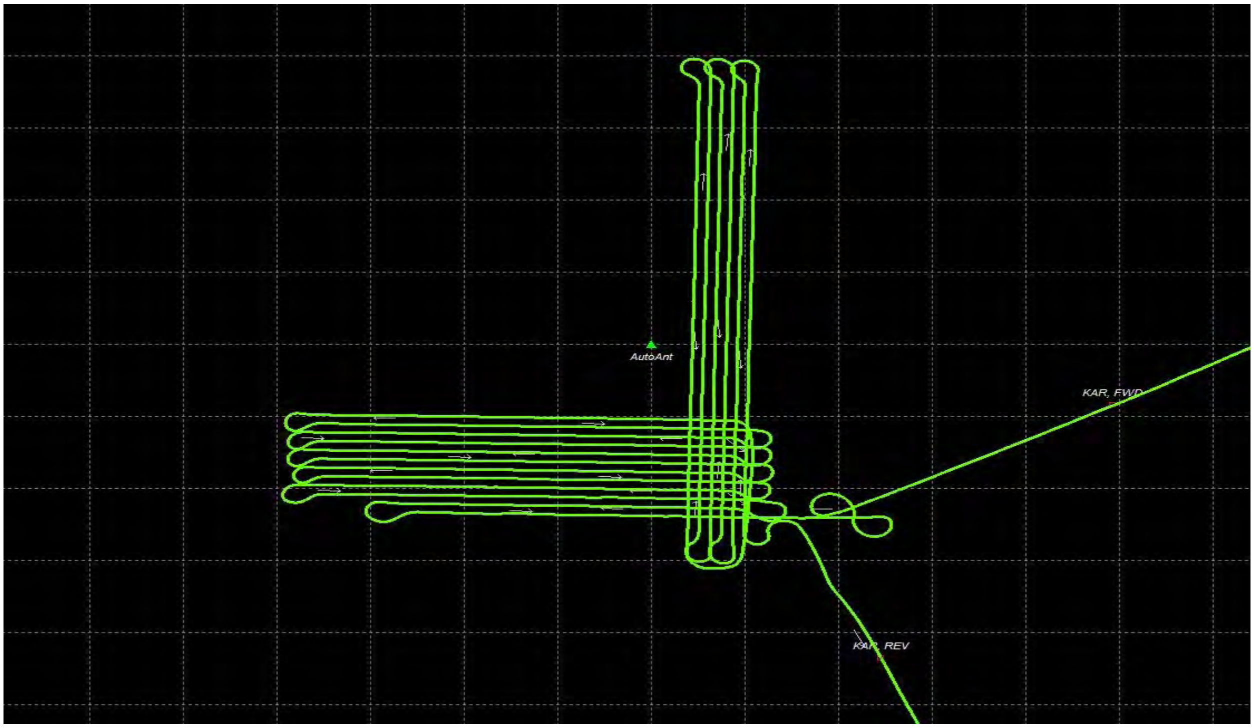
All airborne GNSS and IMU data was post-processed and quality controlled using Applanix 5.3 MMS software. GNSS data was processed at a 1 and 2 Hz data capture rate and the IMU data was processed at 200 Hz.

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 Day32710: N7079F



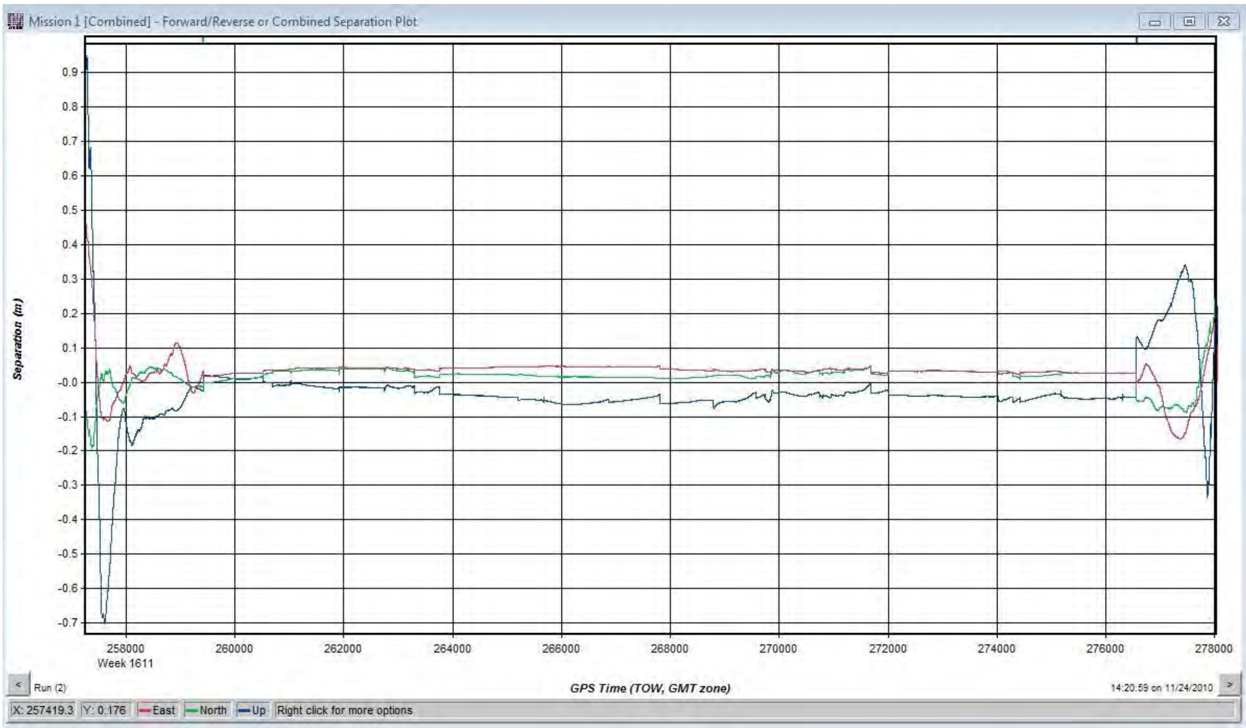
Within the trajectory processing, there are many factors that affect the overall quality, but the most indicative are the Combined Separation, the Estimated Positional Accuracy, and the Positional Dilution of Precision (PDOP).

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 Day32710 of Combined Separation

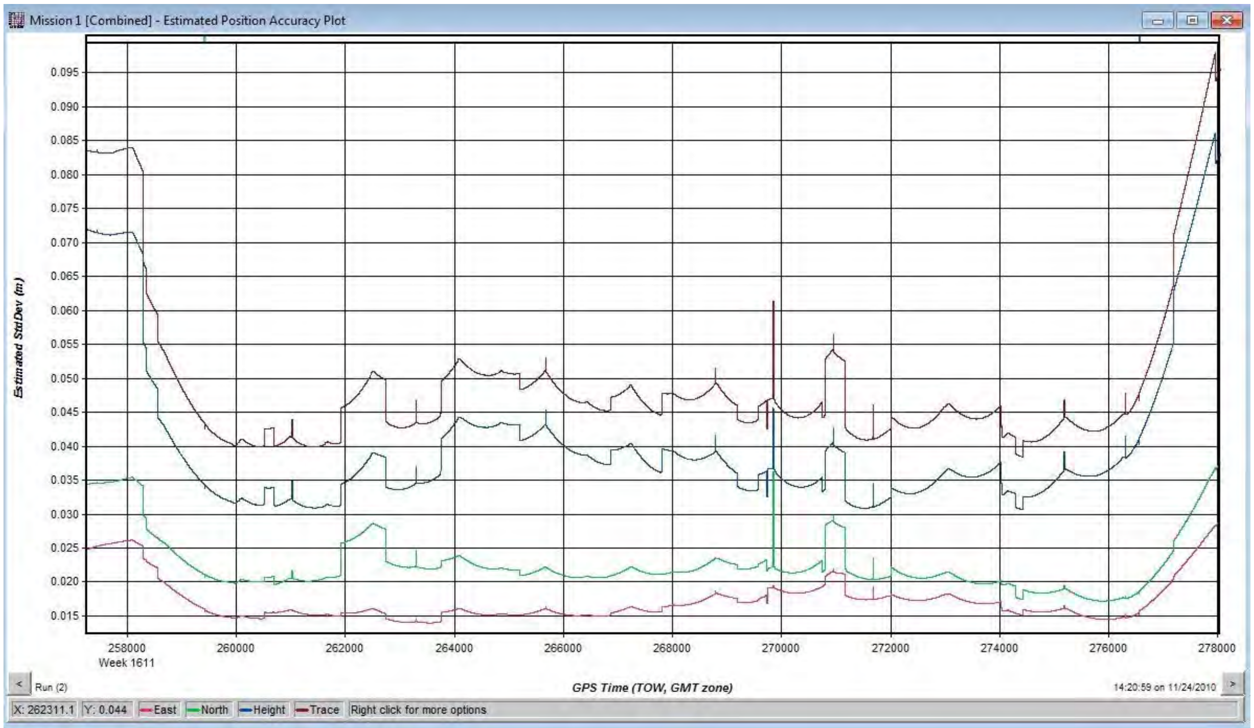


Estimated Positional Accuracy

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 Day32710 of Positional Accuracy



LIDAR DATA PROCESSING

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 raw “Point Cloud” LAS file. 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 the task order tiles and initially filtered to create a ground and non-ground class. Then additional classes were filtered as necessary to meet client specified classes.

- Once all of the task order data was imported and classified, cross flights and 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 reduce any vertical bias to meet or exceed the vertical accuracy requirements.

- The LiDAR tiles were reviewed using a series of proprietary QA/QC procedures to ensure it fulfills the task order requirements. A portion of this requires a manual step to ensure anomalies have been removed from the ground class.

- The bare earth DEM surface was hydrologically flattened for waterbody features that were greater than 2 acres and rivers and streams of 100 feet and greater nominal width.

- The LiDAR LAS files for this task order have been classified into the Default (Class 1), Ground (Class 2), Noise (Class 7), Water (Class 9), Ignored Ground (Class 10) and Overlap (Class 12) classifications.

- FGDC Compliant metadata was developed for the task order in .xml format for the final data products.

- The horizontal datum used for the task order was referenced to Tennessee State Plane (zone 4100) American Datum of 1983. Coordinate positions were specified in units of survey feet. The vertical datum used for the task order was referenced to NAVD 1988, survey feet, Geoid09.

SECTION 4: HYDROLOGIC FLATTENING AND FINAL QUALITY CONTROL

HYDROLOGIC FLATTENING OF LIDAR DEM DATA

This task required the compilation of breaklines defining water bodies and rivers. The breaklines were used to perform the hydrologic flattening of water bodies, and gradient hydrologic flattening of double line streams and rivers. Lakes, reservoirs and ponds, at a minimum size of 2-acres or greater, were compiled as closed polygons. The closed water bodies were collected at a constant elevation. Rivers and streams, at a nominal minimum width of 100 feet (30.5 meters), were compiled in the direction of flow with both sides of the stream maintaining an equal gradient elevation. The hydrologic flattening of the LiDAR DEM data was performed for inclusion in the National Elevation Dataset (NED). The task order area encompassed approximately 392 square miles in Arkansas.

LIDAR DATA REVIEW AND PROCESSING

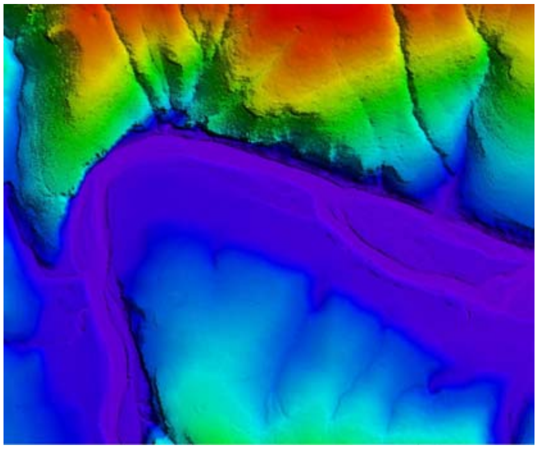
Woolpert utilized the following steps to hydrologically flatten the water bodies and for gradient hydrologic flattening of the double line streams within the existing LiDAR data.

1. Woolpert used the newly acquired (2011) LiDAR data to manually draw the hydrologic features in a 2D environment using the LiDAR bare earth surface. Google Earth was used as reference when necessary.

2. Woolpert utilizes an integrated software approach to combine the LiDAR data and 2D breaklines. This process “drapes” the 2D breaklines onto the 3D LiDAR surface model to assign an elevation. A monotonic process is performed to ensure the streams are consistently flowing in a gradient manner. A secondary step within the program verifies an equally matching elevation of both stream edges. The breaklines that characterize the closed water bodies are draped onto the 3D LiDAR surface and assigned a constant elevation at or just below ground elevation.

3. The lakes, reservoirs and ponds, at a minimum size of 2-acres or greater, were compiled as closed polygons. **Figure 4.1** illustrates a good example of 2-acre lakes and 100 feet (30.5 meters) nominal streams identified and defined with hydrologic breaklines. During the collection of linework, the technical staff used a program that displayed the polygon measurement area as a reference to identify lakes larger than 2-acres. The breaklines defining rivers and streams, at a nominal minimum width of 100 feet (30.5 meters), were draped with both sides of the stream maintaining an equal gradient elevation.

Figure 4.1



4. All ground points were reclassified from inside the hydrologic feature polygons to water, class nine (9).

5. All ground points were reclassified from within a 5 foot (1.5 meter) buffer along the hydrologic feature breaklines to buffered ground, class ten (10).

6. The LiDAR ground points and hydrologic feature breaklines were used to generate a new digital elevation model (DEM).

Figure 4.2

Figure 4.3

Figure 4.2 reflects a DEM generated from original LiDAR bare earth point data prior to the hydrologic flattening process. Note the "tinning" across the lake surface.

Figure 4.3 reflects a DEM generated from LiDAR with breaklines compiled to define the hydrologic features. This figure illustrates the results of adding the breaklines to hydrologically flatten the DEM data. Note the smooth appearance of the lake surface in the DEM.

Terrascan was used to add the hydrologic breakline vertices and export the lattice models. The hydrologically flattened DEM data was provided to USGS in ArcGRID 32-bit FLOAT format at a 1-meter cell size. The final LiDAR data was delivered in a state plane projection tiling format, based on a modular layout. The tiles were clipped to eliminate overlap between adjacent tiles. The 5000 foot x 5000 foot tile file name was derived from the southwest corner of each tile. The prefix is comprised of 10-digits, consisting of a 5-digit x value derived from the x grid-coordinate, truncated to 100 feet, with leading zeros as required, concatenated with a 5-digit y value derived from the y grid-coordinate truncated to 100 ft, with leading zeros as required.

The hydrologic breaklines compiled as part of the flattening process were provided to the USGS as an ESRI shapefile. The breaklines defining the water bodies greater than 2-acres were provided as a PolygonZ file. The breaklines compiled for the gradient flattening of all rivers and streams at a nominal minimum width of 100-feet were provided as a PolylineZ file.

DATA QA/QC

Initial QA/QC for this task order was performed in Global Mapper v11, by reviewing the grids and hydrologic breakline features.

Edits and corrections were addressed individually by tile. If a water body breakline needed to be adjusted to improve the flattening of the ArcGRID DEM, the area was cross referenced by tile number, corrected accordingly, a new ArcGRID DEM was regenerated and then reviewed in Global Mapper.

SECTION 5: 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 5.1: Overall Vertical Accuracy Statistics

Average error	-0.088	feet
Minimum error	-0.039	feet
Maximum error	0.300	feet
Average magnitude	0.172	feet
Root mean square	0.205	feet
Standard deviation	0.192	feet

Table 5.2: QA/QC Analysis Tennessee State Plane, NAD83

Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Laser Elevation (meters)	Dz (meters)
1001	2363493.470	681959.100	1280.050	1279.720	-0.330
1002	2406197.990	724948.750	1156.550	1156.160	-0.390
1003	2465244.460	770814.840	1213.650	1213.820	+0.170
1004	2490897.990	774868.040	1494.620	1494.520	-0.100
1005	2532732.740	788077.570	1339.230	1339.000	-0.230
1006	2520125.720	756628.180	1186.670	1186.470	-0.200
1008	2474253.680	701314.380	1392.430	1392.370	-0.060
1009	2448976.100	729665.830	1271.110	1271.020	-0.090
1010	2465065.660	663280.350	2711.990	2711.810	-0.180
1011	2447751.230	667509.650	1389.690	1389.580	-0.110
1012	2488762.470	745071.570	1766.960	1767.030	+0.070
1013	2410627.090	672248.730	1251.350	1251.650	+0.300
1014	2373970.560	668996.590	1183.840	1183.850	+0.010

VERTICAL ACCURACY CONCLUSIONS

- **Data Accuracy** tested 0.40 feet RMSE vertical accuracy at 95% percent confidence level.

Based on the analysis of the LiDAR data, the accuracy of the data meets the task order requirements.

Approved By:			
Title	Name	Signature	Date
Associate LiDAR Specialist Certified Photogrammetrist #1281	Qian Xiao		April 28, 2011

SECTION 6: FINAL DELIVERABLES

FINAL DELIVERABLES

The final deliverables are listed below. The final LiDAR data was delivered in a state plane foot projection tiling format, based on a modular layout. The tiles were clipped to eliminate overlap between adjacent tiles. The 5000 foot x 5000 foot tile file name was derived from the southwest corner of each tile. The prefix is comprised of 10-digits, consisting of a 5-digit x value derived from the x grid-coordinate, truncated to 100 feet, with leading zeros as required, concatenated with a 5-digit y value derived from the y grid-coordinate truncated to 100 ft, with leading zeros as required.

Hydrologically flattened bare earth 4-foot DEM in ArcGRID format.

- LAS v1.2 classified point cloud.
- LAS v1.2 raw unclassified point cloud flight line strips no greater than 2GB. Long swaths greater than 2GB will be split into segments).
- Breaklines compiled as part of the hydrologic flattening process were provided as ESRI PolygonZ and PolylineZ shapefiles, per area.
- Tile Layout provided as ESRI shapefile.
- Control points provided as ESRI shapefile.
- FGDC compliant metadata by file in XML format.
- The task order data was delivered on external USB 2.0 hard drives.

The DEMs produced under this task order met the following specifications:

- The water body hydrologic flattening was completed using the methodology described in this report and Woolpert's original proposal in response to the task order.
- The DEMs were edge joined with minimal data overlap to avoid data gaps.
- The hydrologically flattened bare earth data was delivered in ArcGRID 32-bit FLOAT format at a 4-foot posting.