LIDAR AND MULTIBEAM SURVEY REPORT

FOR

EAST FORK OF ROCK CREEK AND PAINTED ROCKS RESERVOIRS

Prepared by:

GEOMATICS DATA SOLUTIONS

for:

MONTANA DNRC

On Behalf of:

Eli & Associates, Inc.

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1. INTRODUCTION

Geomatics Data Solutions (GDS), Inc. were sub-contracted by Eli & Associates, Inc. (Eli) to acquire bathymetric and topographic data for the Montana Department of Natural Resources & Conservation (DNRC). Detailed elevation models were developed by GDS at the East Fork of Rock Creek Reservoir and Painted Rocks Reservoir using both airborne lidar and multibeam sonar data. A combination of technologies was required to completely cover the survey areas to the required resolution and accuracy standards. Data from each were processed by GDS and merged into a seamless surface relative to project control for each reservoir.

Details of the surveys, data processing, QC and product creation are provided in detail within this report.

1.1. SURVEY AREA

The survey extents at each reservoir were provided by DNRC. At the East Fork of Rock Creek Reservoir, the area covered 5.3 square kilometers as shown in (Figure 1). At Painted Rocks Reservoir, the area covered 13.8 square kilometers as shown in (Figure 2).

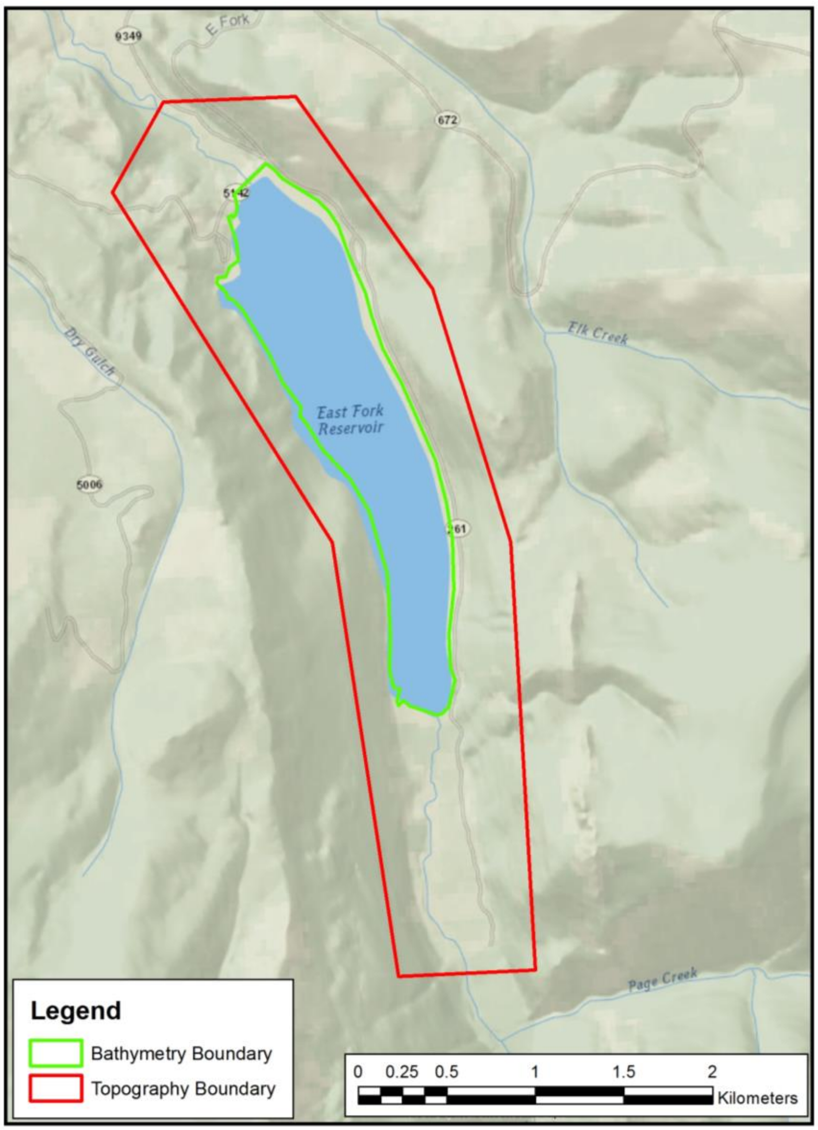


Figure 1: East Fork Reservoir Survey Area

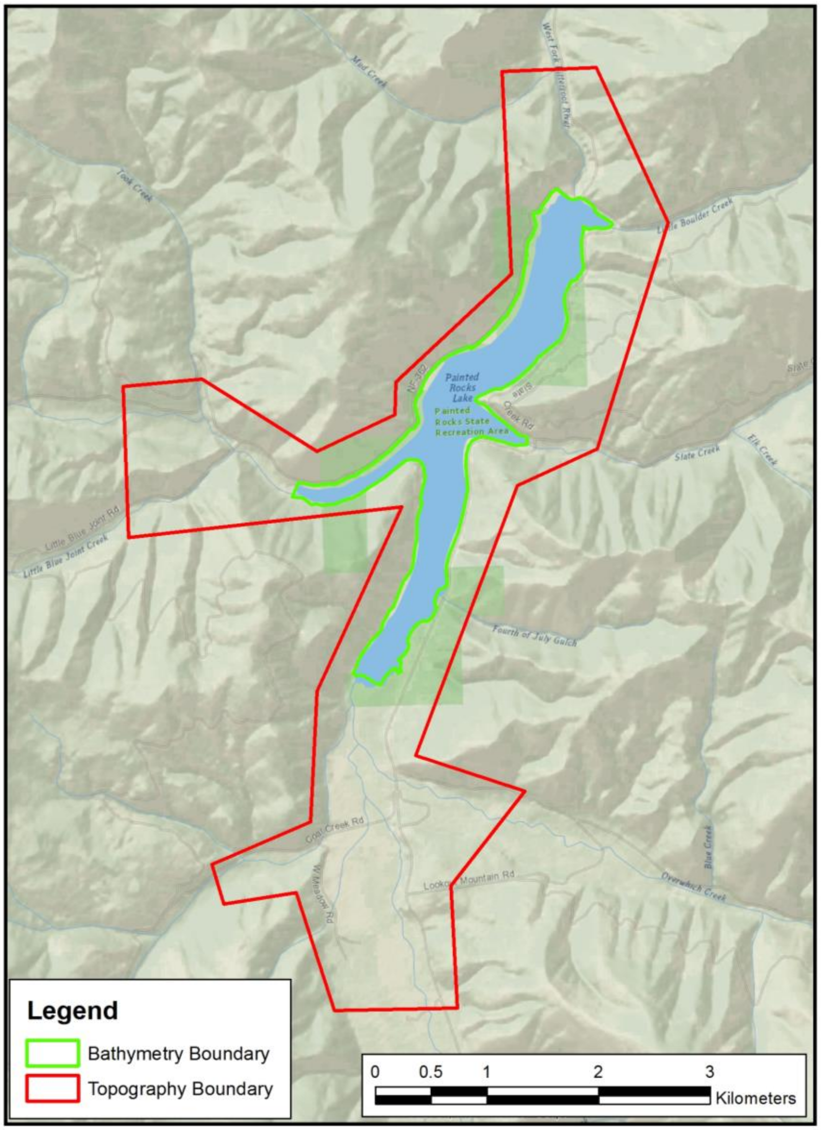


Figure 2: Painted Rocks Reservoir Survey Area

1. SURVEY CONTROL

The coordinate system and datum for this project is Montana State Plane, North American Datum of 1983-2011, Epoch 2010.0 (NAD83-2011). The vertical datum is the North American Vertical Datum of 1988 (NAVD88) using GEOID12B to convert from NAD83-2011 ellipsoid to orthometric heights. Horizontal and vertical units are International Feet unless otherwise noted.

Survey control for the project had been previously established by DJ&A Surveying, Inc. (DJA). No additional control points were required during the airborne lidar or multibeam sonar data acquisition campaigns. GDS established a Global Navigation Satellite System (GNSS) base station on a suitable control point at each reservoir, then conducted Real Time Kinematic (RTK) checks to other points provided by DJA to verify accuracy. Published control values used during the survey are shown in Table 1.

Table 1: GNSS Base Station Coordinates

Point	Site	NAD83-2011 (Epoch 2010.0)			Montana State Plane NAD83, GEOID12B		
		N Latitude	W Longitude	Height (m)	Northing (ift)	Easting (ift)	Height (ift)
CP-1	Painted Rocks	45°43'04.55863"	114°16'48.03727"	1433.981	572465.72	748722.54	4749.28
2A	East Fork	46°07'50.80117"	113°22'51.86544"	1838.42	710082.64	985360.66	6073.42

The results of the control verification survey are shown in Table 2. All control points were found to be within expected uncertainties.

Table 2: RTK Control Point Checks

Point	Site	RTK Observed (MT SPCS, GEOID12B)			Difference		
		Northing (ift)	Easting (ift)	Height (ift)	Northing (ift)	Easting (ift)	Height (ift)
CP-2	Painted Rocks	554686.01	740855.33	4766.39	0.01	0.01	0.04
6	East Fork	710257.38	985306.90	6007.16	-0.02	0.04	0.00
10	East Fork	709707.81	984848.43	6073.44	0.04	0.02	0.06
11	East Fork	710102.28	985388.13	6073.36	-0.06	-0.03	0.00
120	East Fork	710259.30	985366.33	6002.77	0.01	-0.13	0.06
127	East Fork	710130.28	985494.89	6067.52	-0.01	0.00	-0.03

Original field notes are provided in Appendix A.

2. TOPOGRAPHIC AND BATHYMETRIC LIDAR

All lidar data were acquired using a Leica Chiroptera II (CHII), a latest generation topographic and bathymetric lidar sensor. The system provides denser data than previous traditional bathymetric lidar systems and is unique in its ability to acquire bathymetric lidar, topographic lidar and 4-band digital camera imagery simultaneously.

The CHII provides up to 500 kHz topographic data, and 35 kHz shallow bathymetric data. 4-band 80 MP digital camera imagery was also collected simultaneously with the sensor's RCD-30 camera.

The bathymetric and topographic lasers are independent and do not share an optical chain or receivers, so they are optimized for their specific function. As with any bathymetric lidar, maximum depth penetration is a function of water clarity and seabed reflectivity. The CHII is designed to penetrate to approximately 1.5 times the secchi depth. This is also represented as $D_{max} = 2.4/K$, where K is the diffuse attenuation coefficient, and assuming K is between 0.1 and 0.3, a normal sea state and 15% seabed reflectance.

Both the topographic and bathymetric sub-systems use a palmer scanner to produce an elliptical scan pattern of laser points with a degree of incidence ranging from +/-14° (front and back) to +/-20° (sides), providing a 40° field of view. This has the benefit of providing multiple look angles on a single pass and helps to eliminate shadowing effects. This can be of particular use in urban areas, where all sides of a building are illuminated, or for bathymetric features such as the sides of narrow water channels, or features on the seafloor such as smaller objects and wrecks. It also assists with penetration in the surf zone where the back scan passes the same ground location a couple of seconds after the front scan, allowing the areas of whitewater to shift.

The bathymetric laser is a diode pumped class 4 laser which operates in the green spectrum. Full waveform data is acquired for every pulse. The topographic laser operates in the infra-red spectrum at 1064nm. Up to 4 returns per pulse are acquired from each laser.

2.1. MOBILIZATION

The CHII sensor was installed in a Cessna 404 (N7079F) aircraft provided by Woolpert, Inc. (Figure 3).

The aircraft was mobilized at Peachtree City, GA (FFC), on 12 July 2017. A system test flight and calibration was conducted at the airport to ensure the system was firing and there were no power or other install related issues. Due to cloud cover, a complete set of calibration lines could not be acquired at the 400m altitude. The aircraft transited to the survey to begin data acquisition. A final project close-out calibration was collected over Sidney, OH on 08 August 2017. Values from the close-out calibration was used for processing of the project, as no cloud cover issues existed, and all calibration lines were acquired during this flight.

Figure 3: Mobilized Aircraft

2.1.1. Aircraft Offset Survey

Physical mounting offsets between the GNSS antenna, IMU and gyro-stabilized mount were determined through a combination of manual measurements and iterative processing in NovAtel Inertial Explorer software.

Final offsets, shown in the Leica reference frame, are presented in Table 3.

Table 3: Aircraft Offsets

Sensor Head	Lever Arm	X (forward)	Y (right)	Z (down)
CHII (Topo and Shallow Channel)	Reference to GNSS Antenna L1 Phase Center	-0.001 m	-0.003 m	-1.316 m
	Reference to IMU	-0.003 m	-0.005 m	-0.296 m
	Reference to IMU Rotation	0 °	0 °	90 °

2.2. Calibration

Field calibration of the CHII system was carried out to eliminate systematic errors by calculating corrections for boresight errors, scanner angle errors, remaining IMU angle errors and any necessary internal timing errors. Calibration lines were acquired at 1000m, 500m, and 400m altitude. All sets of lines are used to calibrate and verify the topographic lidar, while the 500m and 400m lines are used for the bathymetric lidar.

Calibration values were calculated using the automatic calibration routine within the Leica Lidar Survey Studio (LSS) software. This utility first identifies patches or areas of gentle slope within the overlap region of all the lines to use for calibration. Patch selection prevents areas of vegetation, side of cars or buildings, from being used in the calibration process. Next, the utility compares the front side and back side of the elliptical scan within the same line, as well as comparing all lines to each other, to identify suitable calibration parameters such that data within the patches match. The procedure is iterative and continues until the best possible solution is computed.

Calibration for each channel (topo, and shallow) was done independently. Topo channel calibration was computed using 1000m altitude lines. The 500m and 400m lines were then used for verification. Calibration of the shallow channel were computed using 500m altitude. Any lower altitude data were used for verification.

At each step of the calibration process, quality assurance was conducted to ensure values being calculated are valid. This is done using the Leica LSS Quality Control Utility. Two types of checks are done; firstly, the front scan is compared to the back scan for every line. Secondly, each flightline is compared to every other line. We would expect the average errors from both of these checks to be small. In addition, the data is visually reviewed. In particular, features are studied to ensure lines from different directions show structures in the same position, in other words, verifying horizontal accuracy is maintained. These tests all provide assurance of relative accuracy.

Ground truth is not used within the automatic calibration routine; however, ground truth can be used to verify absolute accuracy.

For this project, calibration lines were acquired over the airport at Sidney, OH. Ground truth data over the area was acquired by GDS using GNSS receivers and post-processed kinematic (PPK) survey techniques.

Results from the calibration verification checks are provided in Table 4 below. Values from the 08 August 2017 calibration were used for the entire project. Results are good and indicate that calibration was successful.

Table 4: Calibration QA Results

Test		Topo 1000m	Topo 500m	Topo 400m	Shallow 500m	Shallow 400m
Front to Back Scan Comparison	Average Error (m)	-0.0006	-0.0098	-0.0104	-0.0002	-0.0079
	Std. Dev. of Error	0.0009	0.0007	0.0012	0.0007	0.0008
Line to Line Comparison	Average Error (m)	0.0032	0.0012	0.0030	0.0022	0.0027
	Std. Dev. of Error	0.0024	0.0008	0.0010	0.0025	0.0009

A comparison to the ground truth at Sidney, OH was also conducted. Results presented below show data is well within required accuracy specifications.

Table 5: Calibration Ground Truth Comparisons - Topo

	1000m	500m	400m	ALL
Average dz (m)	-0.0223	0.0152	0.0183	0.0036
St Dev (m)	0.0153	0.0108	0.0110	0.0124

Table 6: Calibration Ground Truth Comparisons - Bathy

	500m	400m	ALL
Average dz (m)	0.0042	0.0035	0.0038
Root mean square (m)	0.0148	0.0143	0.0145

2.3. Survey Operations

Images showing the initial flight plans for Painted Rocks and East Fork for are provided in Figure 4 and Figure 6. A summary of the daily operations is shown in Table 7, below.

Operations were based out of Missoula, MT (MSO). Airborne collection logs are provided in Appendix C.

For this project, the flight parameters shown in

Table 8 were used to provide 100% coverage.

During acquisition, flight lines are shown on a pilot display, and the aircraft is controlled by the pilot at all times. The CHII system includes a NovAtel SPAN GNSS system with an LCI-100C IMU for aircraft position and orientation. Information from the IMU is also used in real-time by the PAV100 gyro-stabilized mount to compensate for deviations in pitch and roll. Aircraft bank angles were restricted to 20º to avoid any potential GPS dropouts. No flights were planned if the PDOP was expected to go above 3.0.

Data were monitored for quality during acquisition using the Operators Console running on the AHAB collection computer. The operator monitored system status of the scanners and receivers, waveforms, camera images, data coverage, flight lines and the health of the navigation system.

All data were recorded to a removable solid state hard disk. At the end of each flight, the hard disk was removed and taken to the field office where data were copied on to backup disks for transmittal back to the main processing office. Data were reviewed daily in the field for quality and coverage.

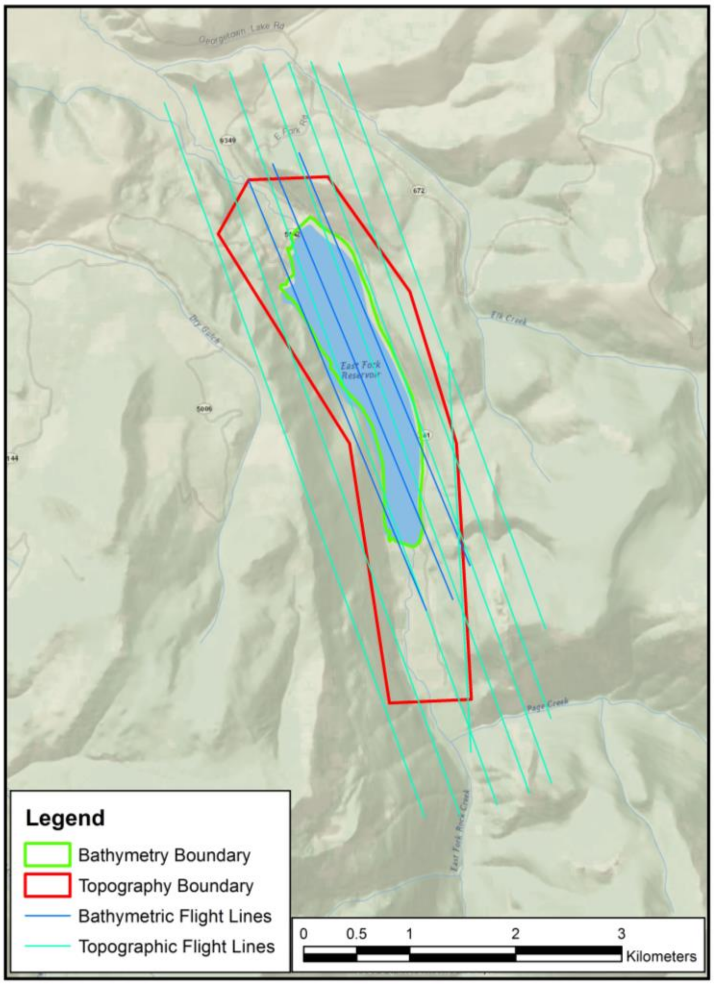


Figure 4: East Fork Planned Flight Lines

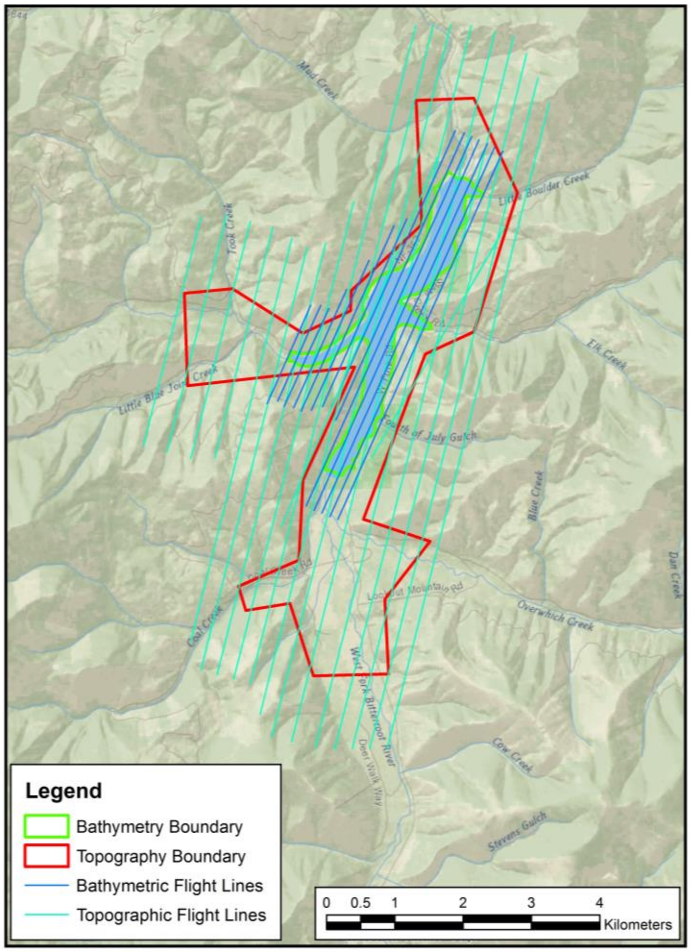


Figure 5: Painted Rocks Planned Flight Lines

Table 7: Painted Rocks Planned Flight Lines

Flight	Activity
2017-07-12	Calibration Flight (Peachtree City), Transit to Missoula, MT
2017-07-13	Survey East Fork and Painted Rock
2017-07-14	No flight - Coverage Analysis
2017-07-15	Refly B5-PR, T8-PR & T8-EF

Table 8: CHII Survey Flight Parameters

Parameter	Topo-Bathy Flight Lines	Topo Only Flight Lines
Topo PRF (kHz)	400	320
Topo Points per m^2	>10	>6
Shallow Bathy PRF (kHz)	35	N/A
Shallow Bathy Points per m^2	1.1	N/A
Swath Width (m)	365	580
Flight Line Sidelap (%)	15	15
Altitude (m)	500	800
Survey Speed (knots)	125	125

2.4. Data Processing

An overview of GDS's established CHII processing workflow is presented in Figure 6. Initial data coverage analysis and quality checks to ensure there were no potential system issues were carried out in the field prior to demobilization of the sensor. Final processing was conducted in GDS's offices.

In general data were initially processed in Leica's Lidar Survey Studio (LSS) using final processed trajectory information. LAS files from LSS were then imported to a Terrascan project where spatial algorithms were used to remove noise and classify bare earth/ground. Manual review was conducted in both Terrascan and LP360 prior to a creation of the final DEM.

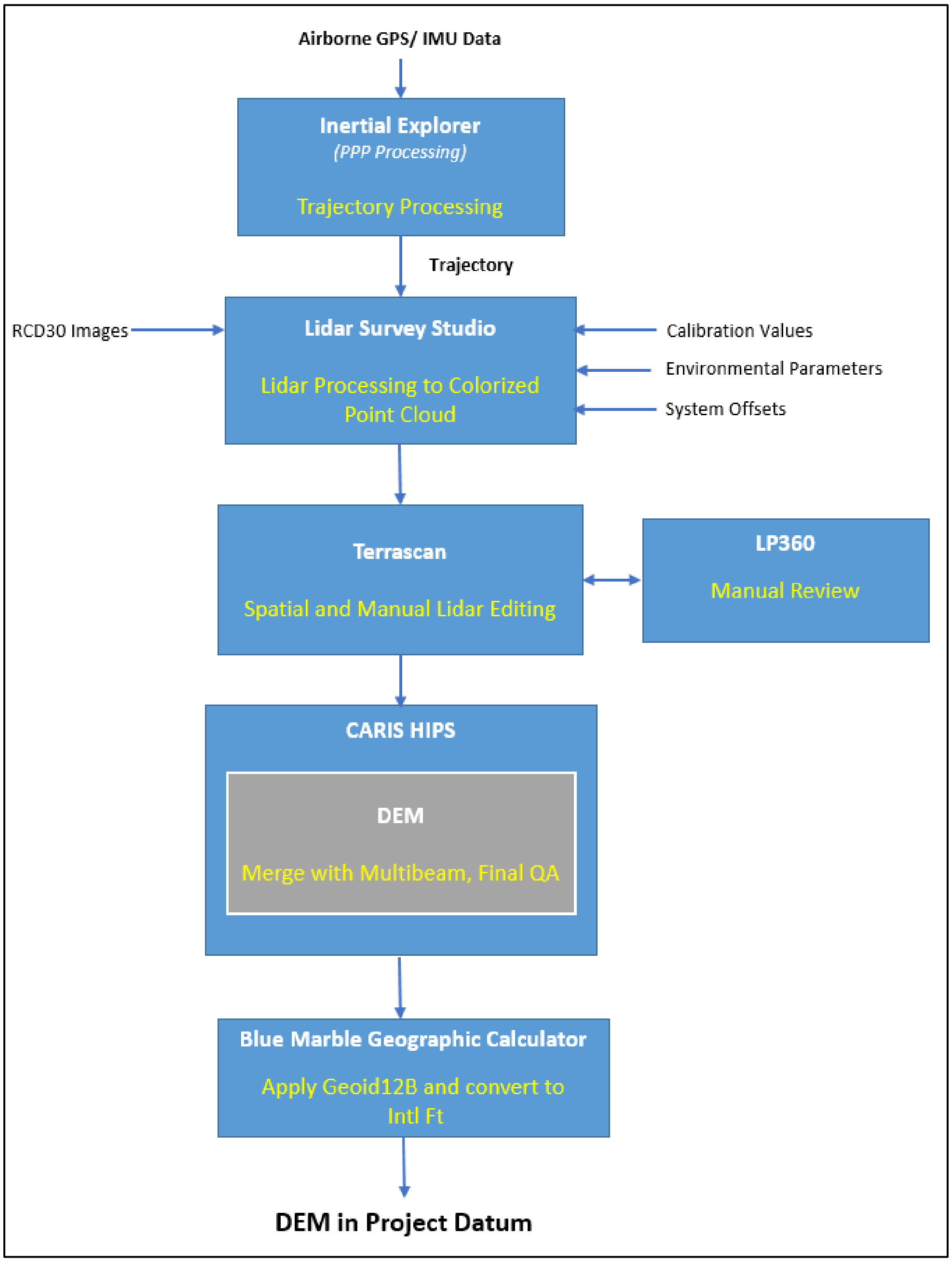


Figure 6: Overview of Processing Work Flow

2.4.1. Trajectory

Final trajectory data were post processed in NovAtel Inertial Explorer. Lever arms, shown in the NovAtel reference frame, are presented in Table 9. Inertial Explorer accounts for the fixed offset between the reference point and IMU and uses a multi-pass algorithm to compute a tightly-coupled solution. Tightly coupled Post Processed Kinematic (PPK) methods were used to compute final trajectories. A single GNSS base station was established at each reservoir on project control to minimize baseline lengths. Trajectory processing logs are provided in Appendix D. Average Forward and Reverse Separation RMS for the project was 0.008m in Easting and Northing, and 0.018m in Height.

Table 9: Inertial Explorer Offsets

Sensor Head	Lever Arm	X (right)	Y (forward)	Z (up)
Chiroptera (Topo, Shallow, Camera)	Reference to GNSS Antenna L1 Phase Center	0.002 m	0.002 m	1.020 m
	Reference to IMU Rotation	0 °	180 °	0 °

2.4.2. Imagery

Imagery data collected with the RCD30 camera were extracted from the raw compressed airborne format to 8-bit RGBN TIFF images using Leica's FramePro software.

Leica's IPAS CO+ was used to finalize the camera calibration. It uses orthogonal lines flown in both directions over an area containing buildings and features. In this case, orthogonal lines from the calibration flight over Falcon Field, GA were used. IPAS CO+ has an automated point matching (APM) feature that identifies the same point in overlapping images and automatically iterates to compute final misalignment and principal point offset (PPO) parameters, which are provided in the table below.

Table 10: RCD30 Camera Misalignment and PPO Parameters

Parameter	X	Y	Z
Lever Arms (m)	0.000	-0.115	0.166
Rotation (deg)	0 °	0 °	90 °
Misalignment (deg)	-0.07052	-0.07116	0.10666
PPO (mm)	0.0734	-0.0011	N/A

IPAS CO+ was then used along with the final camera calibration file and the final GNSS/IMU trajectory file to export valid exterior orientation (EO) parameters for each image.

The TIFF images and the EO files were used by LSS when processing the lidar data, to colorize lidar points that overlapped the imagery with RGB values. The color values are valid for the flight time of each pulse. Where no images overlapped the lidar data, lidar points still remain but are not colored.

A digital terrain model was created from all the valid lidar data at 0.5m resolution for orthorectification. All RGBN TIFF images exported from FramePro were rectified in ERDAS IMAGINE Photogrammetry, using the 0.5m DTM and the EO files created by IPAS CO+. No additional Aerial Triangulation was conducted. Individually rectified images were used to create a 0.25ft resolution color balanced mosaic in OrthoVista. Final 4-band RGBN mosaic images were created for each project tile in 8-bit geotiff format. The tile layout is provided with the imagery in SHP file format.

2.4.3. Raw Lidar Data

Lidar processing was conducted using the Leica Lidar Survey Studio (LSS) software. Calibration information, along with processed trajectory information were combined with the raw laser data to create an accurately georeferenced lidar point cloud for the entire survey in LAS v1.4 format. All points from the topographic and bathymetric laser include 16-bit intensity values.

During this LSS processing stage, an automatic land/water discrimination is made for the bathymetric waveforms. This allows the bathymetric (green) pulses over water to be automatically refracted for the pulse hitting the water surface and travelling through the water column, producing the correct depth. Another advantage of the automatic land/water discrimination is that it permits calculation of an accurate water surface over smaller areas, allowing simple bathymetric processing of smaller, narrower streams and drainage channels. Sloping water surfaces are also handled correctly.

Prior to processing, the hydrographer can adjust waveform sensitivity settings dependent on the environment encountered and enter a value for the refraction index to be used for bathymetry. The index of refraction is an indication of the water type. Values used for sensitivity settings and the index of refraction are included in the LSS processing settings files. A value of 1.336 was used for the index of refraction, indicating fresh water.

A sample waveform is provided in Figure 7, while a sample LSS editing screen is provided in Figure 8.

It is important to note that all digitized waveform peaks are available to be reviewed by the hydrographer; both valid seabed bottom and peaks classed as noise. This allows the hydrographer to review data during Terrascan and LP360 editing for valid data such as objects that may have been misclassified as noise.

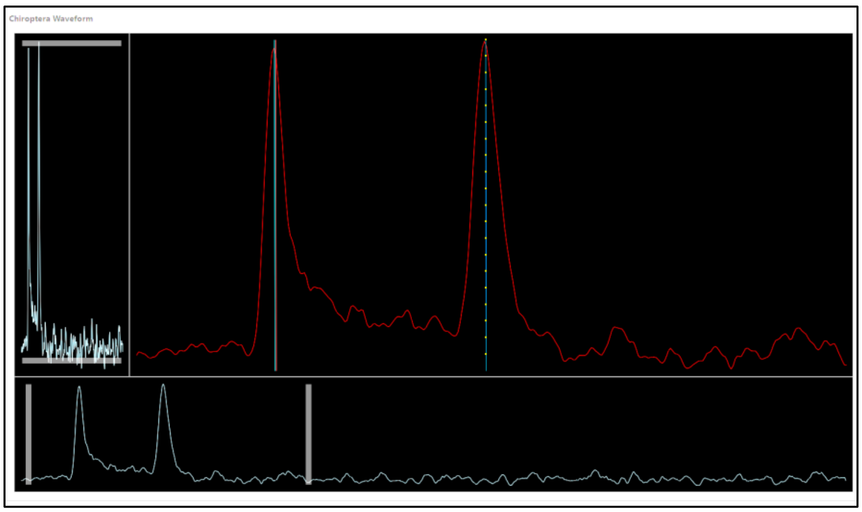


Figure 7: Sample Waveform in Shallow Water

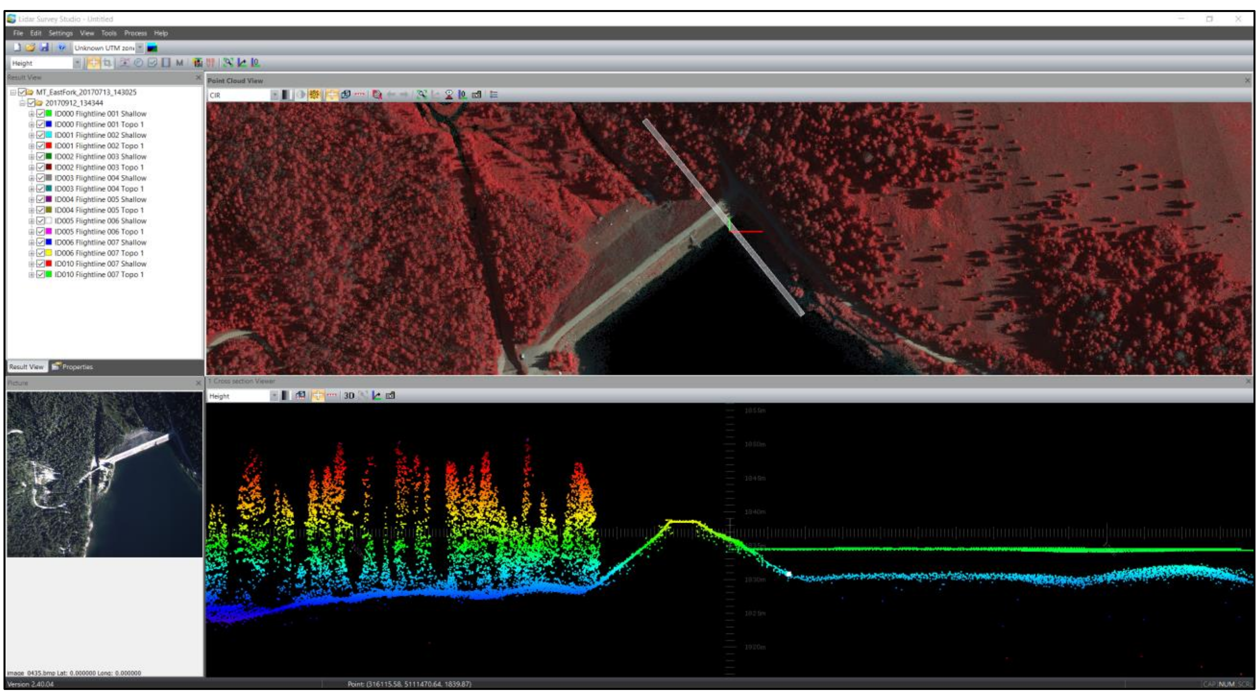


Figure 8: Sample LSS Processing Screen

Once the files were created, the points were colorized within LSS using the RCD30 images extracted from FramePro, as described in Section 2.4.2.

Additional QC steps were performed in LSS prior to import to Terrascan. Firstly, the derived water surface was reviewed to ensure a water surface was correctly calculated for all bathymetry channels. In particular areas of river outside the reservoir but inside the hydro polygon were checked carefully.

Spot checks were also made on the data to ensure the front and back of the scans remained in alignment and no calibration or system issues were apparent prior to further data editing in Terrascan.

Processing Logs are provided in Appendix D, indicating the calibration files used and processing session that data were output too.

2.4.4. Lidar Data Editing

After data were processed in LSS and the data integrity reviewed, data were organized into tiles within a Terrascan project. Data classification and spatial algorithms were applied in Terrasolid's Terrascan software. Customized spatial algorithms, such as isolated points and low point filters, were run to remove gross fliers in the topographic data, and to identify bare earth/ground in the topographic data. In addition, spatial algorithms were run to remove any low noise in the bathymetric data.

All data were reviewed manually to reclassify any valid bathy points incorrectly identified by the automated routines in LSS as invalid, and vice versa. In addition, any topo points remaining over the water were reclassified to correct the ground representation. Manual editing was conducted both in Terrascan and LP360. Steps for manual editing included:

- Re-class any topo unclassified laser data and bathy seabed data from the water surface to a water surface class
- Review bathymetry in cross section. All bathy data were reviewed in 5m increments for the entire project.
    - Re-class suitable data to bathy ground (Class 22).
    - Re-class any noise in the bathy ground class to bathy noise (Class 27).

Although the bathymetry data includes intensity values, these are raw values. Intensity for the seabed ground classes can be normalized for any losses in signal as the light travels through the water column, so that the intensity value better reflects the intensity of the seabed itself. As this was not required for the project, normalization was not conducted. However, this can be conducted at a later date if required.

A final QC of the ground classes was conducted in LP360 and QT Modeler before LAS files containing only the accepted ground data were exported for merging with multibeam sonar data in CARIS HIPS.

3. MULTIBEAM SONAR

Bathymetric data were collected at both reservoirs in areas too deep for the lidar to penetrate using a Teledyne Reson T20-P multibeam sonar. The T20-P is a high resolution multi-frequency sonar system designed to be deployed on smaller vessels. Full bottom coverage was attained from the boundary with the lidar to the full depth of each reservoir.

The T20-P was configured to collect data at 400kHz in a 140-degree swath with 256 equidistant soundings per ping. Ping rate varied based on depth from a maximum of 20 pings/second in shallow water to approximately 5 pings/second in the deepest sections of the reservoir. In this configuration, the beam footprint is 1° x 1° and the system easily measured the entire reservoir depth.

The T20-P was interfaced with an Applanix POS/MV inertial navigation system to provide position, heave, pitch, roll and heading. Data were logged to allow post-processing in Applanix POSPac MMS version 7.2 software to enhance accuracies.

A Trimble SPS985 secondary GNSS system was also integrated to provide redundant horizontal and vertical positioning for quality control.

3.1. Mobilization

The survey vessel mobilized for this project was the *R/V Cari*, a custom built 23' aluminum inboard jet (Figure 9). The vessel was equipped with an enclosed cabin and over-the-side multibeam mount. She is easily trailerable and able to be launched at primitive ramps.

Figure 9: Survey Vessel R/V Cari

The vessel was mobilized with all equipment in GDS's Vancouver, WA warehouse and trailered to the project area. Once in Montana, the GDS field crew met at Eli's office in Missoula for a project kickoff to finalize scheduling and roles.

GDS then continued to Painted Rocks Reservoir to begin calibration and survey operations.

3.2. Calibration

The alignment angles of the multibeam sonar relative to the positioning and orientation system were determined at each reservoir using a standard patch test. A series of lines are collected over a steep slope to calculate the roll, pitch and yaw adjustments. System latency was also verified during the calibration process. Final calibration values are shown in Table 11.

Table 11: Calibration Results

Site	Pitch	Roll	Yaw	Latency
East Fork Reservoir	1.50°	1.35°	-0.50°	0.000 s
Painted Rocks Reservoir	1.50°	1.35°	-0.50°	0.000 s

Sensor offsets for the vessel were established during a dimensional survey during the initial vessel build using a total station and optical level. Accepted values are shown in Table 12.

Table 12: Sensor Offsets

Sensor Head	Lever Arm	X (starboard)	Y (forward)	Z (up)
Applanix POS/MV	Vessel Reference to IMU	0.000 m	0.000 m	0.000 m
	Vessel Reference to Primary GNSS	-2.015 m	0.250 m	1.733 m
Teledyne Reson T20-P	Vessel Reference to Transmit Acoustic Center	0.140 m	-0.057 m	-0.913 m
	Vessel Reference to Receive Acoustic Center	0.140 m	0.136 m	-0.960 m

To verify sonar accuracy and system offsets, a bar check was completed at each reservoir. During this test, a metal plate is suspended below the water surface at a known depth while the acquisition system records the sonar data. The digitized soundings are then queried in the processing software and compared against the known depth. Results are presented in Table 13.

Table 13: Bar Check Results

Site	Bar Depth	Sonar	Difference
East Fork Reservoir	2.000 m	2.009 m	0.009 m
Painted Rocks Reservoir	2.000 m	2.032 m	0.032 m

3.3. Survey Operations

The survey crew arrived at Painted Rocks Reservoir the evening of July 6, 2017 and survey operations began at on July 7, 2017. Three days of data were collected in the deeper sections of the reservoir, up to approximately 5m of water depth. Data collection was halted at this level to allow for the development of lidar coverage to maximize data collection efficiency.

The vessel was then towed to the East Fork on July 10. On the way, the hydrography crew met with the airborne crew to obtain the preliminary coverage from the bathy lidar flight. These data would be used during acquisition to ensure overlap between the two methods.

Survey operations were conducted at the East Fork on July 11 and 12, 2017.

The vessel then returned to Painted Rocks Reservoir on July 13, 2017. The lidar coverage boundary was loaded and the shallow sections of the reservoir were surveyed to complete the survey area coverage.

To control each survey, a Trimble R10 RTK GNSS base station was established on a temporary control point (Table 1). The base station was configured to log raw observables and broadcast corrections to the survey vessel.

Raw data were collected in Teledyne Reson PDS2000 version 3.8.3 software. The data acquisition software was configured to display real-time multibeam data that allowed the operator to navigate for optimum efficiency and ensure complete coverage of the survey areas.

Sound speed profiles were measured using an AML MinosX profiler at an interval of approximately 1-2 hours. Profiles were found to show significant changes due to the thermocline, that varied as the reservoirs warmed over the course of the day.

3.4. Data Processing

Multibeam data were post-processed in CARIS HIPS version 9.1.8 software.

Raw PDS format files were converted to HIPS format and all corrections such as calibration values, heave, pitch, roll, heading and position were applied. Post Processed Kinematic (PPK) trajectories were applied to correct for motion and water levels. Sound velocity profiles were applied using the Nearest in Time function.

The resulting georeferenced soundings were reviewed by a hydrographer in CARIS subset mode to remove any remaining spurious sonar returns. A 60 degree from nadir filter was run on data in East Fork prior to subset editing. No filters were used on Painted Rock reservoir. A 50cm resolution grid was used to guide and QC multibeam data editing (Figure 10) for both reservoirs. The full dataset was reviewed in subset mode, and any spurious noise flagged as rejected.

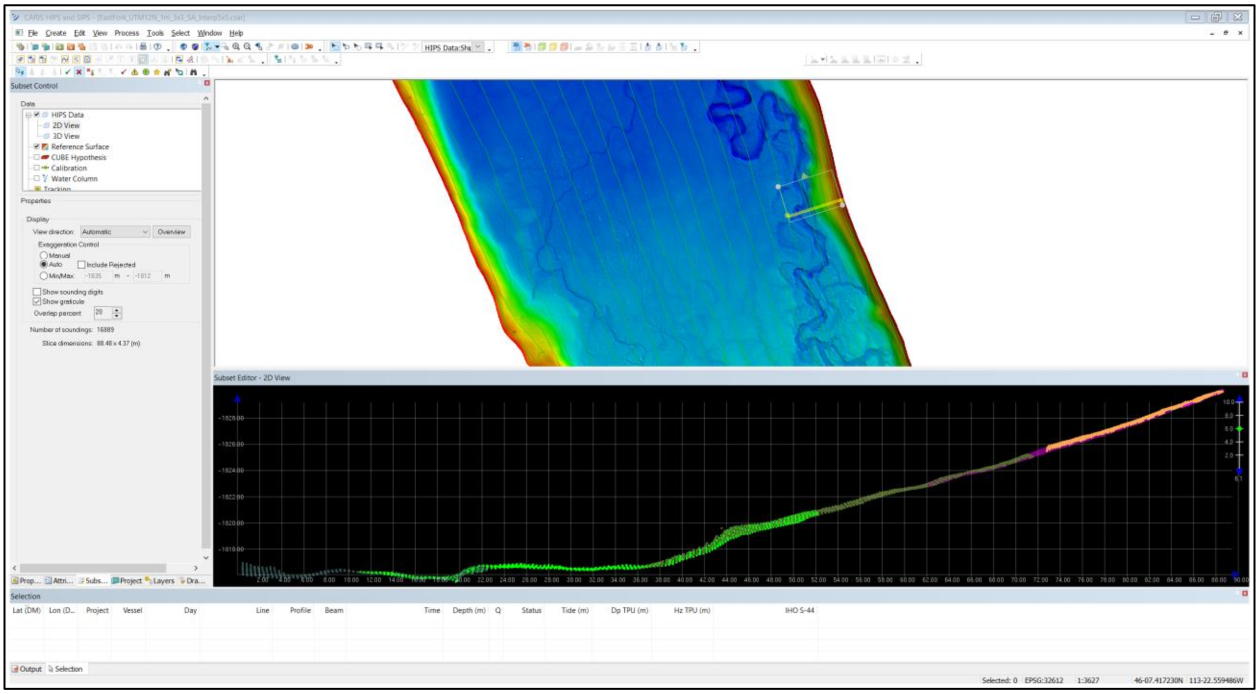


Figure 10: Multibeam Editing in Subset Mode for East Fork

4. SURFACE CREATION

To create the final surface, accepted lidar ground data (topo and bathy ground) were imported into CARIS HIPS, so that a DEM could be made from the full resolution lidar and sonar data.

A 1m resolution DEM was created in the project coordinate system (Montana State Plane International Feet) in CARIS HIPS from all accepted lidar and sonar data. At this point the vertical data was still referenced to the ellipsoid in meters.

Since CARIS makes additional surface layers, such as a shoal grid representing the shallowest sounding in a bin and a deep grid representing the deepest sounding in a bin, additional QC checks were conducted. A difference grid was created between the shoal and deep grid, and where these grids differed by more than 3m, the locations were checked to ensure no fliers remained in the dataset. Once this check was completed, the grids were exported as ASCII XYZ grid nodes.

Blue Marble Geographic Calculator was used to apply Geoid12B to the vertical elevations and convert from meters to International Feet. This produced a set of ASCII XYZ grid nodes in Montana State Plane, International Feet, with the vertical in NAVD88, International Feet.

Finally, the grid nodes were read in to Applied Imagery's QT Modeler software, and any small gaps in the DEM, for example caused by the caused by thick vegetation obscuring the ground in the topo lidar data, were filled. This is standard practice for topo lidar.

During lidar processing, any rivers or streams inside the hydro polygon were processed to extract as much valid bathymetry from the lidar data as possible. However, streams outside the hydro polygon were handled according to the USGS Lidar Base Specification, Version 1.2 (November 2014). In the case of streams narrower than 100ft, typically south of the reservoirs, the DEM only reflects the stream surface, and no hydro-flattening was conducted. In the rivers north of the reservoirs, bathy data was available, despite being outside the hydro polygon. This data was kept and used. Gaps in the DEM have been left, where no bathy data was available in the larger rivers outside the hydro polygon.

The final ASCII XYZ grid nodes were exported from QT Modeler for further use in CADD. The DEM was also provided in 32-bit floating point geotiff format.

5. QUALITY CONTROL

Quality control is carried out through every phase of the project. Several checks were used to ensure data integrity and quality was maintained. Specific statistics were generated during multibeam to lidar comparison, and comparison to topo control acquired with RTK GNSS.

Checks discussed elsewhere in the report, include:

- **Calibration** - This is fundamental to good data accuracy. Calibration is discussed in detail in Section 2.2 and 3.2.
- **Online Checks** - The airborne and vessel operators monitored system status of the sonar or scanners and receivers and health of the navigation system during data acquisition.
- **Positioning** - During lidar acquisition, aircraft bank angles were restricted to 20º to avoid any potential GNSS dropouts. No flights were planned if the PDOP was expected to go above 3.0.
- **Comparison to Adjacent Lines** - Throughout data processing adjacent survey lines of data are compared during editing to ensure there are no data busts, or system artifacts. All differences were within specification.

Additional quality checks are described below.

5.1. Vertical Accuracy Checks

5.1.1. Lidar to RTK Ground Truth

Topo ground truth data were collected at both reservoirs using GNSS RTK and PPK techniques. Terrascan was used to compare the lidar data to known ground control points. For each known location a small TIN was created from the surrounding lidar points and the elevation difference from the TIN plane to the point computed. Data shows good agreement with the topo control (Table 14).

Table 14: Comparison to Topo Ground Truth Results

	East Fork	Painted Rock
Average dZ (m)	0.002	0.002
Std. Deviation	0.024	0.019
RMSE (m)	0.024	0.018

5.1.2. Comparison of Lidar to Multibeam

A 1m resolution DTM grid of multibeam data were compared to 1m resolution DTM grid of bathymetric lidar data to ensure data was aligned. Analysis was performed in ArcGIS. A summary of the statistics is provided in Table 15. Results are well within the required specifications. Standard deviations are high due to the use of grids for comparison, and much of the overlap occurring on slopes.

Table 15: Comparison of Lidar to Multibeam Results

	East Fork	Painted Rock
No. of Grid Nodes Compared	149,197	80,412
Mean Difference (MD) in m	0.053	0.083
Standard Deviation (St. Dev)	0.381	0.340

6. DELIVERABLES

Deliverables provided include:

- Lidar point cloud data in LAS 1.4 file format
- 1m resolution DEMs of the merged multibeam and lidar surfaces in ASCII XYZ gird node in format
- Tiled orthorectified aerial imagery in geotiff format
- Associated metadata

In addition, the following were delivered:

- Tile Layout used for imagery and LAS delivery in SHP format

6.1. Lidar LAS Files

All LAS data are provided in the project datum and projection. One LAS file is delivered per tile. All delivered LAS data include Adjusted GPS Time. In addition, all LAS files include RGB values where imagery was collected for the project. RGB values are valid for the time the lidar was collected and were not generated from an overall mosaic.

LAS file classes delivered are shown in Table 16. In general LAS classes follow ASPRS guidelines for the LAS format, but additional classes are used to separate data from the bathy and topo lidar. However, it is important to note that the LAS files have only be processed/classified to correctly represent ground. Therefore, noise may still remain in the unclassified topo data (Class 1). There are two invalid bathy lidar classes. Class 20 (Bathy Unclassified) specifically indicates data picked as a peak in the bathy waveform, that did not meet the threshold settings set by the user. Class 27 (Bathy Noise) contains all other types of noise generated by the bathymetric sensor. It is important to note that all valid bathy lidar data is found in Class 22 (Bathy Ground/Seabed).

Valid data classes used in generation of the DEM surfaces are highlighted in green in the table below.

Table 16: LAS Classes

Class	Description	Comment
1	Topo Unclassified	
2	Topo Ground	
7	Low Point (Noise)	
9	Topo Water	
17	Bridge Deck	
18	Topo High Noise	
20	Invalid Bathy Unclassified	Not valid. Peak selected from waveform in LSS but did not meet the threshold for valid depth selection.
22	Bathy Ground (Seabed)	
27	Bathy Noise	All bathy noise classes, other than unclassified – not valid
29	Bathy Water Surface	
30	Derived Water Surface	

6.2. Digital Elevation Model (DEM)

1m resolution DEMs of the merged multibeam and lidar surfaces are provided in ASCII XYZ gird node in format and 32-bit floating point geotiff format. Generation of surfaces is described in Section 4.

6.3. Imagery

Tiled orthorectified aerial imagery is provided in geotiff format at 0.25ft resolution. Imagery creation is described in Section 2.4.2.

6.4. Metadata Files

Validated FGDC metadata files were generated for the project in XML format. Information within the metadata file explains the project data and process steps, also included within this report.

APPENDIX A : FIELD NOTES

BASE STATION SETUP 7/11/17.

P2017.013 BH

πe 2A

RPC SET ON WEST END OF EAST FORK RESERVOIR ON TOP OF DAM AT MID POINT

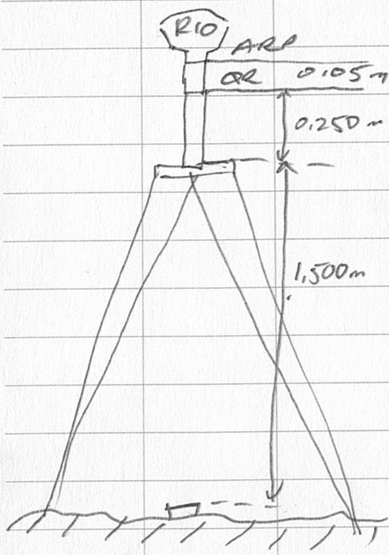
0.25 m EXT

TRIMBLE R10 SN0112 W QR

TRIMBLE TSC3 SN 4901

SECO FIXED LEGS @ 1.500m

HA = 1.800 m TO ARP



START LOGGING + RTK

7/11/17 22:05

01121920.t02

*STARTED W/ WRONG HA
WAS 1.800m TO QR
SHOULD BE TO ARP

7/12/17 14:15

01121930.t02

CORRECT HA

7/13/17 13:42

01121931.t02

CHANGED TO 0.5S

No.312

REF POINTS — BH 07/11/17

P2017-023

TRIMBLE R10 SN ~~1678~~ 1684 w/RR
TRIMBLE 2m FIXED ROD w/ BIPOD
TRIMBLE TSC3 SN 4901

POINT	HA TO ARP	CODE	DESC
1000	2.050m	11	1/2" IP PAINTED PINK w/ORANGE FLAGGING ΔV 0.6'? ΔH ✓
1001	"	10	~~NAG~~ NGA BRASS DISK SET IN CONCRETE OF SPILL WAY STAMPED "2004 EAST FORK" ΔV ?
1002	"	127	GATE HOUSE SCREW @ FIRST GANGWAY SUPPORT OF INTAKE & POOR GPS ΔH ✓ ΔV ~~0.1~~ 0.13'?

⚠ BASE WAS SET w/ INCORRECT HA
REPROCESS 7/11 DATA

Rite in the Rain.

RTK POINTS — BH

P2017.013 — 07/12/17, 07/13/17

POINT	HA TO ARP	CODE	DESC
1003	2.050m	10	NGA BRASS DISK
			Δ < 0.1' ✓
2000	"	EOW	@ ~ 00:30 7/11/17
2001	"	EOW	" RESHOT QC
2002	"	EOW	@ ~ 13:50 7/12/17
1004	"	10	NGA BRASS DISK
			Δ < 0.1' ✓
20	"	TGT	PAINT ⌖ IN SPILLWAY
21	"	TGT	" ON BRIDGE
22	"	TGT	" ON ROCK
23	"	TGT	" ON SIDING
24	"	TGT	" ON ROCK RD
25	"	TGT	" ON GRAVEL
1005	"	6	IP W/ PAINT @ OUTLET
1006		120	OUTLET CENTER (NO MARK)
26		TGT	OUTLET W X

No.312

RTK POINTS — BH

P2017.013 — 07/13/17

POINT	HA TO ARP	CODE	DESC
27	2.050m	TGT	PAINT ⊕ ON GRASS
28	"	QC	TOP CENTER SQUARE ACCESS HATCH (~~NM~~ X)
29	"	QC	TOP CENTER ⊗ WELL
30	"	QC	TOP CENTER ⊠ ACCESS
31	"	QC	"
3000 - 3031	"	TOPO	QC X-SECTION 1
3032 - 3062	"	TOPO	QC CL ROAD
3063 - 3081	"	TOPO	QC SPILLWAY CREST
3082 - 3100	"	TOPO	QC SPILLWAY CL

BASE STATION SETUP

7/7/17

P2017·013

BH

⊼ @ CP-1

DJ&A AL CAP SET IN GRAVEL
ON SE SIDE OF PAINTED ROCKS
DAM SPILLWAY

0.05m QR

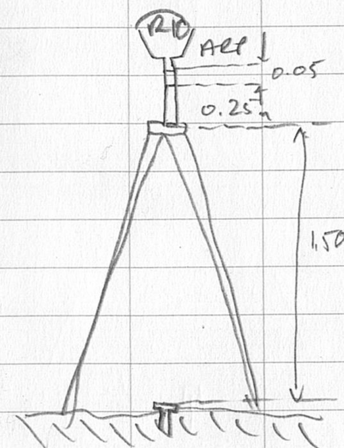
TRIMBLE R10 SN 0112 w/0.25m EXT

INTERNAL RADIO CMR+ 461.1 TT450S
@ 8000 bps 2W

TRIMBLE TSC3

SECO FIXED LEGS @ 1.500 m

HA= 1.800 TO ARP



START LOGGING 1s

7/7/17 @ 14:45
01121881.t02
7/8/17 @ 12:48
01121890.t02
7/9/17 @ 16:01
01121900.t02
7/14/17 @ 19:19
01121950.t02
7/15/17 @ 14:12
01121960.t02

No.312

RTK POINTS BH

P2017-013 7/7/17

TRIMBLE R10 SN 1684 w/QR

TRIMBLE TSC3

TRIMBLE 2m CARBON ROD w BIPOD

POINT	HA	CODE	DESC
	TO APP		USGS
		NGS-3JD	~~NGS~~ BRASS DISK
100	2.050m		SET IN SE CONCRETE
	3 min		CORNER OF SPILLWAY
	CONTROL		AT PAINTED ROCKS
	OBS		DAM STAMPED
			"1957 ELEVATION
			4744. FT 3JD"
101	"	DJA-CP4	RPC SET IN GRAVEL
			ON SOUTH SIDE OF
			ROAD AT ENTRANCE
			TO BOAT RAMP
102	"	DJA-CP2	DJA ALCAP SET
			IN GROUND
			7/14/17
1000	2.050	CP4-2017	CHECK INTO CP4
			DH DV ✓.

P2017.013 RTK POINTS 07/14/17

BH

POINT	HA TO ARP	CODE	DESC
1001	2.050m	EOW	ON/AT RAMP @ P.K. CAMP GOOD FOR TOPO COMP
			7/15/17
1002	"	EOW	ON RAMP @ 13:50
1003	"	EOW	" @

APPENDIX B : MULTIBEAM ACQUISITION LOGS

Geomatics Data Solutions
Hydro Survey Log

Date: 07/07/2017 DN: 188
Project Name: MT RESERVOIRS
Project Number: P2017-013
Contract Number:
Task/PO Number:

Project Information

Description of Operations: MULTIBEAM AT RESERVOIRS
Time Zone (UTC/Local): UTC
Locality: PAINTED ROCKS & EAST FORK RESERVOIRS
Sub-Locality:

Horizontal Control

Primary Positioning System	APPLANIX POS MV	Serial Number	
Antenna Type (if applicable)	TRIMBLE	Serial Number	
Secondary Positioning System	TRIMBLE SPS985	Serial Number	3139
Antenna Type (if applicable)		Serial Number	
GNSS Reference Station	TRIMBLE R10	Serial Number	0112
Antenna Type (if applicable)		Serial Number	
Horizontal Datum	NAD83 (2010)		
Horizontal Projection	MONTANA STATE PLANE		
Horizontal Units	INT. FEET		

Vertical Control

Primary Water Levels	PPK POSPAC	Datum	NAVD88
Secondary Water Levels	RTK/PPK TRIMBLE SPS985		GEOID12B
Vertical Units	INT. FEET		

Instrumentation

Sonar	RESON T20-P	
Motion Reference System	APPLANIX POS MV	
Vessel Heading Instrument	APPLANIX POS MV	
Primary Sound Velocity	AML MINOS X	
Secondary Sound Velocity	AML SMART X	
Primary Acquisition Software	PDS 2000	
Secondary Acquisition		
Other Systems		
Other Systems		

Vessel Loading and Crew

Vessel Name and Description: R/V CARI
Pilot: BH
Draft on Pole:
At Roll Angle:
Port/Starboard Draft: 0.775m TO TOP POLE
Average:
Fixed distance Antenna->Sonar ______ - Draft ______ = Antenna Phase Center to WL ______ (Hypack)
Crew:

Comments: PRELIM PATCH ROLL: 1.35
PITCH: 1.50
YAW: -0.5

Geomatics Data Solutions
Hydro Survey Log

Project Name: MT RESERVOIRS
Project Number: PR017-013

Date: 07/07/2017 DN: 188

Weather: CLEAR 90 - 100°
Sea State: CALM

Line Types: MS = Main Scheme, XL = Cross Line, SL = Shore Line, P = Patch, T = Testing, R = Reject

TIME	LINE #	RPM	LINE Az.	TYPE	NOTES
					BASE SET ON DJA CP.1
					CHECKED INTO DJA CONTROL CP4 & CP2 W/ R10
					SET UP & LAUNCHED VESSEL
					MET WITH KURT OF GMT
					~~PROB~~ STARTED ROVER LOG 3139 1880.tgz
					POS PAC LOG 20170707.CARI-A
					PROBLEMS WITH SONAR
					TROUBLESHOOTING
					ISSUE WAS IO NOT LOADING AT
					STARTUP
					START POSPAC 20170707-CARI-B
					STILL HAVING ENGINE TROUBLES
					WORKING...

Geomatics Data Solutions
Hydro Survey Log

Project Name: MT RESERVOIRS
Project Number: P2017.013

Page 3 of 11

Date: July 7, 2017 DN: 188
Weather: 20.600 CLEAR
Sea State: CALM

Line Types: MS = Main Scheme, XL = Cross Line, SL = Shore Line, P = Patch, T = Testing, R = Reject

TIME	LINE #	RPM	LINE Az.	TYPE	NOTES
1851	55/55			MS	
					MOTOR DIED. END POS FILE B
					PULL BOAT & WORK ON FUEL SYSTEM
2310					LAUNCH - CRACKED FUEL LINES & LOOSE FITTING
					SEEMS TO RUN TRYING A FEW MBES LINES
					ROVER 3139188I.T02
					POS PAC 20170707.CARI.C
2328	55/55			MS	BEGIN MS
2339					
2347					
2355					
0006					
0014					
0018					
0024					
0027					
0032	0035			MS	
0040			→	P	PATCH } CL PAIR
0047			←	P	
0048			→	P	}
0050			←	P	
0051			→	P	}
0053			←	P	
0059				MS	RUN ONE LINE BACK TO DOCK
					END FOR DAY, RECOVER BASE

Geomatics Data Solutions
Hydro Survey Log

Project Name:	MT RESERVOIRS
Project Number:	P2017.013

Date: 07/08/17 DN: 189

Weather: 85 PTLY CLDY
Sea State: CALM

Line Types: MS = Main Scheme, XL = Cross Line, SL = Shore Line, P = Patch, T = Testing, R = Reject

TIME	LINE #	RPM	LINE Az.	TYPE	NOTES
					DRAFT = 0.70 m GUNNEL TO WTR SFC
					(~10cm TO PIPE)
1405					START LOGGING POSPAC A
					ROVER 31391890.t02
1410					SV CAST #1 ~10 m
1411					BAR CHECK - BAR @ 2.00 m TO WTR SFC
1426					POS FILE NOT UPDATING SIZE - RESTART
					TO BE SURE - B
1431					SVP #2 ~15 m
	55/55				BEGIN MS
1439					SVP #3
1538					SVP #4
1638					SVP #5 IN OFFSHOOT
					SVP #6 OUTSIDE OF OFFSHOOT
1755					SVP #7 IN OTHER OFFSHOOT.
					SVP #8 OUTSIDE OFFSHOOT
1849					SVP #9 NEAR CAMP
1920					SVP #10 MID BLOCK

Geomatics Data Solutions
Hydro Survey Log

Project Name: MT RESERVOIRS
Project Number: P2017.013

Date: 07/08/2017 DN: 189
Weather: 85-90 BROKEN
Sea State: CALM

Line Types: MS = Main Scheme, XL = Cross Line, SL = Shore Line, P = Patch, T = Testing, R = Reject

TIME	LINE #	RPM	LINE Az.	TYPE	NOTES
2000					SVP # 11 MID BLOCK
2015					SVP # 12 SHALLOW END OF BLOCK
2045					SVP # 13 NEAR RAMP
2104					SVP # 14 DEEP 14/15 IN PROBE
2139					SVP # 15 DEEP
					FILTER DEEP LINES 45/45
					SVP # 16 DEEP
2246					SVP # 17 DEEP
2350					SVP # 18 DEEP.
0008					END SURVEY STOP ALL LOGGING
					NO DATA LOGGED AFTER
					UTC ROLLOVER
0040					PULLED BOAT

Geomatics Data Solutions
Hydro Survey Log

Project Name:	MT RESERVOIRS
Project Number:	P2017.013

Date: 07/09/2017 DN: 190

Weather: BROKEN / OVC. 75°

Sea State: CALM <5KTS

Line Types: MS = Main Scheme, XL = Cross Line, SL = Shore Line, P = Patch, T = Testing, R = Reject

TIME	LINE #	RPM	LINE Az.	TYPE	NOTES
					LAUNCH BOAT
1555					START POSPAC -A
1600					ROVER 31391900.E02
					PROBLEMS CONNECTING TO T20P
1615					RESTART POS LOGGING C
1620					SUP 001
					SUP 002
1810					SUP 003
1825					SUP 004 @ BOAT LAUNCH SHALLOW
1903					SUP 005
1920					SUP 006 IN ARM
1950					SUP 007
2045					SUP 008
					SUP 009 (#1 IN WAYPOINTS)
2131					SUP 010 DEEP
2145					SUP 011
2153					END SURVEY
					PULL BASE & BOAT
					PAINTED ROCKS COMPLETE

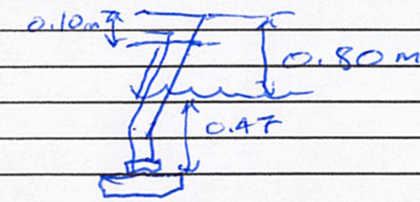
Geomatics Data Solutions
Hydro Survey Log

Project Name: MT RESERVOIRS
Project Number: P2017.013

Date: 07/11/17 DN: 192

Weather: BROKEN, 80° N 5-10 KTS
Sea State: RIPPLED

Line Types: MS = Main Scheme, XL = Cross Line, SL = Shore Line, P = Patch, T = Testing, R = Reject

TIME	LINE #	RPM	LINE Az.	TYPE	NOTES
					SET BASE ON 2A - BEGIN EAST FORK
					DRAFT TOP 
2204					START LOGGING ROVER 31391920.t02
2208					POS - B
2218					BAR CHECK BAR @ 2m
2220					START MS 55/55
2220					SUP #1
2240					SUP #2
2322					SUP #3 < PATCH TEST
2352					SUP #4
2359					END FOR DAY
					☆ NOTE INCORRECT HA @ BASE TODAY
					WAS 0.05 cm OFF
					SET TO 1.800 TO QR WAS ACTUALLY
					1.750 TO QR

Geomatics Data Solutions
Hydro Survey Log

Project Name: MT RESERVOIRS
Project Number: P2017.013

Date: 07/12/2017 DN: 193
Weather: CLEAR 65°
Sea State: CALM

Line Types: MS = Main Scheme, XL = Cross Line, SL = Shore Line, P = Patch, T = Testing, R = Reject

TIME	LINE #	RPM	LINE Az.	TYPE	NOTES
1420					START REVOC LOGGING 3139 1930.602
					(BASE SET ON 2A 1.75m TO QR)
1422					POSPAC - A
1445					SUP #001
1536					SUP #002
1627					SUP #003
1712					SUP #004
1753					SUP #005 MID BLOCK
1915					SUP #006 DEEP END
1940					SUP #007 SHALLOW END
~~204~~ 2040					SUP #008
2116					SUP #009
2126					SUP #010
2241					SUP #011 STARTING SC
2236					SUP #012 MID R
2258					SUP #013
2330					
					SUP #014 END PROJECT.

Geomatics Data Solutions
Hydro Survey Log

Project Name: MT RESERVOIRS
Project Number: P2017.013

Date: 07/13/17 DN: 194

Weather: BROKEN 85°
Sea State: 5 KTS CALM

Line Types: MS = Main Scheme, XL = Cross Line, SL = Shore Line, P = Patch, T = Testing, R = Reject

TIME	LINE #	RPM	LINE Az.	TYPE	NOTES
					SET BASE ON 2A
1845					START POSPAC - A
					ROVER 31391940.t02
					EOW W/RTK 2005
					RTK SHOT ON IMU ~~BULLSEYE~~ PLATE #2006
					BULLSEYE ~ 0.105m ABOVE
1946					BAR CHECK - BAR @ 2m
					DRAFT 0.70m WTR SFC → GUNNEL
2000					SV CAST
					END SURVEY.

Geomatics Data Solutions
Hydro Survey Log

Project Name: MT RESERVOIRS
Project Number: P2017.013

Date: 07/14/17 DN: 195

Weather: CLEAR 85°
Sea State: CALM

Line Types: MS = Main Scheme, XL = Cross Line, SL = Shore Line, P = Patch, T = Testing, R = Reject

TIME	LINE #	RPM	LINE Az.	TYPE	NOTES
					PAINTED ROCKS FILL
					BASE @ CP1 1.800m TO ARP RIO
1911					START ROVER 31391950.t02
1930					POSPAC A
19					
2130					SU CAST #1 "DEEP" END OF AREA
2015					SU CAST #2 IN FIRST BAYLET
					END SURVEY OF THIS AREA - STUMPS
2033					SU CAST #3
2108					SU CAST #4 - TOO MANY PEOPLE IN WATER
2151					SUP CAST #5
2233					SUP CAST #6 DEEP
2240					GNSS ACCURACY POOR - MOVING TO NEW AREA
2320					SUP CAST #7 NEAR RAMP
0055					SUP CAST #8
					END FOR DAY

Geomatics Data Solutions
Hydro Survey Log

Project Name:	MT RESERVOIRS
Project Number:	P2017.013

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Date: 07/15/2017 DN: 196

Weather: CLEAR / CALM

Sea State: CALM

Line Types: MS = Main Scheme, XL = Cross Line, SL = Shore Line, P = Patch, T = Testing, R = Reject

TIME	LINE #	RPM	LINE Az.	TYPE	NOTES
					BASE ON CP1 @ 1.800 m TO ARP
1402					START ROVER 31391960.T02
1407					START POSPAC-A
1415					SVP #001 DEEP END OF ARM
1435					SVP #002 SHALLOW END OF ARM
1450					SVP #003 ON OTHER SIDE TO CONTINUE AROUND
1520					SVP #004 IN OTHER ARM
1620					SVP #005 "
1650					SVP #006 DEEP ENTRANCE TO ARM
					CLOSING PATCH TEST WHILE IN DEEPS
1710					SVP 007 IN ARM BY RAMP
1740					SVP 008 END!
					LOOKING FOR JETSKI HOOD

APPENDIX C : AIRBORNE ACQUISITION LOGS

FLIGHT LOG

GEOMATICS DATA SOLUTIONS

PROJECT NAME:	P2016-013 - PR & EF - Bathy-Topo Lidar	**BASE AIRPORT:**	Falcon Field, GA (FFC)
LOCATION / AREA:	Montana / Peachtree City, GA	**DATE:**	12 July 2017
AIRCRAFT:	Cessna 404 - N7079F	**PILOT:**	Ray L.
SYSTEM:	Chiroptera II	**OPERATOR:**	Dushan A.

MISSION ID:	CAL-FFC	**CLOUDS:**	Hazy / Cloudy
BASE STATION:	FFC1	**WIND:**	10kts @ 250

ENGINE START:	12:13	**ENGINE OFF:**	13:50	**ENGINE TIME:**	01:37
GNSS START:	12:17	**GNSS START:**	13:50		
TAKEOFF:	12:26	**TOUCHDOWN:**	13:46	**AIR TIME**	01:20

FL #	LINE #	START TIME	END TIME	TOPO PRF	TOPO PWR	CHII PWR	REMARKS
		12:32:34					DS: 1000m_20170712_123318
000_FL1	101	12:32:52	12:34:36	250	35	295	
001_FL2	102	12:37:24	12:39:16	250	35	295	
002_FL3	103	12:41:26	12:43:11	250	35	295	
003_FL4	104	12:47:59	12:49:44	250	35	295	
004_FL5	105	12:52:30	12:54:08	250	35	295	
005_FL6	106	12:56:38	12:58:19	250	35	295	
		13:01:21					DS: 500m_20170712_130205
000_FL1	51	13:01:40	13:03:13	400	13	90	
001_FL2	52	13:05:46	13:07:27	400	13	90	
002_FL3	53	13:09:28	13:11:07	400	13	90	
003_FL4	54	13:15:23	13:16:59	400	13	90	
004_FL5	55	13:19:43	13:21:13	400	13	90	
005_FL6	56	13:23:47	13:25:19	400	13	90	
		13:27:00					Clouds Moving In
		13:27:31					DS: 400m_20170712_132815
000_FL1	41	13:27:50	13:29:42	300	10	80	Clouds at End
001_FL2		13:32:15					BAD: Low Clouds
002_FL2		13:32:42					BAD: Low Clouds
003_FL2		13:32:54					BAD: Low Clouds
004_FL2	42	13:32:55	13:33:42	300	10	80	Clouds at Start
005_FL5	45	13:36:16	13:38:00	300	10	80	
006_FL6	46	13:40:22	13:42:11	300	10	80	Clouds at End
		13:42:00					Abort Mission: Low Clouds

GEOMATICS DATA SOLUTIONS

FLIGHT LOG

PROJECT NAME:	P2016-013 - PR & EF - Bathy-Topo Lidar	**BASE AIRPORT:**	Missoula (MSO)
LOCATION / AREA:	Montana / B5-EF, B5-PR, T8-EF, T8-PR	**DATE:**	13 July 2017
AIRCRAFT:	Cessna 404 - N7079F	**PILOT:**	Ray L.
SYSTEM:	Chiroptera II	**OPERATOR:**	Dushan A.

MISSION ID:	P2017-013_MT	**CLOUDS:**	Clear
BASE STATION:	CP1 and 2A	**WIND:**	5-10kts @ 205

ENGINE START:	13:46	**ENGINE OFF:**	18:16	**ENGINE TIME:**	04:30
GNSS START:		**GNSS START:**			
TAKEOFF:	14:02	**TOUCHDOWN:**	18:13	**AIR TIME**	04:11

FL #	LINE #	START TIME	END TIME	TOPO PRF	TOPO PWR	CHII PWR	REMARKS
		14:26:00					Initialize GNSS over 2AFlown a bit low
		14:29:40					DS: EastFork_20170713_143025
000_FL1	501	14:30:01	14:32:20	320	31	300	
001_FL2	502	14:35:30	14:37:50	320	31	300	
002_FL3	503	14:39:26	14:41:46	320	31	300	
003_FL4	504	14:44:32	14:46:54	320	31	300	
004_FL5	505	14:48:23	14:50:37	320	31	300	
005_FL6	506	14:53:32	14:55:36	320	31	300	
006_FL7	507	14:57:36	14:59:27	320	31	300	Flown a bit low
007_FL12	701	15:02:40	15:04:26	400	13	300	
008_FL13	702	15:08:04	15:09:50	400	13	300	
009_FL14	703	15:13:36	15:15:17	400	13	300	
010_FL7	507	15:19:15	15:21:08	320	31	300	Re-flown
		15:24:00					Close GNSS over 2A
		15:42:00					Initialize GNSS over CP1
		15:46:55					DS: PaintedRock_20170713_154740
000_FL1	101	15:47:13	15:48:30	320	31	300	
001_FL2	102	15:51:06	15:52:27	320	31	300	
002_FL3	103	15:54:54	15:56:12	320	31	300	
003_FL4	104	15:58:57	16:00:19	320	31	300	
004_FL5	105	16:02:23	16:04:21	320	31	300	
005_FL6	106	16:07:09	16:09:18	320	31	300	
006_FL7	107	16:11:37	16:13:40	320	31	300	
007_FL8	108	16:16:14	16:18:28	320	31	300	
008_FL9	109	16:21:01	16:23:58	320	31	300	
009_FL10	110	16:26:44	16:29:50	320	31	300	
010_FL11	111	16:32:34	16:35:41	320	31	300	
011_FL12	112	16:38:05	16:41:18	320	31	300	
012_FL13	113	16:43:50	16:46:59	320	31	300	
013_FL14	114	16:49:33	16:52:46	320	31	300	

FLIGHT LOG

PROJECT NAME:	P2016-013 - PR & EF - Bathy-Topo Lidar	**BASE AIRPORT:**	Missoula (MSO)
LOCATION / AREA:	Montana / B5-EF, B5-PR, T8-EF, T8-PR	**DATE:**	13 July 2017
AIRCRAFT:	Cessna 404 - N7079F	**PILOT:**	Ray L.
SYSTEM:	Chiroptera II	**OPERATOR:**	Dushan A.

MISSION ID:	P2017-013_MT	**CLOUDS:**	Clear
BASE STATION:	CP1 and 2A	**WIND:**	5-10kts @ 205

ENGINE START:	13:46	**ENGINE OFF:**	18:16	**ENGINE TIME:**	04:30
GNSS START:		**GNSS START:**			
TAKEOFF:	14:02	**TOUCHDOWN:**	18:13	**AIR TIME**	04:11

FL #	LINE #	START TIME	END TIME	TOPO PRF	TOPO PWR	CHII PWR	REMARKS
014_FL15	115	16:55:34	16:58:34	320	31	300	
015_FL16	116	17:01:13	17:04:12	320	31	300	
016_FL17	117	17:06:44	17:09:39	320	31	300	
017_FL26	301	17:13:39	17:14:40	400	13	300	
018_FL27	302	17:16:22	17:17:29	400	13	300	
019_FL28	303	17:19:39	17:21:01	400	13	300	
020_FL29	304	17:22:56	17:24:42	400	13	300	
021_FL30	305	17:29:59	17:32:08	400	13	300	
022_FL31	306	17:35:55	17:38:03	400	13	300	
023_FL32	307	17:41:37	17:43:43	400	13	300	
		17:48:00					Close GNSS over CP1

FLIGHT LOG

GEOMATICS DATA SOLUTIONS

PROJECT NAME:	P2016-013 - PR & EF - Bathy-Topo Lidar	**BASE AIRPORT:**	Missoula (MSO)
LOCATION / AREA:	Montana / B5-PR, T8-EF, T8-PR	**DATE:**	15 July 2017
AIRCRAFT:	Cessna 404 - N7079F	**PILOT:**	Ray L.
SYSTEM:	Chiroptera II	**OPERATOR:**	Dushan A.

MISSION ID:	P2017-013_MT	**CLOUDS:**	Clear
BASE STATION:	CP1 and 2A	**WIND:**	5kts @ 130

ENGINE START:	14:07	**ENGINE OFF:**	16:24	**ENGINE TIME:**	02:17
GNSS START:		**GNSS START:**			
TAKEOFF:	14:17	**TOUCHDOWN:**	16:22	**AIR TIME**	02:05

FL #	LINE #	START TIME	END TIME	TOPO PRF	PWR	CHII PWR	REMARKS
		14:47:00					Initialize GNSS over CP1
		14:51:21					DS: PaintedRock_20170715_145206
000_FL40	121	14:51:39	14:53:15	320	31	300	
001_FL33	311	14:56:52	14:57:51	400	13	300	
002_FL34	312	15:00:03	15:01:04	400	13	300	
003_FL35	313	15:03:48	15:05:06	400	13	300	
004_FL36	314	15:07:06	15:08:32	400	13	300	
005_FL37	315	15:10:46	15:12:31	400	13	300	
006_FL38	316	15:14:28	15:16:33	400	13	300	
007_FL39	317	15:20:30	15:22:34	400	13	300	
008_FL41	122	15:27:57	15:30:09	320	31	300	
		15:33:00					Close GNSS over CP1
		15:50:00					Initialize GNSS over 2A
		15:54:44					DS: EastFork_20170715_155529
000_FL15	511	15:55:03	15:56:41	320	31	300	
		15:59:00					Close GNSS over 2A

FLIGHT LOG

PROJECT NAME:	P2017-014 - Great Bahama Bank 8 - Bathy Lidar	**BASE AIRPORT:**	Dayton (DAY)
LOCATION / AREA:	Great Bahama Bank, BHS / Sidney, OH	**DATE:**	8 August 2017
AIRCRAFT:	Cessna 404 - N7079F	**PILOT:**	Ray L.
SYSTEM:	Chiroptera II	**OPERATOR:**	Dushan A.

MISSION ID:	CAL-SidneyOH	**CLOUDS:**	Clear
BASE STATION:	SIDN (CORS)	**WIND:**	10-15kts @ 50

ENGINE START:	11:47	**ENGINE OFF:**	14:00	**ENGINE TIME:**	02:13
GNSS START:		**GNSS START:**			
TAKEOFF:	12:00	**TOUCHDOWN:**	13:56	**AIR TIME**	01:56

FL #	LINE #	START TIME	END TIME	TOPO PRF	TOPO PWR	CHII PWR	REMARKS
		12:15:00					Initialize GNSS over SIDN
		12:18:49					DS: 1000m_20170808_121946
000_FL3	1003	12:19:11	12:21:25	250	35	295	
001_FL4	1004	12:24:01	12:26:19	250	35	295	
002_FL5	1005	12:29:01	12:31:17	250	35	295	
003_FL6	1006	12:36:15	12:38:29	250	35	295	
004_FL1	1001	12:42:00	12:44:16	250	35	295	
005_FL2	1002	12:46:57	12:49:17	250	35	295	
		12:53:33					DS: 500m_20170808_125430
000_FL1	501	12:53:54	12:55:20	400	13	90	
001_FL2	502	12:57:59	12:59:31	400	13	90	
002_FL3	503	13:01:56	13:03:28	400	13	90	
003_FL4	504	13:05:47	13:07:13	400	13	90	
004_FL5	505	13:09:58	13:11:29	400	13	90	
005_FL6	506	13:14:47	13:16:18	400	13	90	
		13:18:56					DS: 400m_20170808_131953
000_FL3	403	13:19:16	13:20:38	300	10	80	
001_FL4	404	13:23:05	13:24:28	300	10	80	
002_FL5	405	13:26:44	13:28:06	300	10	80	
003_FL6	406	13:32:04	13:33:25	300	10	80	
004_FL1	401	13:36:31	13:37:53	300	10	80	
005_FL2	402	13:40:33	13:41:59	300	10	80	
		13:45:00					Close GNSS over SIDN

APPENDIX D : PROCESSING LOGS

RCD30 CALIBRATION LOG

PROJECT NAME: P2017-013 - PaintedRock & EastFork - Lidar
LOCATION: Montana
AIRCRAFT: Cessna 404 - N7079F
SYSTEM: Chiroptera II

RCD30 Dataset	FramePro				IPAS CO+					Estimate Misalignment													Comments
	Download RCD30 Data	Run Dataset	Image Type Created	Bits	IPAS Solution	Camera File	PPO X (mm)	PPO Y (mm)	Camera File Status	APM	Run AT	Sigma0	PPA X (mm)	PPA Y (mm)	Misalign X (arcmin)	Misalign Y (arcmin)	Misalign Z (arcmin)	Misalign X RMS (arcmin)	Misalign Y RMS (arcmin)	Misalign Z RMS (arcmin)	Accept / Reject		
2017-07-12A	DA	CL	RGB	8	2017-07-12A	IPAS_RCD30_82541	0.0000	0.0000	Initial	5x5	CL	80	0.0000	0.0000	-2.720	-7.460	2.520	0.970	1.160	1.380	IPAS_RCD30_82541_r1		1000m
					2017-07-12A	IPAS_RCD30_82541_r1	0.0000	0.0000	Interim	5x5	CL	6.3	0.0734	0.0011	-1.510	3.190	3.870	0.060	0.050	0.120	IPAS_RCD30_82541_r2		
Exported to RCD30_Geometry_CameraHead-82541-D-798528_LensSystem-50149---785422_DateTime-20170809-193527.xml																							
2017-07-12A	DA	CL	RGB	8	2017-07-12A	IPAS_RCD30_82541	0.0000	0.0000	Final														400m

GEOMATICS DATA SOLUTIONS

LSS CALIBRATION

PROJECT NAME: P2017-013 - PaintedRock & EastFork - Lidar
LOCATION: Montana
AIRCRAFT: Cessna 404 - N7079F
SYSTEM: Chiroptera II

Mission	Copied to Disk	Nav Session	Nav Type	Calibration File	Cal Type	Processing Parameters	Check Processing Parameters	Processing Session	Number of FL	Process Topo	Process Shallow	Process Deep	QA Stats Created	Mirror Calibration	Comments
PRE-SURVEY CALIBRATION															
Cal-FFC_1000m_20170712_123318	DA	2017-07-12A	Final	CAL_TSD_20170712_r0	Initial	ProcessingCal_20170712_1000	CL	20170719_104928	6	6	--	--	MC		
								Calibration_2017-07-27_08.58.00		6	--	--			Topo - Update Angles (r1)
Cal-FFC_500m_20170712_130205	DA	2017-07-12A	Final	CAL_TSD_20170712_r0	Initial	ProcessingCal_20170712_500	CL	20170719_113306	6	6	6	--	MC		
								Calibration_2017-07-26_17.14.59			6	--			Shallow - Update Angles (r1)
Cal-FFC_400m_20170712_132815	DA	2017-07-12A	Final	CAL_TSD_20170712_r0	Initial	ProcessingCal_20170712_400	CL	20170719_120426	4	4	4	--	MC		
															Update Topo, Shallow - Angles & Slant Ranges (r1)
Cal-FFC_1000m_20170712_123318	DA	2017-07-12A	Final	CAL_TSD_20170712_r1	Interim	ProcessingCal_20170712_1000	CL	20170802_185720	6	6	--	--	CL		
								Calibration_2017-08-03_15.55.24							Topo - Update Angles (r2)
Cal-FFC_500m_20170712_130205	DA	2017-07-12A	Final	CAL_TSD_20170712_r1	Interim	ProcessingCal_20170712_500	CL	20170803_072654	6	6	6	--	CL		
								Calibration_2017-08-03_15.42.38							Shallow - Update Angles (r2)
Cal-FFC_400m_20170712_132815	DA	2017-07-12A	Final	CAL_TSD_20170712_r1	Interim	ProcessingCal_20170712_400	CL	20170802_194032	4	4	4	--	CL		
															Update Topo, Shallow - Angles & Slant Ranges (r2)
Cal-FFC_1000m_20170712_123318	DA	2017-07-12A	Final	CAL_TSD_20170712_r2	Interim	ProcessingCal_20170712_1000	CL	20170804_082327	6	6	--	--	CL		
								20170804_124327_MirrorCalibration						CL	Topo - Mirror Cal (r3)
Cal-FFC_500m_20170712_130205	DA	2017-07-12A	Final	CAL_TSD_20170712_r2	Interim	ProcessingCal_20170712_500	CL	20170804_082412	6	6	6	--	CL		
								20170804_125455_MirrorCalibration							Shallow - Mirror Cal (r3)
Cal-FFC_400m_20170712_132815	DA	2017-07-12A	Final	CAL_TSD_20170712_r2	Interim	ProcessingCal_20170712_400	CL	20170804_082452	4	4	4	--	CL		
															Update Topo, Shallow - Mirror Cal (r3)
Cal-FFC_1000m_20170712_123318	DA	2017-07-12A	Final	CAL_TSD_20170712_r3	Final	ProcessingCal_20170712_1000	CL	20170804_130011	6	6	--	--	CL		
Cal-FFC_500m_20170712_130205	DA	2017-07-12A	Final	CAL_TSD_20170712_r3	Final	ProcessingCal_20170712_500	CL	20170804_130109	6	6	6	--	CL		
Cal-FFC_400m_20170712_132815	DA	2017-07-12A	Final	CAL_TSD_20170712_r3	Final	ProcessingCal_20170712_400	CL	20170804_130203	4	4	4	--	CL		
20170712 CAL NOT USED FOR PROJECT PROCESSING															
POST-SURVEY CALIBRATION															
CAL-SIDN_1000m_20170808_121946	DA	2017-08-08A	Final	CAL_TS_20170808_r0	Final	ProcessingCal_20170808_1000	MC	20170814_092804	6	6	--	--	MC		
								Calibration_2017-08-14_15.44.23							Topo - Update Angles (r1)
CAL-SIDN_500m_20170808_125430	DA	2017-08-08A	Final	CAL_TS_20170808_r0	Final	ProcessingCal_20170808_500	MC	20170814_092940	6	6	6	--	MC		
								Calibration_2017-08-14_15.49.01							Shallow- Update Angles (r1)
CAL-SIDN_400m_20170808_131953	DA	2017-08-08A	Final	CAL_TS_20170808_r0	Final	ProcessingCal_20170808_400	MC	20170814_092339	6	6	6	--	MC		
															Update Topo, Shallow - Angles & Slant Ranges (r1)
CAL-SIDN_1000m_20170808_121946	DA	2017-08-08A	Final	CAL_TS_20170808_r1	Final	ProcessingCal_20170808_1000	MC	20170814_160632	6	6	--	--	MC		
								Calibration_2017-08-15_08.34.02							Topo - Update Angles (r2)
CAL-SIDN_500m_20170808_125430	DA	2017-08-08A	Final	CAL_TS_20170808_r1	Final	ProcessingCal_20170808_500	MC	20170814_161021	6	6	6	--	MC		
								Calibration_2017-08-15_08.36.02							Shallow- Update Angles (r2)
CAL-SIDN_400m_20170808_131953	DA	2017-08-08A	Final	CAL_TS_20170808_r1	Final	ProcessingCal_20170808_400	MC	20170814_161210	6	6	6	--	MC		

LSS CALIBRATION

PROJECT NAME: P2017-013 - PaintedRock & EastFork - Lidar
LOCATION: Montana
AIRCRAFT: Cessna 404 - N7079F
SYSTEM: Chiroptera II

Mission	Copied to Disk	Nav Session	Nav Type	Calibration File	Cal Type	Processing Parameters	Check Processing Parameters	Processing Session	Number of FL	Process Topo	Process Shallow	Process Deep	QA Stats Created	Mirror Calibration	Comments
															Update Topo, Shallow - Angles & Slant Ranges (r2)
CAL-SIDN_1000m_20170808_121946	DA	2017-08-08A	Final	CAL_TS_20170808_r2	Final	ProcessingCal_20170808_1000	MC	20170815_111658	6	6	--	--	MC		
CAL-SIDN_500m_20170808_125430	DA	2017-08-08A	Final	CAL_TS_20170808_r2	Final	ProcessingCal_20170808_500	MC	20170815_111713	6	6	6	--	MC		
								Calibration_2017-08-15_13.44.36							Topo - Update Angles (r3)
								Calibration_2017-08-15_13.45.42							Shallow - Update Angles (r3)
CAL-SIDN_400m_20170808_131953	DA	2017-08-08A	Final	CAL_TS_20170808_r2	Final	ProcessingCal_20170808_400	MC	20170815_111722	6	6	6	--	MC		
															Update Topo, Shallow - Angles (r3) & Slant Ranges (r1)
CAL-SIDN_1000m_20170808_121946	DA	2017-08-08A	Final	CAL_TS_20170808_r3	Final	ProcessingCal_20170808_1000	MC	20170815_141947	6	6	--	--	MC		
CAL-SIDN_500m_20170808_125430	DA	2017-08-08A	Final	CAL_TS_20170808_r3	Final	ProcessingCal_20170808_500	MC	20170815_141954	6	6	6	--	MC		
								Calibration_2017-08-15_17.16.24							Topo - Update Angles (r4)
								Calibration_2017-08-15_17.16.15							Shallow - Update Angles (r4)
CAL-SIDN_400m_20170808_131953	DA	2017-08-08A	Final	CAL_TS_20170808_r3	Final	ProcessingCal_20170808_400	MC	20170815_142000	6	6	6	--	MC		
															Update Topo, Shallow - Angles & Slant Ranges (r4)
CAL-SIDN_1000m_20170808_121946	DA	2017-08-08A	Final	CAL_TS_20170808_r4	Final	ProcessingCal_20170808_1000	MC	20170815_172838	6	6	--	--	MC		
CAL-SIDN_500m_20170808_125430	DA	2017-08-08A	Final	CAL_TS_20170808_r4	Final	ProcessingCal_20170808_500	MC	20170815_192248	6	6	6	--	MC		
								20170816_101555_MirrorCalibration						MC	Topo - Mirror Cal (r5)
								20170816_101735_MirrorCalibration						MC	Shallow - Mirror Cal (r5)
CAL-SIDN_400m_20170808_131953	DA	2017-08-08A	Final	CAL_TS_20170808_r4	Final	ProcessingCal_20170808_400	MC	20170815_182330	6	6	6	--	MC		
															Update Topo, Shallow - Mirror Cal (r5)
CAL-SIDN_1000m_20170808_121946	DA	2017-08-08A	Final	CAL_TS_20170808_r5	Final	ProcessingCal_20170808_1000	MC	20170816_103506	6	6	--	--	MC		
CAL-SIDN_500m_20170808_125430	DA	2017-08-08A	Final	CAL_TS_20170808_r5	Final	ProcessingCal_20170808_500	MC	20170816_103614	6	6	6	--	MC		
CAL-SIDN_400m_20170808_131953	DA	2017-08-08A	Final	CAL_TS_20170808_r5	Final	ProcessingCal_20170808_400	MC	20170816_103704	6	6	6	--	MC		
Copy CAL_TS_20170808_r5 to CAL_TS_Survey_20170712 for Survey															

PROJECT NAME: P2017-013 - PaintedRock & EastFork - Lidar
LOCATION: Montana
AIRCRAFT: Cessna 404 - N7079F
SYSTEM: Chiroptera II

RCD30 Dataset	FramePro				IPAS CO+									LPS						OrthoVista	Comments
	Download	Run Dataset	Image Type Created	Bits	IPAS Solution	Camera File	PPO X (mm)	PPO Y (mm)	Camera File Status	Output File (Output in LPS .dat)	Output Datum	Output Units	Output Geographic ASCII.txt	Update EO .dat file paths	Create Block File	Set IO	Set EO	Import DTM	Ortho rectification	Mosaic (0.25ft)	
2017-07-13A	DA	CL	RGBN	8	2017-07-13A	IPAS_RCD30_82541	0	0	Final	EO-2017-07-13A-EF-MTSP-IntlFt	MT SP (NAD83)	Ift	CL	CL	EF/2017-07-13A-MTSP	5.2	CL	CL	CL	CL	East Fork
2017-07-13A	DA	CL	RGBN	8	2017-07-13A	IPAS_RCD30_82541	0	0	Final	EO-2017-07-13A-PR-MTSP-IntlFt	MT SP (NAD83)	Ift	CL	CL	PR/2017-07-13A-MTSP	5.2	CL	CL	CL	CL	Painted Rock

GEOMATICS DATA SOLUTIONS

LIDAR PROCESSING LOG

PROJECT NAME: P2017-013 - PaintedRock & EastFork - Lidar
LOCATION: Montana
AIRCRAFT: Cessna 404 - N7079F
SYSTEM: Chiroptera II

Mission	Copied to Disk	Nav Session	Nav Type	Calibration File	Cal Type	Processing Parameters	Check Processing Parameters	Processing Session	Number of FL	Process Topo	Process Shallow	Process Deep	Verify Derived Water Surface (Coverage and Height)	Review Submerged Data for any settings issues	Review Shallow to Deep, Shallow to Topo	Colorize in LSS	Review FL SHP	Export Trajectories	Merge in FME	Comments
MT_EastFork_20170713_143025	DA	2017-07-13A	Final	CAL_TS_Survey_20170712	Final	ProcessingSurvey_20170712_500_r0	MC	20170912_134344	11	8	8	--	MC	MC	MC	MC	MC	MC	MC	
						ProcessingSurvey_20170712_800_r0	MC	20170912_140424		3	3	--	MC	MC	MC	MC	MC	MC	MC	
MT_PaintedRock_20170713_154740	DA	2017-07-13A	Final	CAL_TS_Survey_20170712	Final	ProcessingSurvey_20170712_500_r0	MC	20170912_133951	24	7	7	--	MC	MC	MC	MC	MC	MC	MC	
						ProcessingSurvey_20170712_800_r0	MC	20170912_133802		17	17	--	MC	MC	MC	MC	MC	MC	MC	
MT_PaintedRock_20170715_145206	DA	2017-07-15A	Final	CAL_TS_Survey_20170712	Final	ProcessingSurvey_20170712_500_r0	MC	20170912_153907	9	7	7	--	MC	MC	MC	MC	MC	MC	MC	
						ProcessingSurvey_20170712_800_r0	MC	20170912_184019		2	2	--	MC	MC	MC	MC	MC	MC	MC	
MT_EastFork_20170715_155529	DA	2017-07-15A	Final	CAL_TS_Survey_20170712	Final	ProcessingSurvey_20170712_800_r0	MC	20170912_224734	1	1	1	--	MC	MC	MC	MC	MC	MC	MC	