2007 Yellowstone River Lidar Certification

2007 YELLOWSTONE RIVER LIDAR

STATE OF MONTANA DEPARTMENT OF NATURAL RESOURCES

CONTRACT NUMBER: WO-WI-131

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DESIGN | GEOSPATIAL | INFRASTRUCTURE

PROJECT REPORT

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STATE OF MONTANA DEPARTMENT OF NATURAL RESOURCES

CONTRACT NUMBER: WO-WI-131

For:

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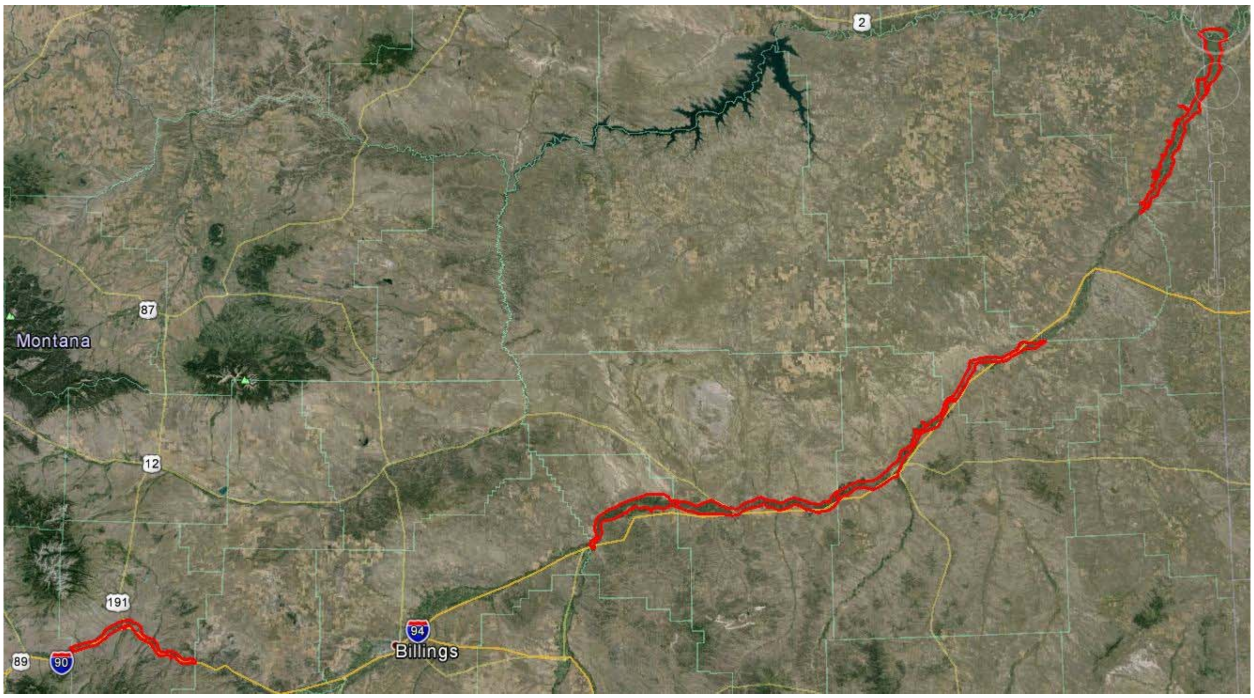
SECTION 1: OVERVIEW, ACQUISITION, AND PROCESSING PROCEDURES

This report contains an outline of the 2007 Yellowstone lidar certification procedure. This task is issued under Contract Number WO-WI-131. The project data was acquired in October of 2007 through an agreement with the U.S. Army Corps of Engineers (USACE). The project area covers all counties along the Yellowstone River Corridor except Stillwater, Yellowstone, and Dawson counties. The lidar data was processed and projected in Montana State Plane (FIPS 2500), North American Datum of 1983 in units of survey feet. The vertical datum used for the task order was referenced to NAVD 1988, GEOID03, in units of survey feet.

Figure 1.1 Lidar Task Order AOI



ACQUISITION INFORMATION

The data was collected using a Leica ALS50 II 150 kHz Multiple Pulses in Air (MPiA) lidar sensor. The ALS50 II sensor collects up to four returns per pulse, as well as intensity data, for the first three returns. If a fourth return was captured, the system does not record an associated intensity value. The aerial lidar was collected at the following sensor specifications:

Post Spacing (Minimum):	6.56 ft / 2.0 m
AGL (Above Ground Level) average flying height:	7,431 ft / 2,265 m
Average Ground Speed:	150 knots / 172.6 mph
Field of View (full):	44 degrees
Pulse Rate:	45 kHz
Scan Rate:	25 Hz
Side Lap (Average):	30%

WORK FLOW OVERVIEW

- 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).

- 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.

- 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.

- The LAS files were evaluated through a series of manual QA/QC steps to eliminate remaining artifacts from the ground class.

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 the acquisition mission, and was operated by a member of the Woolpert acquisition team. 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.

The GNSS base station operated during the lidar acquisition missions is listed below:

Table 1.1: GNSS Base Station

Station	Latitude	Longitude	Ellipsoid Height (L1 Phase center)
Name	(DMS)	(DMS)	(Meters)
13	47º38'42.75190" N	104º09'47.85779" W	1893.08
19	46ø43'33.28849"N	105ø26'09.24398"W	2244.62
22	46º29'59.94373" N	105º45'10.02392" W	2275.72
33	46º17'40.95044" N	106º40'52.73925" W	2684.38
36	46º19'52.61332" N	107º04'12.51199" W	2570.58
55	45º49'19.99959" N	109º53'33.49899" W	4009.67

DATA PROCESSING

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

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 project data was imported and classified, survey ground control data was imported and calculated for an accuracy assessment. As a QC measure, Woolpert has developed a routine to generate accuracy statistical reports by comparisons against the TIN and the DEM using surveyed ground control of higher accuracy. The lidar is adjusted accordingly 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 lidar LAS files are classified into the client specified ASPRS classifications.

SURVEY DATA PROCESSING

Project control and base station services which included a network of quality check points and control data was provided to Woolpert for the 2007 Yellowstone lidar collection by the project's prime consultant Eisenbraun and Associates, Inc. A geometric and observation plan was designed and carried out by an experienced GPS field crew. Real-time kinematic and rapid-static GPS survey techniques were utilized for this project. Rapid Static GPS surveying was utilized in areas where existing monumentation did not exist within a reasonable distance from the project site. Following are the GPS surveying techniques utilized:

Real-Time Kinematics GPS Survey: A Trimble Navigation 4700 or 5700 GPS dual frequency receiver and a modem for the RTK GPS base station(s); for roving, Trimble Navigation R8/5800 dual frequency GPS receivers with Trimble Navigation TSC2 data collector were utilized. For this survey technique, a 1-second epoch rate, in fixed solution RTK mode with each observation lasting 60 to 180 seconds. Each photogrammetric control station was observed twice from two different base stations and at entirely different constellation times to ensure the necessary horizontal and vertical accuracies were being met.

Rapid-Static GPS Survey: Rapid-Static GPS surveying requires a minimum of two receivers to occupy stations at either end of a baseline for approximately 10-15 minutes, depending upon the baseline length, number of satellites, and satellite geometry. This is similar in theory to static surveying; however, shorter observation time is made possible due to advances in both hardware and software. This project utilized Trimble Navigation 4000/4700/5700/5800 dual-frequency GPS receivers for the field data collection. Eisenbraun/Woolpert utilized a 5-second sync rate with each observation lasting between 20-40 minutes.

LIDAR CERTIFICATION PROCEDURE

Upon request from Montana Department of Natural Resources, Woolpert analyzed the 2007 Yellowstone lidar project data to provide a lidar certification. These procedures included:

- Restore project data from offsite storage facility and upload to Woolpert's production network
- Review and determine the final adjusted LAS data
- Review and determine the final adjusted control coordinates
- Perform control comparison review to determine absolute accuracy; this will be performed using methodology outlined in NSSDA FGDC-STD-007.3-1998 (National Standards for Spatial Data Accuracy). The statement 'Compiled to meet' will be used in the assessment, as the data was produced according to procedures that have been demonstrated to produce data with particular horizontal and vertical values.
- Compile statistics and report accuracy; this control comparison and subsequent statistical output will be performed using a combination of Terrasolid software and spreadsheet functions. Terrasolid software has the ability to generate a TIN from points within a set proximity to control data and determine a delta z value based on the difference. The statistical accuracy report was based on the RMSE (square root of the average of the set of square differences) of the reported delta z values. The accuracy z value is determined by multiplying the RMSE * 1.96. This implies that 95% of the positions in the dataset will have an error with respect to true ground position that is equal to or smaller than the reported accuracy value.

SECTION 2: VERTICAL ACCURACY ASSESSMENT

The vertical accuracy statistics were calculated by comparison of the lidar bare earth points to the ground surveyed quality check points.

Table 2.1: Overall Vertical Accuracy Statistics

Average error	-0.331	meters
Minimum error	-1.028	meters
Maximum error	0.551	meters
Root mean square	0.425	meters

Table 2.2: Swath Quality Check Point Analysis

Point ID	Easting (UTM meters)	Northing (UTM meters)	TIN Elevation (meters)	Dz (meters)
901	3273566.67	1286725.64	1925.55	-0.216
1001	3287043.81	1291377.02	1912.30	-0.332
1002	3286943.45	1291399.43	1911.77	-0.316
1003	3286843.15	1291422.55	1911.46	-0.301
1004	3286744.82	1291444.84	1911.48	-0.217
1005	3286638.15	1291468.92	1911.45	-0.198
1006	3286527.45	1291493.73	1911.56	-0.2
1007	3286419.10	1291518.25	1911.61	-0.388
1008	3286315.08	1291541.50	1911.53	-0.17
1009	3286206.53	1291566.24	1911.48	-0.334
1010	3286100.18	1291589.92	1911.28	-0.072
1011	3285993.73	1291614.04	1911.14	-0.294
22	2911323.39	842849.88	2328.36	-0.65
910	2897765.54	817613.25	2345.75	-0.025
911	2904400.06	826467.39	2358.56	0.511
1086	2915032.17	858338.47	2335.54	-0.35
1087	2915131.69	858344.97	2334.69	-0.263
1088	2915232.27	858351.55	2333.83	-0.473

Point ID	Easting (UTM meters)	Northing (UTM meters)	TIN Elevation (meters)	Dz (meters)
1089	2915331.21	858357.61	2333.21	-0.349
1090	2915430.99	858363.94	2332.56	-0.385
1091	2915533.02	858370.58	2332.13	-0.414
1092	2915631.60	858376.81	2331.69	-0.224
1093	2915731.16	858383.32	2331.78	-0.195
1094	2915831.57	858389.63	2331.61	-0.269
1095	2915930.81	858396.07	2331.57	-0.275
1096	2916029.35	858402.51	2331.41	-0.348
36	2581910.23	768316.95	2619.79	-0.302
906	2570280.79	753867.90	2605.98	-0.001
907	2574133.64	753313.54	2603.71	-0.307
1050	2564474.98	767434.10	2620.19	-0.337
1051	2564376.85	767429.54	2619.99	-0.456
1052	2564273.51	767423.68	2619.92	-0.625
1053	2564175.74	767418.99	2619.77	-0.465
1054	2564074.74	767414.24	2619.75	-0.41
1055	2563975.53	767409.77	2619.59	-0.403
1056	2563874.85	767404.62	2619.10	-0.622
1057	2563776.49	767399.42	2618.84	-0.612
1058	2563675.40	767393.40	2618.61	-0.515
1059	2563575.88	767389.22	2618.80	-0.462
1060	2563475.84	767384.38	2619.39	-0.577
1069	2588805.16	772445.11	2696.46	0.198
1070	2588763.47	772354.52	2694.51	0.069
1071	2588720.92	772263.61	2693.60	0.273
33	2680508.28	758283.56	2734.58	-0.02
916	2682425.48	748477.19	2522.31	-0.942

Point ID	Easting (UTM meters)	Northing (UTM meters)	TIN Elevation (meters)	Dz (meters)
1100	2690825.41	758971.41	2513.52	-0.141
1101	2690925.54	758975.23	2513.62	-0.019
1102	2691025.03	758979.18	2513.68	-0.177
1103	2691124.95	758982.61	2513.58	-0.1
1104	2691226.01	758985.96	2513.84	-0.078
1105	2691326.37	758989.50	2513.99	-0.129
1106	2691426.42	758992.90	2513.99	0.029
1107	2691525.15	758995.92	2514.22	-0.053
1108	2691625.35	758999.64	2514.21	-0.034
1109	2691726.46	759003.60	2514.10	-0.116
1110	2691826.67	759007.19	2514.01	-0.095
1111	2670745.11	752061.12	2555.45	-0.663
1112	2670645.34	752064.03	2554.91	-0.738
1113	2670545.44	752067.06	2554.08	-0.645
1114	2670445.15	752070.05	2553.18	-0.757
1115	2670345.16	752072.79	2552.59	-0.625
1116	2670243.91	752075.91	2551.90	-0.673
1117	2670144.94	752078.68	2551.14	-0.637
1118	2670045.44	752081.40	2550.40	-0.436
1119	2669944.40	752084.79	2549.63	-0.49
1120	2669845.55	752087.59	2548.93	-0.695
1121	2669744.95	752090.40	2548.22	-0.52
55	1868433.94	573499.25	4047.87	-0.7
910	1868390.44	576549.50	4013.00	-0.054
911	1863370.62	580056.35	4047.70	-1.028
1100	1867619.46	577214.68	4022.99	-0.644
1101	1867698.72	577155.38	4022.34	-0.648

Point ID	Easting (UTM meters)	Northing (UTM meters)	TIN Elevation (meters)	Dz (meters)
1102	1867780.96	577094.52	4021.49	-0.694
1103	1867860.51	577035.30	4020.76	-0.54
1104	1867941.55	576974.94	4019.98	-0.583
1105	1868020.35	576916.82	4019.14	-0.427
1106	1868102.80	576856.31	4018.35	-0.497
1107	1868183.26	576796.67	4017.57	-0.428
1108	1868262.89	576738.24	4016.87	-0.667
1109	1868343.01	576679.00	4015.98	-0.44
1110	1868422.58	576619.94	4015.24	-0.497
1111	1856683.11	585075.53	4036.24	-0.099
1112	1856785.58	585085.02	4033.96	-0.316
1113	1856882.08	585097.31	4033.43	-0.167
1114	1856980.12	585107.39	4032.71	-0.139
1115	1857080.70	585118.71	4031.81	-0.096
1116	1857181.03	585128.97	4030.72	-0.132
1117	1857280.12	585138.04	4029.80	0.069
1118	1857380.19	585146.85	4029.56	-0.101
1119	1857477.51	585155.22	4028.89	-0.129
1120	1857581.53	585164.90	4027.54	-0.134
1121	1857677.96	585173.77	4026.00	-0.284

VERTICAL ACCURACY CONCLUSIONS

A total of 92 checkpoints in open terrain were provided by Eisenbraun Consultants and used to assess the vertical accuracy of the Digital Terrain Model (DTM) from which the 1.0 Meter contours were derived. Results of the checkpoint assessment yielded an RMSEz of 12.9cm or Accuracyz = 25.28cm (Accuracyz = 1.96 x RMSEz). Thus, the vertical accuracy can be reported as:
Compiled to meet 25.28cm vertical accuracy at the 95% confidence level
The resulting RMSEz of 12.9cm (0.425') is well within the vertical accuracy requirements of 1.64' RMSEz as defined by ASPRS Accuracy Standards for Large Scale Maps, Class 1, for 1.0' contours.

SECTION 3: LIDAR CERTIFICATE OF COMPLIANCE

Shown below is the lidar certificate of compliance for this project.

Project Name:	2007 Yellowstone River LiDAR, Montana
Statement of Work No.:	N/A
Interagency Agreement No.:	N/A
CTP Agreement No.:	Montana DNRC-FEMA
Statement/Agreement Date:	March 18, 2005
Certification Date:	November 14, 2014

	Tasks/Activities Covered by This Certification (Check All That Apply)
☐	Base Map
☒	Topographic Data Development – Yellowstone River
☒	Survey – Yellowstone River
☐	Hydrologic Analysis
☐	Hydraulic Analysis
☐	Alluvial Fan Analysis
☐	Coastal Analysis
☐	Floodplain Mapping
	This is to certify that the work summarized above was completed in accordance with the statement/agreement cited above and all amendments thereto, together with all such modifications, either written or oral, as the Regional Project Officer and/or Assistance Officer or their representative have directed, as such modifications affect the statement/agreement, and that all such work has been accomplished in accordance with the provisions contained in *Guidelines and Specifications for Flood Hazard Mapping Partners* cited in the contract document, and in accordance with sound and accepted engineering practices within the contract provisions for respective phases of the work. This is also to certify that data files submitted for the work summarized above are complete and final. Any revisions made to the already submitted data are included in the final submittal.

Name:	Brett R. Kennedy
Title:	Professional Land Surveyor
Firm/Agency Represented:	Eisenbraun and Associates, Inc.
Registration No.:	22301
Signature:	Brett R. Kennedy

This form must be signed by a representative of the firm or agency contracted to perform the work, who must be a registered or certified professional in the area of work performed, in compliance with Federal and State regulations.

MONTANA
BRETT R. KENNEDY
No. 22301LS
LICENSED
PROF. LAND SURVEYOR

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