AIRBORNE LIDAR REPORT

# YELLOWSTONE RIVER ORTHOPHOTOGRAPHY IMAGERY AND LIDAR

## W912P9-10-D-0533/0006

**Woolpert Project Number: 71876**
**July 2012**

WOOLPERT
DESIGN | GEOSPATIAL | INFRASTRUCTURE

# AIRBORNE LIDAR TASK ORDER REPORT

## YELLOWSTONE RIVER – ORTHOPHOTOGRAPHY IMAGERY AND LIDAR/FEATURE EXTRACT TASK ORDER

## WOOLPERT PROJECT # 71876

For:

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# SECTION 1: OVERVIEW

## PROJECT NAME: YELLOWSTONE RIVER - ORTHOPHOTOGRAPHY IMAGERY AND LIDAR

## WOOLPERT PROJECT #71876

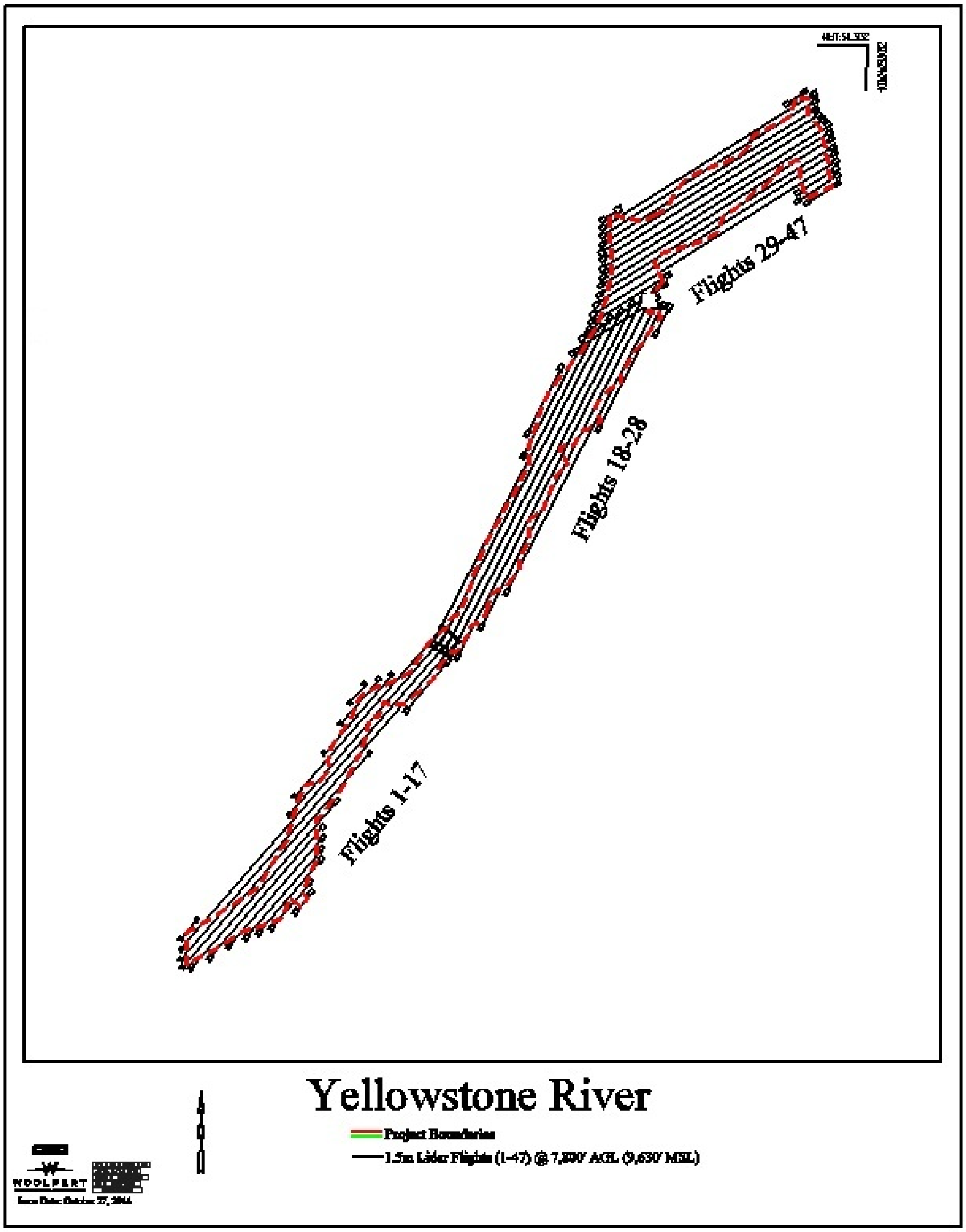
This report contains a comprehensive outline of the airborne LiDAR data acquisition consisting of a 442 square mile area along the Yellowstone River, for the United States Army Corps of Engineers (USACE). The LiDAR was collected and processed to meet a maximum Nominal Post Spacing (NPS) of 1.4 meters. 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 installed in a shock isolator sled mount. The ALS70 500 kHz sensor collects up to four returns (echos) 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): | 4.92 ft / 1.5 m |
| AGL (Above Ground Level) average flying height: | 7,800 ft / 2,377 m |
| MSL (Mean Sea Level) average flying height: | 9,630 ft / 2,935 m |
| Average Ground Speed: | 145 knots / 167 mph |
| Field of View (full): | 40 degrees |
| Pulse Rate: | 115.3 kHz |
| Scan Rate: | 25.1 Hz |
| Side Lap (Minimum): | 25% |

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

**Figure 1.1 Task Order and LiDAR Flight Layout - Yellowstone River**



# 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 404. 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 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 Sidney-Richland Municipal Airport (SDY) for the airborne GPS support on days 112 and 113A. Coordinates 47 41 35.28381 (N), 104 12 08.89007 (W), Elipsoid Height 582.051 meters.

Woolpert survey crews were onsite, operating a Global Navigation Satellite System (GNSS) Base Station DH9106 for the airborne GPS support on days 105, 106, and 113B. Coordinates 47 07 55.31281 (N), 104 48 03.13769 (W), Elipsoid Height 732.010 meters.

The LiDAR data was collected in (5) missions

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 |
| Apr 14, 2012 – S/N 7177 | 1-5 | 19:00 – 20:09 | 01:00 PM – 02:09 PM |
| Apr 15, 2012 – S/N 7177 | 4-17 | 15:17 – 18:27 | 09:17 AM – 12:27 PM |
| Apr 21, 2012 – S/N 7177 | 18-27 | 14:48 – 17:48 | 8:48 AM – 11:48 AM |
| Apr 22, 2012 – S/N 7177 A | 7, 9, 21, 24-46 | 14:44 - 19:04 | 08:44 AM – 01:04 PM |
| Apr 22, 2012 – S/N 7177 B | 7, 9 | 21:24 – 22:04 | 03:24 PM – 04:04 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.1.35.

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. 11.07.

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.12.005.

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.12.005.

5. All water bodies greater than two acres and all rivers with a nominal 100 foot width or larger were hydro-flattened using stereo compilation methods.
   **Software:** Summit Evolution v6.4, Microstation v8**,** TerraScan v.12.005.

## 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.

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 Stations at the Sidney-Richland Municipal Airport (SDY) and DH9106 for the airborne GPS support. The GNSS base stations operated during the LiDAR acquisition missions is listed below:

**Table 3.1: GNSS Base Stations**

| Station | Latitude | Longitude | Ellipsoid Height (L1 Phase Center) |
|---|---|---|---|
| Name | (DMS) | (DMS) | (Meters) |
| SDY | N 47° 41' 35.28" | W 104° 12' 08.89" | 582.051 |
| DH9106 | N 47° 07' 55.31" | W 104° 48' 03.14" | 732.010 |

## DATA PROCESSING

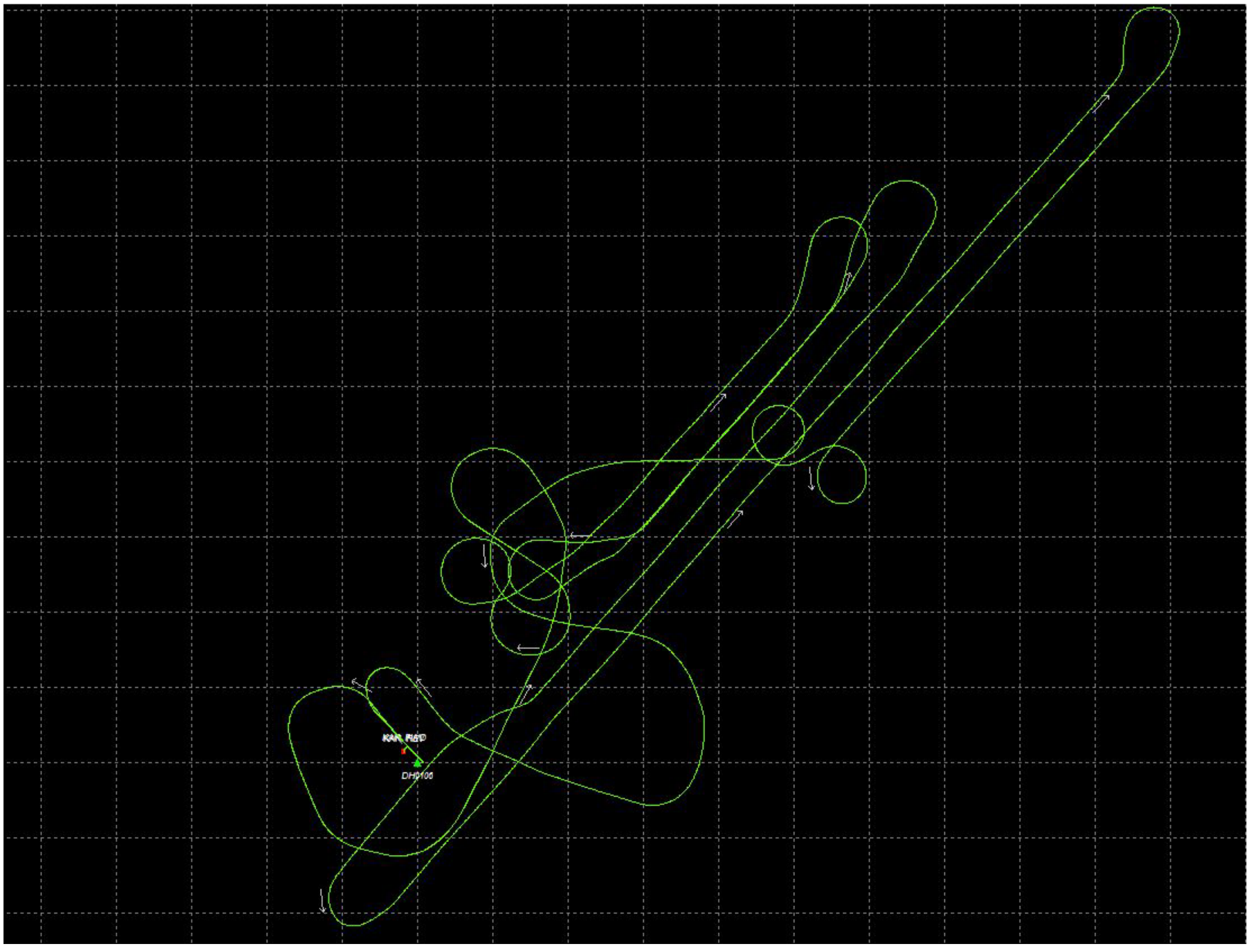
All airborne GNSS and IMU data was post-processed and quality controlled using Applanix 5.3 MMS software. GNSS data was processed at a 1 and 2 Hz data capture rate and the IMU data was processed at 200 Hz.

## 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 Day10512: N7079F**



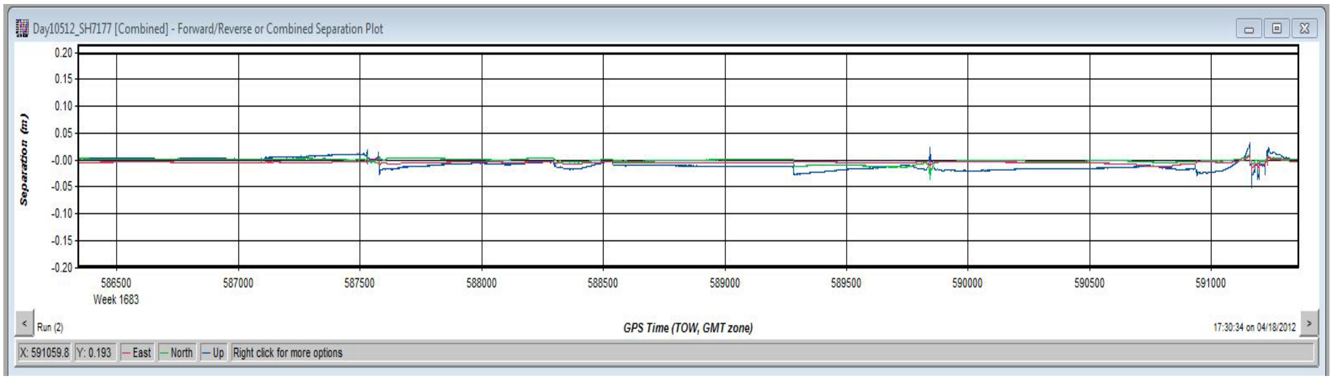
Within the trajectory processing, there are many factors that affect the overall quality, but the most indicative are the Combined Separation, the Estimated Positional Accuracy, and the Positional Dilution of Precision (PDOP).

## 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 Day10512 of Combined Separation**

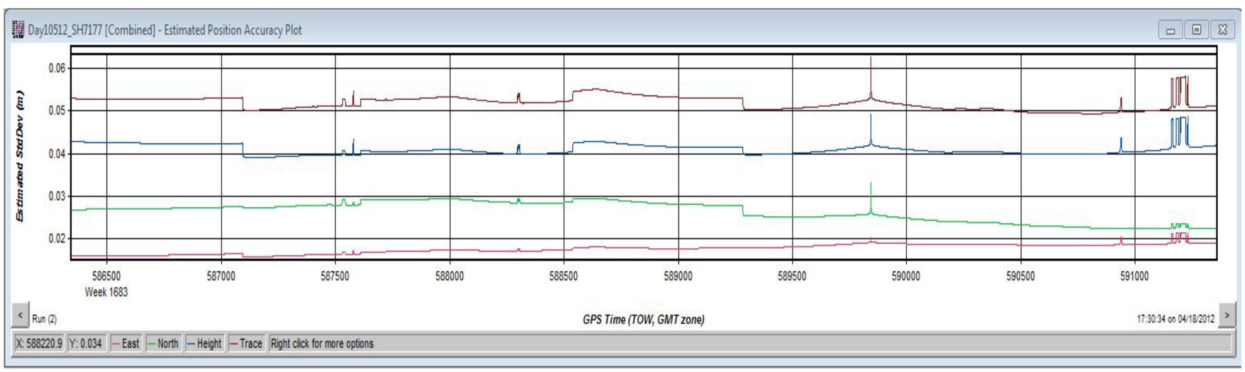



Estimated Positional Accuracy

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.

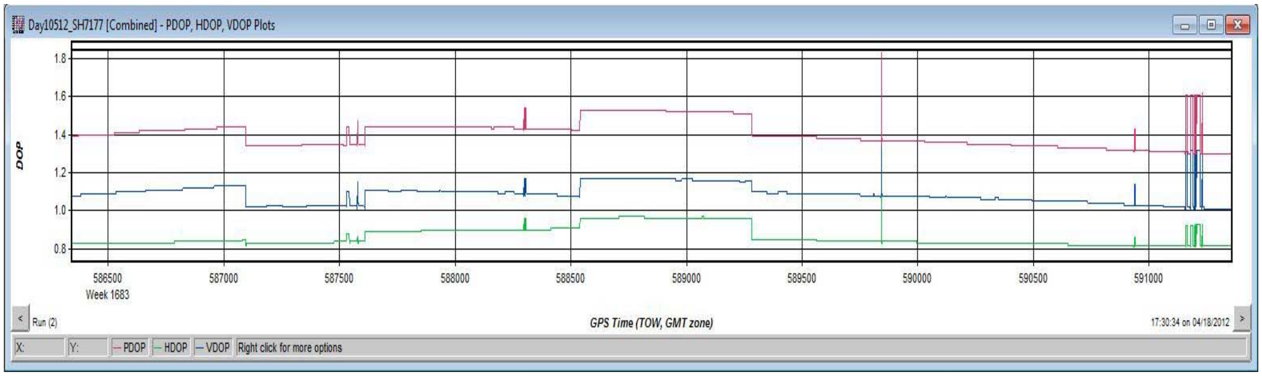
**Figure 3.3: Representative Graph from Day10512 of Positional Accuracy**



### PDOP

Position Dilution of precision (DOP) is a measure of the quality of the GPS data being received from the satellites. Woolpert's goal is to maintain an average PDOP of 3 or less.

**Figure 3.4: Representative Graph from Day 10512 of PDOP**




# 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), Model Keypoints (class 8), Water (Class 9), 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 State Plane Montana (FIPS2500), North American Datum of 1983. Coordinate positions were specified in units of U.S. survey feet for the Yellowstone River. The vertical datum used for the task order was referenced to NAVD 1988, U.S. 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.

## 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.

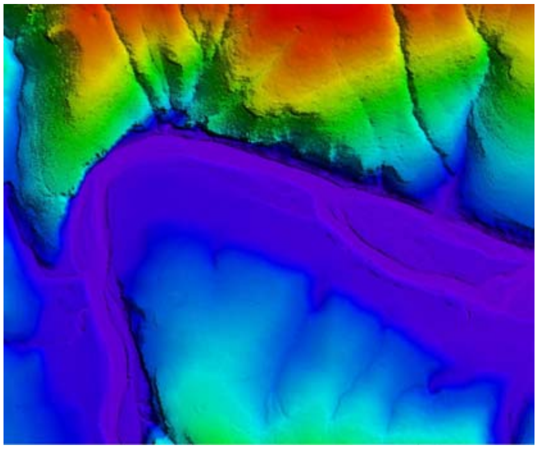
1. Woolpert used the ADS stereo imagery in combination with contours generated from the LiDAR acquired to analyze the water needed to be collected.

2. To make sure that the water was compiled correctly, we used contours generated from the raw LiDAR, using Terrascan and Terramodeler, to assist with the determination of the elevation of the water in combination with the stereo imagery, using Summit Evolution v6.4 and Microstation V8. This is to help determine the elevation of the water and help with the horizontal placement of the line. (Vegetation could be obscuring)

3. The stereo compilers collected any Lakes, reservoirs or ponds of a minimum size of 2-acres or greater, as closed polygons 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.

4. 4. In addition to the water collection, 2' contours were generated from the ground points of the LiDAR. Breaklines were supplemented to enforce the contour accuracy. All waterlines and breaklines were included in the final contour generation.

**Figure 4.1**



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

6. 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).

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

**Figure 4.2**

**Figure 4.3**

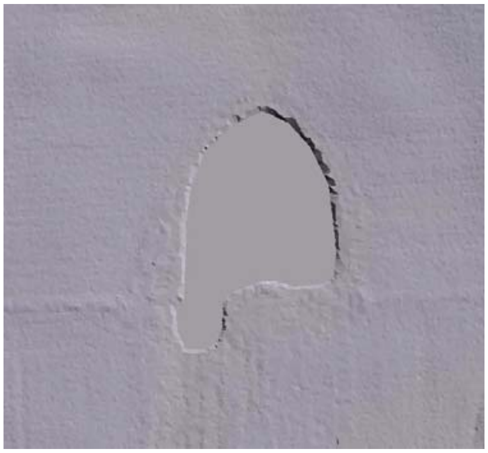


**Figure 4.2** reflects a DEM generated from original LiDAR bare earth point data prior to the hydrologic flattening process. Note the "tinning" across the lake surface.

**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 .img format at a 4-foot cell size.
The hydrologic breaklines compiled as part of the flattening process were provided to the USACE 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 Yellowstone River**

| | | |
|---|---|---|
| Average error | -0.005 | meters |
| Minimum error | -0.320 | meters |
| Maximum error | +0.280 | meters |
| Average magnitude | 0.106 | meters |
| Root mean square | 0.138 | meters |
| Standard deviation | 0.142 | meters |

**Table 5.2: QA/QC Analysis, State Plane Montana, NAD83, Yellowstone River**

| Point ID | Easting (UTM meters) | Northing (UTM meters) | Elevation (meters) | Laser Elevation (meters) | Dz (meters) |
|---|---|---|---|---|---|
| 100 | 3423808.210 | 1449223.220 | 2079.830 | 2079.760 | -0.070 |
| 101 | 3402609.870 | 1482680.460 | 1869.400 | 1869.330 | -0.070 |
| 102 | 3346770.160 | 1438102.640 | 1918.580 | 1918.370 | -0.210 |
| 103 | 3302191.810 | 1414183.910 | 1898.480 | 1898.460 | -0.020 |
| 104 | 3335752.830 | 1392210.940 | 2135.600 | 2135.640 | +0.040 |
| 105 | 3311381.500 | 1348243.590 | 1890.690 | 1890.650 | -0.040 |
| 106 | 3269220.310 | 1292269.390 | 1972.570 | 1972.500 | -0.070 |
| 107 | 3287356.640 | 1285361.400 | 1984.130 | 1984.180 | +0.050 |
| 108 | 3256779.090 | 1238075.840 | 1940.120 | 1940.230 | +0.110 |
| 109 | 3238434.590 | 1195179.060 | 1963.880 | 1963.790 | -0.090 |
| 110 | 3207685.770 | 1142876.660 | 2085.020 | 2084.810 | -0.210 |
| 111 | 3178716.700 | 1136687.450 | 2044.760 | 2044.820 | +0.060 |

| Point ID | Easting (UTM meters) | Northing (UTM meters) | Elevation (meters) | Laser Elevation (meters) | Dz (meters) |
|---|---|---|---|---|---|
| 112 | 3131073.020 | 1030851.170 | 2203.110 | 2203.160 | +0.050 |
| 113 | 3152241.180 | 1027315.750 | 2475.820 | 2476.040 | +0.220 |
| 114 | 3090131.920 | 994570.660 | 2192.260 | 2192.540 | +0.280 |
| 2001 | 3360370.610 | 1447411.000 | 1880.970 | 1880.650 | -0.320 |
| 2002 | 3288441.450 | 1309562.280 | 1930.350 | 1930.380 | +0.030 |
| 2003 | 3201409.380 | 1147409.620 | 2052.260 | 2052.250 | -0.010 |
| 2004 | 3153138.140 | 1077146.380 | 2063.980 | 2064.040 | +0.060 |
| 2005 | 3102624.730 | 1001404.300 | 2196.820 | 2196.940 | +0.120 |

## VERTICAL ACCURACY CONCLUSIONS

- **Data Accuracy** tested 0.27 meters 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<br>LiDAR Specialist<br>Certified Photogrammetrist #1281 | Qian Xiao |  | Jul 24, 2012 |

# SECTION 6: FINAL DELIVERABLES

## FINAL DELIVERABLES

The final lidar deliverables are listed below.

- 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)
- ESRI flight line strip shape files
- Hydrologically flattened Polygon z and Polyline z shapefiles
- Hydrologically flattened bare earth 1-meter DEM in IMG format
- ESRI Hillshades
- Model Keypoint 1-meter DEM in IMG format
- Model Keypoint in Microstations v8i format
- Tile Layout and data extent provided as ESRI shapefile
- Control points provided as ESRI shapefile
- FGDC compliant metadata by file in XML format
- LiDAR processing report in pdf format
- Survey report in pdf format
- The task order data was delivered on an external USB 2.0 hard drive