Airborne LiDAR Report

MT STILLWATER COMPLEX QL2 LIDAR

Contract Number: G16PC00022
Task Number: G15PD00899

Contractor: Woolpert, Inc.
Woolpert Project # 76827

July 2017

Airborne LiDAR Report

UNITED STATES GEOLOGICAL SURVEY

USGS_MT STILLWATER COMPLEX QL2

Contract Number: G16PC00022
Task Number: G15PD00899

Woolpert
4454 Idea Center Boulevard
Dayton, Ohio 45430.1500
Phone: 937.461.5660

Table of Contents

List of Figures

List of Tables

Section 1: Overview

TASK ORDER NAME: MT STILLWATER COMPLEX QL2 LIDAR

Project: # 76827

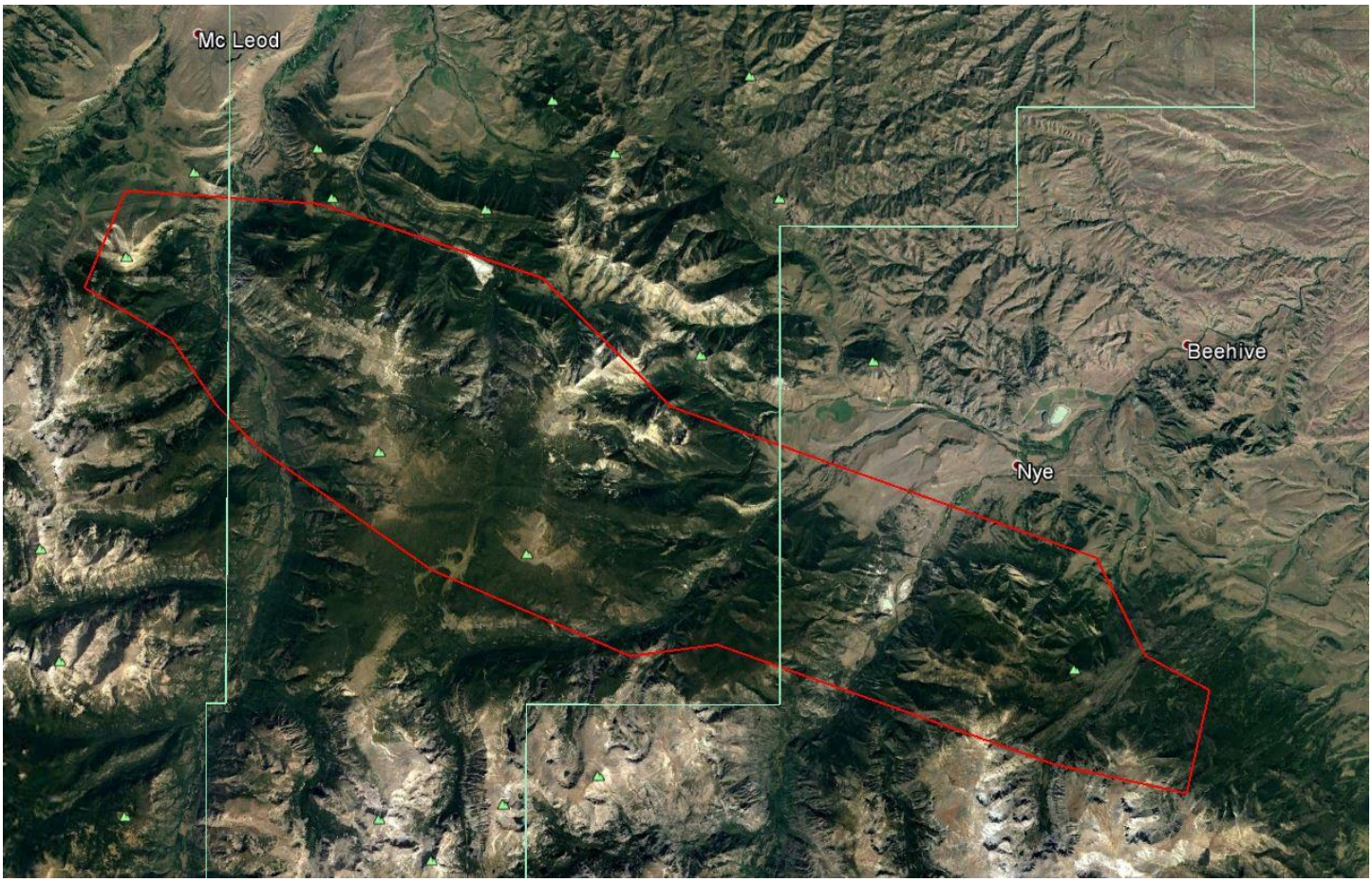
This report contains a comprehensive outline of the MT Stillwater Complex QL2 Lidar Processing task order for the United States Geological Survey (USGS). This task is issued under USGS Contract No. G16PC00022, Task Order No. G15PD00899. This task order requires lidar data to be covering portions of south-central Montana including portions of Sweetgrass, Stillwater and Park Counties (approximately 162 square miles). The lidar was collected and processed to meet a maximum Nominal Post Spacing (NPS) of 0.7 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 Dual-Head DragonEye (DE) sensor. The sensor was mounted in a Leica PAV100 gyro-stabilized mount integrated with a NovAtel SPAN GNSS and LCI-100C IMU. This sensor collects up to four returns (echo) per pulse, as well as intensity data, for the first three returns. The aerial lidar was collected at the following sensor specifications:

Table 1.1: Dual-Head DragonEye (DE) Specifications	
Post Spacing	0.7 m
AGL (Above Ground Level) average flying height	1500 m
Average Ground Speed:	125 knots / 144 mph
Field of View (full)	40 degrees
Pulse Rate	180
Scan Rate	55 Hz
Side Lap	15%

LiDAR data was produced in NAD83 (2011) UTM12N. Coordinate positions were specified in units of meters. The vertical datum used for the project was referenced to NAVD 1988, meters, GEOID12B.

Figure 1.1: Lidar Task Order AOI



Section 2: Acquisition

The LiDAR data was acquired with a Leica Leica Dual-Head DragonEye (DE) sensor, on board Woolpert's Cessna aircraft. The Leica system, developed by Leica of Herrburgg, Switzerland. The innovative dual scanner head design of the DragonEye features a unique oblique scan pattern. In one single pass, each ground target may be illuminated by four laser shots at multiple incidence angles from ±8 to ±20 degrees, maximizing vertical surface definition and minimizing shadows in the survey data. Each topographic laser operates in the infra-red spectrum at 1064nm. Up to 15 returns per pulse are acquired from each laser.

Figure 2.1: The Leica DragonEye LiDAR System has the following specifications:

Laser Characterization	
Laser wavelength [6]	1064 nm
Laser divergence	0.5 mrad ($1/e^2$)
Pulse repetition frequency (PRF)	Up to 1 MHz
Return pulses	Programmable up to 15 returns, with full waveform record option
Operation altitude [1]	300 – 1600 m AGL
Scanner pattern	Dual head oblique scanner
Scanner speed	Programmable up to 70 RPS per scanner (i.e., 280 scans/second)
Field of view	±8° and ±20° front/back, ±20° left/right
Swath width	70 % of AGL
Point density [2]	> 16 pts/m^2
Ranging accuracy [2], [3], [4]	2 cm (1σ)
Vertical accuracy [2], [3], [5]	6 cm (1σ)
Horizontal accuracy [2], [3], [5]	25 cm (1σ)

Prior to mobilizing to the project site, flight crews coordinated with the necessary Air Traffic Control personnel to ensure airspace access.

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

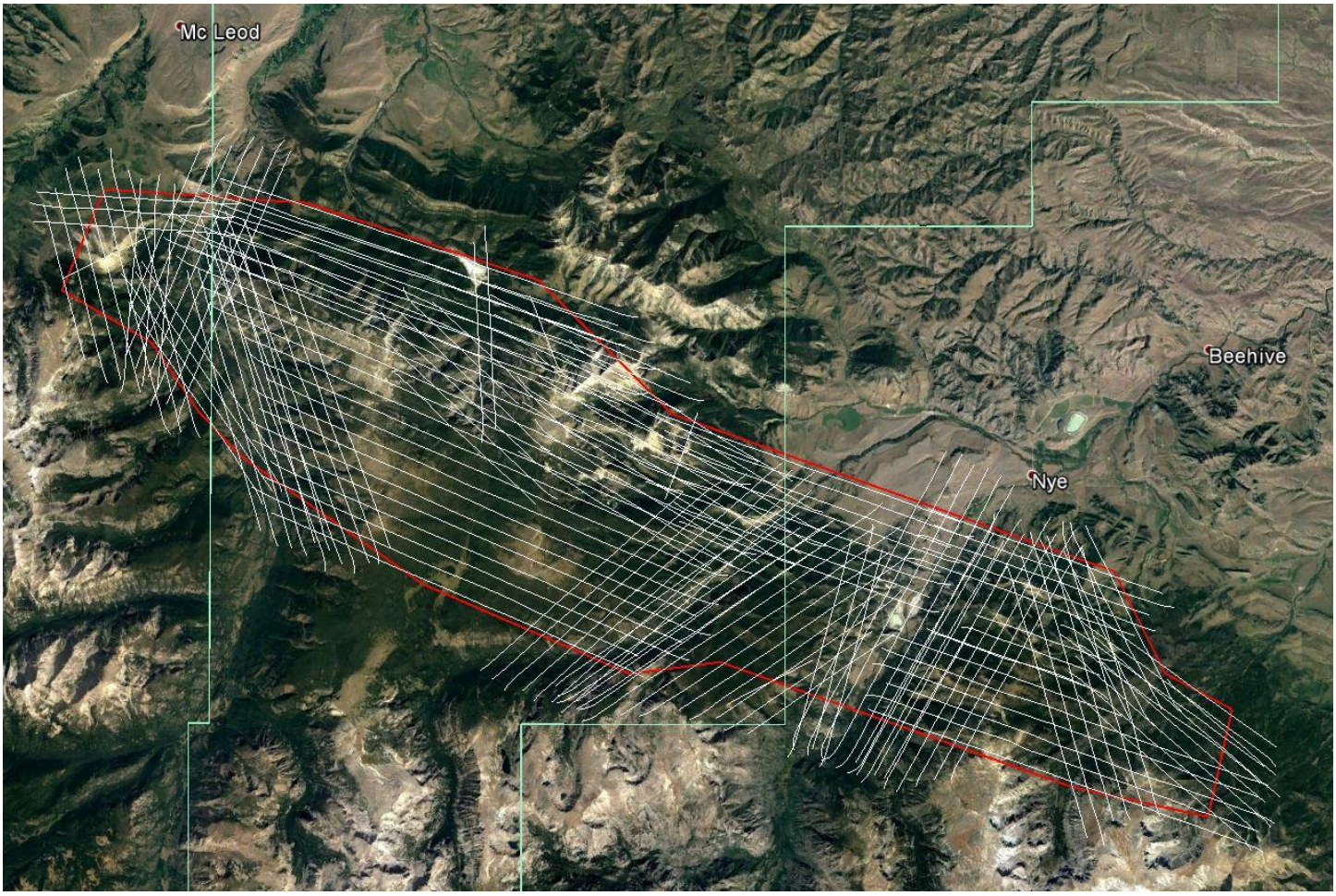
The LiDAR data was collected in six (6) missions, flown as close together as the weather permitted, to ensure consistent ground conditions across the project area. An initial quality control process was performed immediately on the lidar data to review the data coverage, airborne GPS data, and trajectory solution.

Table 2.1: Airborne Lidar Acquisition Flight Summary

Table 2.1: Airborne Lidar Acquisition Flight Summary

Date of Mission	Lines Flown	Mission Time (UTC) Wheels Up/Wheels Down
August 6, 2016	**1-3, 11-13, 21-24, 31-36, 57-59**	**19:05 – 21:33**
August 8, 2016	**125-131, 137-165**	**13:33 – 18:32**
August 9, 2016_A	**74-82, 95-115, 122-124, 132-136**	**12:16 – 17:18**
August 9, 2016_B	**7-9, 59-73**	**17:51 – 20:35**
August 10, 2016	**37-56, 92-94, 116-121**	**12:11 – 17:29**
August 11, 2016	**1-6, 14-20, 25-30, 83-91**	**12:12 – 16:14**

Figure 2.2: LiDAR Flight Layout, MT STILLWATER COMPLEX QL2 Lidar



Section 3: LiDAR Data Processing

Applications and Work Flow Overview

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. In general, data were initially processed in Leica's Lidar Survey Studio (LSS) using final processed trajectory information. LAS files from LSS were imported to a Terrascan project where spatial algorithms were used to remove gross system noise and a basic ground classification was conducted per flight line for Terra Match use. Terra Match was then run on the project, and a comparison to the lidar control points was conducted. Final trajectory data were post processed in NovAtel Inertial Explorer. Base station data were converted to GPB format and imported with aircraft GNSS and IMU data. 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. 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 v1.2 format. All points from the topographic lasers include 16-bit intensity values. Additional QC steps were then performed in LSS prior to import to Terrascan. For example, spot checks were 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.

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 is configured with a NovAtel SPAN GNSS and LCI-100C IMU.

Base stations were set by acquisition staff and were used to support the lidar data acquisition. The base stations used during the lidar acquisition missions:

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

Table 3.1: GNSS Base Station

Station (Name)	Latitude (DMS)	Longitude (DMS)	Ellipsoid Height (L1 Phase center) (Meters)
QX0005	45° 41' 50.57506"	110° 27' 19.42752"	1408.018
NYE1	45° 26' 7.99823"	109° 48' 29.33971"	1466.549

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 Default (Class 1), Ground (Class 2), Low Noise (Class 7), Water (Class 9), Ignored ground (Class 10), Bridge Decks (Class 17), High Noise (Class 18) classifications.
- FGDC Compliant metadata was developed for the task order in .xml format per product.
- The horizontal datum used for the task order was referenced to NAD83 (2011) UTM12N meters. The vertical datum used for the task order was referenced to NAVD 1988, meters, GEOID12B.

Section 4: Hydrologic Flattening

HYDROLOGIC FLATTENING OF LIDAR DEM DATA

MT Stillwater Complex QL2 Lidar processing task order 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-acre 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 30 meters (100 feet), 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 newly acquired lidar data to manually draw the hydrologic features in a 2D environment using the lidar intensity and bare earth surface. Open Source imagery was used as reference when necessary.
2. Woolpert utilizes an integrated software approach to combine the lidar data and 2D breaklines. This process “drapes” the 2D breaklines onto the 3D lidar surface model to assign an elevation. A monotonic process is performed to ensure the streams are consistently flowing in a gradient manner. A secondary step within the program verifies an equally matching elevation of both stream edges. The breaklines that characterize the closed water bodies are draped onto the 3D lidar surface and assigned a constant elevation at or just below ground elevation.
3. The lakes, reservoirs and ponds, at a minimum size of 2-acre or greater and streams at a minimum size of 30 meters (100 feet) nominal width, were compiled to meet task order requirements. **Figure 4.1** illustrates an example of 30 meters (100 feet) nominal streams identified and defined with hydrologic breaklines. The breaklines defining rivers and streams, at a nominal minimum width of 30 meters (100 feet), were draped with both sides of the stream maintaining an equal gradient elevation.
4. All ground points were reclassified from inside the hydrologic feature polygons to water, class nine (9).
5. All ground points were reclassified from within a buffer along the hydrologic feature breaklines to buffered ground, class ten (10).
6. The lidar ground points and hydrologic feature breaklines were used to generate a new digital elevation model (DEM).

Figure 4.1: Example Hydrologic Breaklines

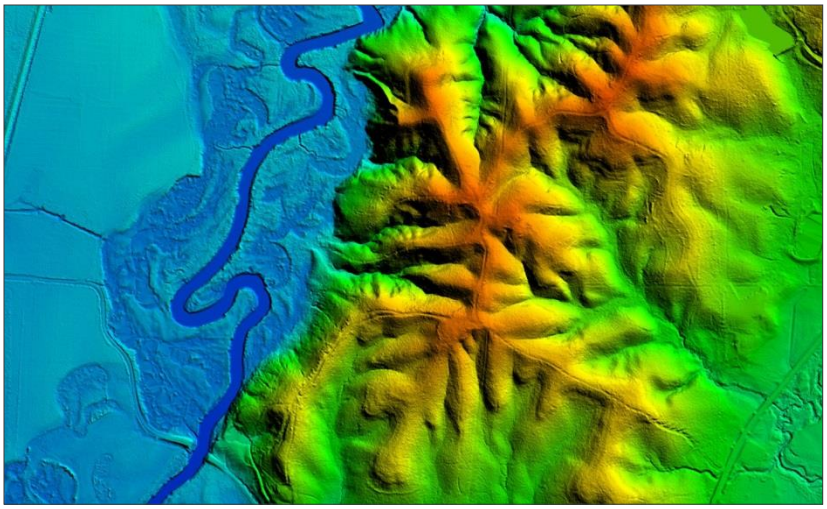


Figure 4.2 reflects a DEM generated from original lidar bare earth point data prior to the hydrologic flattening process. Note the "tinning" across the lake surface.

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.

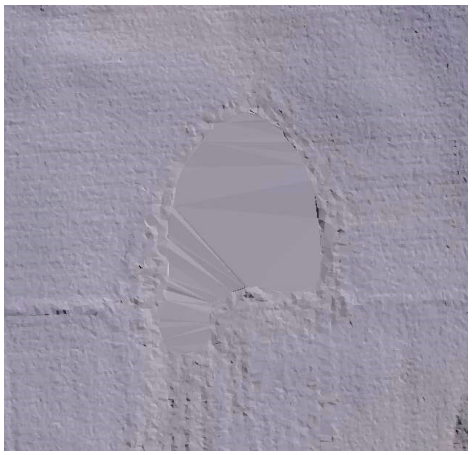


Figure 4.2

Figure 4.3

Terrascan was used to add the hydrologic breakline vertices and export the lattice models. The hydrologically flattened DEM data was provided to USGS in ERDAS .IMG format.

The hydrologic breaklines compiled as part of the flattening process were provided to the USGS as an ESRI GDB file The breaklines defining the water bodies greater than 2-acre and for the gradient flattening of all rivers and streams at a nominal minimum width of 30 meters (100 feet) were provided as a Polygon-Z and Polyline-Z ESRI GDB format, respectively.

DATA QA/QC

Initial QA/QC for this task order was performed in Global Mapper v18, by reviewing the grids and hydrologic breakline features. Additionally, ESRI software and proprietary methods were used to review the overall connectivity of the hydrologic breaklines.

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

Section 5: Accuracy Assessment

Final Vertical Accuracy Assessment

The vertical accuracy statistics were calculated by comparison of the LiDAR bare earth points to the ground surveyed QA/QC points.

Table 5.1: Overall Vertical Accuracy Statistics		
Average error	-0.034	meter
Minimum error	-0.158	meter
Maximum error	0.059	meter
Average magnitude	0.052	meter
Root mean square	0.065	meter
Standard deviation	0.056	meter

Table 5.2: RAW Swath Quality Check Point Analysis NVA

Point ID	Easting (meter)	Northing (meter)	Elevation (meter)	TIN Elevation (meter)	Dz (meter)
2001	561074.985	5037661.428	1599.698	1599.570	-0.128
2002	560531.027	5041299.277	1592.108	1591.950	-0.158
2003	562790.000	5035086.636	1621.479	1621.450	-0.029
2004	570543.090	5040144.515	1917.522	1917.540	0.018
2005	562767.617	5033754.251	1636.392	1636.320	-0.072
2006	563406.593	5031835.730	1657.734	1657.650	-0.084
2007	567812.716	5041254.538	1804.533	1804.510	-0.023
2008	573413.631	5038760.012	1991.159	1991.170	0.011
2009	583383.307	5031252.713	1864.157	1864.150	-0.007
2010	580747.464	5031566.530	2055.070	2055.060	-0.010
2011	579479.590	5031208.135	2148.791	2148.850	0.059
2012	567219.763	5032095.193	3062.152	3062.150	-0.002
2012A	567177.477	5032049.665	3068.036	3068.020	-0.016
2013	568560.763	5032051.711	2910.552	2910.570	0.018
2013A	568525.523	5032038.300	2911.661	2911.600	-0.061
2014	570728.468	5030303.963	2683.568	2683.600	0.032
2015	572138.154	5029287.443	2803.572	2803.510	-0.062
2015A	571993.197	5029374.942	2800.485	2800.460	-0.025
2016	586398.596	5023920.200	1555.181	1555.120	-0.061
2016A	586419.933	5023948.697	1554.272	1554.190	-0.082
2017	587144.202	5024832.118	1529.719	1529.610	-0.109
2018	588184.140	5025861.637	1526.805	1526.810	0.005
2019	596556.751	5026763.452	1845.935	1845.850	-0.085
2020	593440.485	5024135.126	2584.484	2584.490	0.006

2020A	593448.243	5024165.311	2584.655	2584.580	-0.075
2021	593632.945	5023321.343	2570.784	2570.840	0.056
2022	597792.385	5024885.782	2151.762	2151.710	-0.052
2022A	597710.138	5024898.924	2155.646	2155.670	0.024
2023	589660.370	5029342.139	1480.115	1479.990	-0.125
2023A	589622.892	5029360.660	1479.928	1479.860	-0.068
2024	586679.402	5029655.409	1869.613	1869.650	0.037
2024A	586717.419	5029634.060	1869.718	1869.740	0.022
2025	589065.370	5028028.183	1487.782	1487.700	-0.082

VERTICAL ACCURACY CONCLUSIONS

Raw Swath Non-Vegetated Vertical Accuracy (NVA) Tested 0.105 Meters Non vegetated vertical accuracy at a 95 percent confidence level, derived according to NSSDA, in open terrain using (RMSEz) x 1.96000 as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation Program (NDEP)/ASPRS Guidelines and tested against the TIN using all lidar points against 33 NVA points.
LAS Swath Non-Vegetated Vertical Accuracy (NVA) Tested 0.127 Meters Non vegetated vertical accuracy at a 95 percent confidence level, derived according to NSSDA, in open terrain using (RMSEz) x 1.96000 as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation Program (NDEP)/ASPRS Guidelines and tested against the TIN using lidar ground points against 33 NVA points.

Table 5.3: NVA Check Point Analysis DEM

Point ID	Easting (meter)	Northing (meter)	Elevation (meter)	DEM Elevation (meter)	Dz (meter)
2001	561074.985	5037661.428	1599.698	1599.560	0.138
2002	560531.027	5041299.277	1592.108	1591.940	0.168
2003	562790.000	5035086.636	1621.479	1621.460	0.019
2004	570543.090	5040144.515	1917.522	1917.550	-0.028
2005	562767.617	5033754.251	1636.392	1636.300	0.092
2006	563406.593	5031835.730	1657.734	1657.660	0.074
2007	567812.716	5041254.538	1804.533	1804.530	0.003
2008	573413.631	5038760.012	1991.159	1991.150	0.009
2009	583383.307	5031252.713	1864.157	1864.180	-0.023
2010	580747.464	5031566.530	2055.070	2055.050	0.020
2011	579479.590	5031208.135	2148.791	2148.810	-0.019
2012	567219.763	5032095.193	3062.152	3062.140	0.012
2012A	567177.477	5032049.665	3068.036	3068.020	0.016
2013	568560.763	5032051.711	2910.552	2910.580	-0.028
2013A	568525.523	5032038.300	2911.661	2911.570	0.091
2014	570728.468	5030303.963	2683.568	2683.600	-0.032
2015	572138.154	5029287.443	2803.572	2803.510	0.062
2015A	571993.197	5029374.942	2800.485	2800.470	0.015
2016	586398.596	5023920.200	1555.181	1555.130	0.051

2016A	586419.933	5023948.697	1554.272	1554.200	0.072
2017	587144.202	5024832.118	1529.719	1529.610	0.109
2018	588184.140	5025861.637	1526.805	1526.810	-0.005
2019	596556.751	5026763.452	1845.935	1845.850	0.085
2020	593440.485	5024135.126	2584.484	2584.460	0.024
2020A	593448.243	5024165.311	2584.655	2584.590	0.065
2021	593632.945	5023321.343	2570.784	2570.920	-0.136
2022	597792.385	5024885.782	2151.762	2151.720	0.042
2022A	597710.138	5024898.924	2155.646	2155.760	-0.114
2023	589660.370	5029342.139	1480.115	1479.990	0.125
2023A	589622.892	5029360.660	1479.928	1479.870	0.058
2024	586679.402	5029655.409	1869.613	1869.640	-0.027
2024A	586717.419	5029634.060	1869.718	1869.730	-0.012
2025	589065.370	5028028.183	1487.782	1487.720	0.062

VERTICAL ACCURACY CONCLUSIONS

Bare-Earth DEM Non-Vegetated Vertical Accuracy (NVA) Tested 0.139 Meters Non-Vegetated vertical accuracy at a 95 percent confidence level, derived according to NSSDA, in open terrain using (RMSEz) x 1.96000 as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation Program (NDEP)/ASPRS Guidelines and tested against the DEM against 33 NVA points.

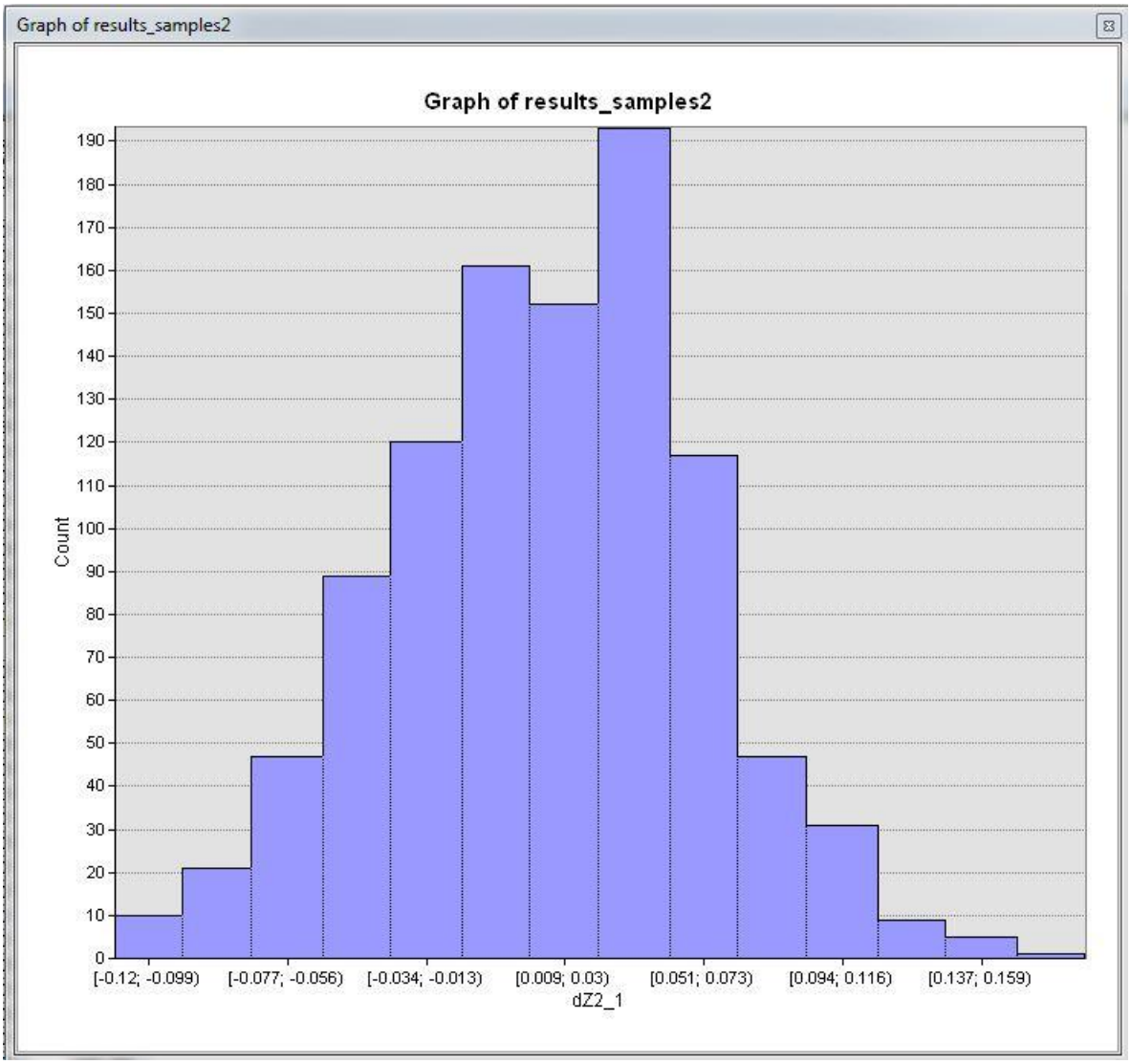
Table 5.4: VVA Quality Check Point Analysis DEM					
Point ID	Easting (meter)	Northing (meter)	Elevation (meter)	DEM Elevation (meter)	Dz (meter)
3001	560341.798	5040083.827	1589.052	1589.100	-0.048
3002	560420.306	5038742.025	1598.568	1598.320	0.248
3003	562787.416	5033518.131	1639.548	1639.600	-0.052
3004A	563417.052	5031989.258	1669.889	1669.810	0.079
3005	570179.321	5040378.932	1865.856	1866.000	-0.144
3006	569959.152	5039033.665	2125.264	2125.330	-0.066
3007	589262.208	5029365.207	1498.586	1498.620	-0.034
3008	596452.886	5027109.489	1826.622	1826.910	-0.288
3009	594230.958	5022395.971	2590.842	2590.990	-0.148
3010	586093.570	5022968.072	1578.634	1578.910	-0.276

Vertical Accuracy Conclusions

Vegetated Vertical Accuracy (VVA) Tested 0.282Meters at the 95th percentile reported using National Digital Elevation Program (NDEP)/ASPRS Guidelines and tested against the DEM against 10 VVA points. VVA Errors larger than 95th percentile include:

Point 3008, Easting 596452.886, Northing 5027109.489, Z-Error 0.288 Meters

Figure 5.1: LIDAR Relative Accuracy Histogram for MT STILLWATER COMPLEX QL2 Lidar



Relative Accuracy Assessment and Conclusion

Relative accuracy also known as "between swath" accuracy was tested through a series of well distributed flight line overlap locations. The relative accuracy for the MT STILLWATER COMPLEX QL2 Lidar measured at 0.098 meters RMSDz.

Approved by:	Name	Signature	Date
Associate Member, Lidar Specialist Certified Photogrammetrist #1381	Qian Xiao		July 2017

Section 6: LiDAR Acquisition Flight Logs

This section contains the Flight Log(s) covering the project. Flight Logs list mission specific details such as crew members, airports, weather conditions, real time PDOP values and document any issues encountered during the mission. Flight Logs are filled out by the sensor operator during the acquisition flight.

GEOMATICS DATA SOLUTIONS

FLIGHT LOG

PROJECT NAME:	P2016.012 - Stillwater MT - QL2 Lidar	**BASE AIRPORT:**	Bozeman Int. (BZN)
LOCATION / AREA:	Stillwater, MT / BL01, 03, 05, 07, 09	**DATE:**	06 August 2016
AIRCRAFT:	Cessna 401 - N6255Q	**PILOT:**	Ray L.
SYSTEM:	Dual DragonEye	**OPERATOR:**	Dushan A.
MISSION ID:	P2016-012_StillwaterMT_1500m	**CLOUDS:**	Cloudy
BASE STATION:	QX0005	**WIND:**	10kts @ 250°

ENGINE START:	19:05	**ENGINE OFF:**	21:36	**ENGINE TIME:**	03:22
GNSS START:	19:09	**GNSS STOP:**	21:36		
TAKEOFF:	19:17	**TOUCHDOWN:**	21:33	**AIR TIME**	02:47

FL #	START TIME	END TIME	TOPO PRF | PWR		BATHY PWR CHII	REMARKS
	17:57:00					Start Engines at Bozeman (BZN)
	18:07:00					Takeoff from Bozeman (BZN)
	18:23:00					Land at Livingston (LVM)
	18:26:00					Stop Engines at Livingston (LVM)
	19:09:00					Initialise GNSS at QX0005
	19:29:00					Dataset: 20160806_192911
000_FL1	19:29:16	19:31:26	180	55	-	Start BL01
001_FL2	19:33:59	19:36:13	180	55	-	
002_FL3	19:39:02	19:41:15	180	55	-	
003_FL11	19:45:01	19:47:23	180	55	-	Start BL03
004_FL12	19:50:02	19:52:19	180	55	-	
005_FL13	19:55:34	19:57:50	180	55	-	
006_FL21	20:01:35	20:04:12	180	55	-	Start BL05
007_FL22	20:07:10	20:10:02	180	55	-	
008_FL23	20:13:21	20:16:21	180	55	-	
009_FL24	20:19:35	20:22:10	180	55	-	
010_FL31	20:26:36	20:30:31	180	55	-	Start BL07
011_FL32	20:33:55	20:37:49	180	55	-	
012_FL33	20:40:28	20:44:23	180	55	-	
013_FL34	20:47:09	20:50:55	180	55	-	
014_FL35	20:54:11	20:57:33	180	55	-	
015_FL36	21:00:12	21:03:18	180	55	-	
016_FL57	21:07:06	21:11:44	180	55	-	Start BL09
017_FL58	21:14:25	21:19:27	180	55	-	
018_FL59	21:22:10	21:22:30	180	55	-	BAD: Rain Abort Mission
	21:36:00					Close GNSS at QX0005
	21:53:00					Start Engines at Livingston (LVM)
	21:57:00					Takeoff from Livingston (LVM)

GEOMATICS DATA SOLUTIONS

FLIGHT LOG

PROJECT NAME:	P2016.012 - Stillwater MT - QL2 Lidar	**BASE AIRPORT:**	Bozeman Int. (BZN)
LOCATION / AREA:	Stillwater, MT / BL01, 03, 05, 07, 09	**DATE:**	06 August 2016
AIRCRAFT:	Cessna 401 - N6255Q	**PILOT:**	Ray L.
SYSTEM:	Dual DragonEye	**OPERATOR:**	Dushan A.

MISSION ID:	P2016-012_StillwaterMT_1500m	**CLOUDS:**	Cloudy
BASE STATION:	QX0005	**WIND:**	10kts @ 250°

ENGINE START:	19:05	**ENGINE OFF:**	21:36	**ENGINE TIME:**	03:22
GNSS START:	19:09	**GNSS STOP:**	21:36		
TAKEOFF:	19:17	**TOUCHDOWN:**	21:33	**AIR TIME**	02:47

FL #	START TIME	END TIME	TOPO PRF | PWR		BATHY PWR CHII	REMARKS
	22:12:00					Land at Livingston Bozeman (BZN)
	22:15:00					Stop Engines at Bozeman (BZN)

GEOMATICS DATA SOLUTIONS

FLIGHT LOG

PROJECT NAME:	P2016.012 - Stillwater MT - QL2 Lidar	**BASE AIRPORT:**	Bozeman Int. (BZN)
LOCATION / AREA:	Stillwater, MT / BL21, 23 to 27	**DATE:**	08 August 2016
AIRCRAFT:	Cessna 401 - N6255Q	**PILOT:**	Ray L.
SYSTEM:	Dual DragonEye	**OPERATOR:**	Dushan A.
MISSION ID:	P2016-012_StillwaterMT_1500m	**CLOUDS:**	Clear
BASE STATION:	NYE1	**WIND:**	20-25kts @ 250°

ENGINE START:	13:33	**ENGINE OFF:**	18:35	**ENGINE TIME:**	05:02
GNSS START:	-	**GNSS STOP:**	-		
TAKEOFF:	13:46	**TOUCHDOWN:**	18:32	**AIR TIME**	04:46

FL #	START TIME	END TIME	TOPO PRF | PWR		BATHY PWR CHII	REMARKS
	14:20:00					Initialise GNSS over NYE1
	14:25:00					Dataset: 20160808_142508
000_FL146	14:25:13	14:28:14	180	55	-	Start BL24
001_FL145	14:30:44	14:33:45	180	55	-	
002_FL144	14:36:50	14:40:06	180	55	-	
003_FL143	14:42:20	14:45:25	180	55	-	
004_FL142	14:48:19	14:51:28	180	55	-	
005_FL141	14:54:12	14:57:04	180	55	-	
006_FL161	15:00:05	15:02:35	180	55	-	Start BL26
007_FL160	15:05:37	15:08:23	180	55	-	
008_FL159	15:10:51	15:13:35	180	55	-	
009_FL158	15:17:18	15:20:07	180	55	-	
010_FL157	15:22:29	15:24:58	180	55	-	
011_FL156	15:28:25	15:30:11	180	55	-	
012_FL131	15:33:12	15:36:00	180	55	-	Start BL21
013_FL130	15:38:58	15:42:05	180	55	-	
014_FL129	15:45:00	15:48:04	180	55	-	
015_FL128	15:50:52	15:54:12	180	55	-	
016_FL127	15:57:26	16:00:36	180	55	-	
017_FL126	16:03:12	16:06:31	180	55	-	
018_FL125	16:09:25	16:12:22	180	55	-	
019_FL155	16:18:47	16:23:14	180	55	-	Start BL25
020_FL154	16:26:14	16:30:41	180	55	-	
021_FL153	16:33:13	16:37:17	180	55	-	
022_FL152	16:40:46	16:45:01	180	55	-	
023_FL151	16:47:32	16:51:34	180	55	-	
024_FL150	16:54:19	16:57:01	180	55	-	
025_FL149	16:59:36	17:01:34	180	55	-	Upto 100m offline

GEOMATICS DATA SOLUTIONS

FLIGHT LOG

PROJECT NAME:	P2016.012 - Stillwater MT - QL2 Lidar	**BASE AIRPORT:**	Bozeman Int. (BZN)
LOCATION / AREA:	Stillwater, MT / BL21, 23 to 27	**DATE:**	08 August 2016
AIRCRAFT:	Cessna 401 - N6255Q	**PILOT:**	Ray L.
SYSTEM:	Dual DragonEye	**OPERATOR:**	Dushan A.
MISSION ID:	P2016-012_StillwaterMT_1500m	**CLOUDS:**	Clear
BASE STATION:	NYE1	**WIND:**	20-25kts @ 250°

ENGINE START:	13:33	**ENGINE OFF:**	18:35	**ENGINE TIME:**	05:02
GNSS START:	-	**GNSS STOP:**	-		
TAKEOFF:	13:46	**TOUCHDOWN:**	18:32	**AIR TIME**	04:46

FL #	START TIME	END TIME	TOPO PRF | PWR		BATHY PWR CHII	REMARKS
026_FL148	17:04:31	17:06:08	180	55	-	
027_FL147	17:08:49	17:10:24	180	55	-	
028_FL149	17:13:43	17:15:38	180	55	-	
029_FL165	17:21:18	17:23:56	180	55	-	Start BL27
030_FL164	17:26:45	17:29:17	180	55	-	
031_FL163	17:31:47	17:34:35	180	55	-	
032_FL162	17:36:55	17:39:26	180	55	-	
033_FL140	17:42:38	17:44:53	180	55	-	Start BL23
034_FL139	17:47:01	17:49:08	180	55	-	
035_FL138	17:52:07	17:54:20	180	55	-	
036_FL137	17:56:34	17:58:41	180	55	-	
	18:05:00					Close GNSS over NYE1

GEOMATICS DATA SOLUTIONS

FLIGHT LOG

PROJECT NAME:	P2016.012 - Stillwater MT - QL2 Lidar	**BASE AIRPORT:**	Bozeman Int. (BZN)
LOCATION / AREA:	Stillwater, MT / BL13, 16, 17, 18, 20, 22	**DATE:**	09 August 2016
AIRCRAFT:	Cessna 401 - N6255Q	**PILOT:**	Ray L.
SYSTEM:	Dual DragonEye	**OPERATOR:**	Dushan A.
MISSION ID:	P2016-012_StillwaterMT_1500m	**CLOUDS:**	Cloudy
BASE STATION:	NYE1	**WIND:**	20-25kts @ 200°

ENGINE START:	12:16	**ENGINE OFF:**	17:21	**ENGINE TIME:**	05:05
GNSS START:	-	**GNSS STOP:**	-		
TAKEOFF:	12:28	**TOUCHDOWN:**	17:18	**AIR TIME**	04:50

FL #	START TIME	END TIME	TOPO PRF | PWR		BATHY PWR CHII	REMARKS
	12:50:00					Initialise GNSS over NYE1
	12:57:00					Dataset: 20160809_125746
000_FL136	12:57:51	13:00:34	180	55	-	Start BL22
001_FL135	13:03:26	13:06:02	180	55	-	
002_FL134	13:08:52	13:11:26	180	55	-	
003_FL133	13:14:17	13:16:49	180	55	-	
004_FL132	13:19:37	13:22:14	180	55	-	
005_FL95	13:27:50	13:31:15	180	55	-	Start BL16
006_FL96	13:33:57	13:37:15	180	55	-	
007_FL97	13:39:55	13:43:15	180	55	-	
008_FL98	13:45:55	13:49:16	180	55	-	
009_FL99	13:52:07	13:55:29	180	55	-	
010_FL100	13:58:29	14:01:55	180	55	-	
011_FL101	14:04:48	14:07:37	180	55	-	
012_FL102	14:10:47	14:13:43	180	55	-	
013_FL113	14:20:00	14:22:34	180	55	-	Start BL18
014_FL114	14:25:49	14:28:13	180	55	-	
015_FL115	14:31:40	14:34:10	180	55	-	
016_FL122	14:37:13	14:40:16	180	55	-	Start BL20
017_FL123	14:43:41	14:46:45	180	55	-	
018_FL124	14:49:30	14:52:18	180	55	-	
019_FL103	15:02:17	15:05:50	180	55	-	Start BL17
020_FL104	15:08:26	15:12:09	180	55	-	
021_FL105	15:16:41	15:20:39	180	55	-	
022_FL106	15:23:06	15:26:34	180	55	-	
023_FL107	15:30:18	15:33:36	180	55	-	
024_FL108	15:36:20	15:38:56	180	55	-	
025_FL109	15:43:23	15:45:53	180	55	-	

GEOMATICS DATA SOLUTIONS

FLIGHT LOG

PROJECT NAME:	P2016.012 - Stillwater MT - QL2 Lidar	**BASE AIRPORT:**	Bozeman Int. (BZN)
LOCATION / AREA:	Stillwater, MT / BL13, 16, 17, 18, 20, 22	**DATE:**	09 August 2016
AIRCRAFT:	Cessna 401 - N6255Q	**PILOT:**	Ray L.
SYSTEM:	Dual DragonEye	**OPERATOR:**	Dushan A.
MISSION ID:	P2016-012_StillwaterMT_1500m	**CLOUDS:**	Cloudy
BASE STATION:	NYE1	**WIND:**	20-25kts @ 200°

ENGINE START:	12:16	**ENGINE OFF:**	17:21	**ENGINE TIME:**	05:05
GNSS START:	-	**GNSS STOP:**	-		
TAKEOFF:	12:28	**TOUCHDOWN:**	17:18	**AIR TIME**	04:50

FL #	START TIME	END TIME	TOPO PRF | PWR		BATHY PWR CHII	REMARKS
026_FL110	15:48:50	15:51:04	180	55	-	
027_FL111	15:54:53	15:56:53	180	55	-	
028_FL112	15:59:44	16:01:27	180	55	-	
029_FL74	16:07:05	16:09:53	180	55	-	Start BL13
030_FL75	16:12:31	16:15:45	180	55	-	
031_FL76	16:18:38	16:21:54	180	55	-	
032_FL77	16:24:52	16:28:17	180	55	-	
033_FL78	16:31:06	16:34:31	180	55	-	
034_FL79	16:37:21	16:40:33	180	55	-	
035_FL80	16:43:54	16:46:41	180	55	-	
036_FL81	16:49:36	16:52:03	180	55	-	
037_FL82	16:55:29	16:57:45	180	55	-	
	17:03:00					Close GNSS over NYE1
	17:18:00					Land at Livingston (LVM)

GEOMATICS DATA SOLUTIONS

FLIGHT LOG

PROJECT NAME:	P2016.012 - Stillwater MT - QL2 Lidar	**BASE AIRPORT:**	Bozeman Int. (BZN)
LOCATION / AREA:	Stillwater, MT / BL02, 09, 10, 11, 12	**DATE:**	09 August 2016
AIRCRAFT:	Cessna 401 - N6255Q	**PILOT:**	Ray L.
SYSTEM:	Dual DragonEye	**OPERATOR:**	Dushan A.
MISSION ID:	P2016-012_StillwaterMT_1500m	**CLOUDS:**	Cloudy
BASE STATION:	QX0005	**WIND:**	20-25kts @ 200°

ENGINE START:	17:51	**ENGINE OFF:**	20:38	**ENGINE TIME:**	02:47
GNSS START:	17:53	**GNSS STOP:**	-		
TAKEOFF:	18:00	**TOUCHDOWN:**	20:35	**AIR TIME**	02:35

FL #	START TIME	END TIME	TOPO PRF | PWR		BATHY PWR CHII	REMARKS
	17:53:00					Initialise GNSS at QX0005
	18:00:00					Takeoff from Livingston (LVM)
	18:14:00					Dataset: 20160809_181407
000_FL63	18:14:12	18:18:48	180	55	-	Start BL10
001_FL64	18:21:30	18:26:01	180	55	-	
002_FL65	18:28:46	18:33:38	180	55	-	
003_FL66	18:37:54	18:40:15	180	55	-	Start BL11
004_FL67	18:43:56	18:46:08	180	55	-	
005_FL68	18:51:04	18:53:25	180	55	-	Start BL12
006_FL69	18:56:59	18:58:44	180	55	-	
007_FL70	19:01:17	19:03:31	180	55	-	
008_FL71	19:06:37	19:08:56	180	55	-	
009_FL72	19:11:31	19:14:11	180	55	-	
010_FL73	19:17:11	19:19:19	180	55	-	
011_FL59	19:24:00	19:28:51	180	55	-	Start BL09
012_FL60	19:31:17	19:36:17	180	55	-	
013_FL61	19:39:14	19:44:23	180	55	-	
014_FL62	19:46:59	19:51:53	180	55	-	
015_FL10	19:57:19	20:00:19	180	55	-	Start BL02
016_FL9	20:03:08	20:05:58	180	55	-	
017_FL8	20:09:13	20:12:11	180	55	-	
018_FL7	20:15:00	20:17:38	180	55	-	
	20:25:00					Close GNSS over QX0005

GEOMATICS DATA SOLUTIONS

FLIGHT LOG

PROJECT NAME:	P2016.012 - Stillwater MT - QL2 Lidar	**BASE AIRPORT:**	Bozeman Int. (BZN)
LOCATION / AREA:	Stillwater, MT / BL08, 15, 19	**DATE:**	10 August 2016
AIRCRAFT:	Cessna 401 - N6255Q	**PILOT:**	Ray L.
SYSTEM:	Dual DragonEye	**OPERATOR:**	Dushan A.
MISSION ID:	P2016-012_StillwaterMT_1500m	**CLOUDS:**	Clear
BASE STATION:	NYE1	**WIND:**	35-40kts @ 200°

ENGINE START:	12:11	**ENGINE OFF:**	17:32	**ENGINE TIME:**	05:21
GNSS START:	-	**GNSS STOP:**	-		
TAKEOFF:	12:23	**TOUCHDOWN:**	17:29	**AIR TIME**	05:06

FL #	START TIME	END TIME	TOPO PRF | PWR		BATHY PWR CHII	REMARKS
	14:20:00					Initialise GNSS over NYE1
	14:25:00					Dataset: 20160810_125116
000_FL116	12:51:21	12:55:27	180	55	-	Start BL19
001_FL117	13:01:00	13:05:04	180	55	-	
002_FL118	13:10:20	13:14:18	180	55	-	
003_FL119	13:20:39	13:24:28	180	55	-	
004_FL120	13:30:41	13:34:20	180	55	-	
005_FL121	13:39:54	13:43:29	180	55	-	
006_FL94	13:47:59	13:51:06	180	55	-	Start BL15
007_FL93	13:53:43	13:56:25	180	55	-	
008_FL92	14:00:13	14:03:29	180	55	-	
	14:05:00					Abort Block due to turbulance
009_FL56	14:10:37	14:14:42	180	55	-	Start BL08
010_FL55	14:18:54	14:23:06	180	55	-	
011_FL54	14:25:50	14:30:33	180	55	-	
012_FL53	14:34:45	14:39:24	180	55	-	
013_FL52	14:42:04	14:47:08	180	55	-	
014_FL51	14:50:37	14:55:46	180	55	-	
015_FL50	14:58:27	15:03:26	180	55	-	
016_FL49	15:06:02	15:11:32	180	55	-	
017_FL48	15:14:17	15:19:30	180	55	-	
018_FL47	15:23:16	15:29:09	180	55	-	
019_FL46	15:31:37	15:37:16	180	55	-	
020_FL45	15:40:53	15:47:27	180	55	-	
021_FL44	15:49:58	15:55:16	180	55	-	
022_FL43	15:59:36	16:06:10	180	55	-	
023_FL42	16:08:52	16:15:05	180	55	-	
024_FL41	16:18:54	16:25:41	180	55	-	

GEOMATICS DATA SOLUTIONS

FLIGHT LOG

PROJECT NAME:	P2016.012 - Stillwater MT - QL2 Lidar	**BASE AIRPORT:**	Bozeman Int. (BZN)
LOCATION / AREA:	Stillwater, MT / BL08, 15, 19	**DATE:**	10 August 2016
AIRCRAFT:	Cessna 401 - N6255Q	**PILOT:**	Ray L.
SYSTEM:	Dual DragonEye	**OPERATOR:**	Dushan A.
MISSION ID:	P2016-012_StillwaterMT_1500m	**CLOUDS:**	Clear
BASE STATION:	NYE1	**WIND:**	35-40kts @ 200°

ENGINE START:	12:11	**ENGINE OFF:**	17:32	**ENGINE TIME:**	05:21
GNSS START:	-	**GNSS STOP:**	-		
TAKEOFF:	12:23	**TOUCHDOWN:**	17:29	**AIR TIME**	05:06

FL #	START TIME	END TIME	TOPO PRF	TOPO PWR	BATHY PWR CHII	REMARKS
025_FL40	16:28:34	16:34:36	180	55	-	
026_FL39	16:39:39	16:43:59	180	55	-	
027_FL38	16:46:56	16:49:19	180	55	-	
028_FL37	16:52:44	16:55:24	180	55	-	
	17:00:00					Close GNSS over NYE1

GEOMATICS DATA SOLUTIONS

FLIGHT LOG

PROJECT NAME:	P2016.012 - Stillwater MT - QL2 Lidar	**BASE AIRPORT:**	Bozeman Int. (BZN)
LOCATION / AREA:	Stillwater, MT / BL02, 04, 06, 14, 15 & Reflights	**DATE:**	11 August 2016
AIRCRAFT:	Cessna 401 - N6255Q	**PILOT:**	Ray L.
SYSTEM:	Dual DragonEye	**OPERATOR:**	Dushan A.
MISSION ID:	P2016-012_StillwaterMT_1500m	**CLOUDS:**	Cloudy
BASE STATION:	NYE1	**WIND:**	20kts @ 220°

ENGINE START:	12:12	**ENGINE OFF:**	16:17	**ENGINE TIME:**	04:05
GNSS START:	-	**GNSS STOP:**	-		
TAKEOFF:	12:26	**TOUCHDOWN:**	16:14	**AIR TIME**	03:48

FL #	START TIME	END TIME	TOPO PRF | PWR		BATHY PWR CHII	REMARKS
	12:50:00					Initialise GNSS over NYE1
	12:55:00					Dataset: 20160811_125511
000_FL91	12:55:15	12:58:26	180	55	-	Start BL15
001_FL90	13:01:34	13:03:33	180	55	-	
002_FL89	13:09:19	13:12:54	180	55	-	Start BL14
003_FL88	13:15:16	13:18:45	180	55	-	
004_FL87	13:21:49	13:25:27	180	55	-	
005_FL86	13:27:40	13:31:10	180	55	-	
006_FL85	13:34:08	13:37:36	180	55	-	
007_FL84	13:39:34	13:42:36	180	55	-	
008_FL83	13:46:19	13:49:17	180	55	-	
009_FL30	13:56:46	14:00:05	180	55	-	Start BL06
010_FL29	14:02:10	14:05:30	180	55	-	
011_FL28	14:08:00	14:11:15	180	55	-	
012_FL27	14:13:43	14:17:03	180	55	-	
013_FL26	14:19:54	14:22:53	180	55	-	
014_FL25	14:25:28	14:28:23	180	55	-	
015_FL20	14:31:59	14:35:04	180	55	-	Start BL04
016_FL19	14:37:17	14:40:14	180	55	-	
017_FL18	14:42:38	14:45:35	180	55	-	
018_FL17	14:47:40	14:50:25	180	55	-	
019_FL16	14:52:53	14:55:23	180	55	-	
020_FL15	14:57:31	14:59:58	180	55	-	
021_FL14	15:02:34	15:04:28	180	55	-	
022_FL6	15:12:21	15:14:41	180	55	-	Start BL02
023_FL5	15:17:37	15:19:44	180	55	-	
024_FL4	15:22:49	15:24:43	180	55	-	
	15:28:00					Relights (Offset by 200)

GEOMATICS DATA SOLUTIONS

FLIGHT LOG

PROJECT NAME:	P2016.012 - Stillwater MT - QL2 Lidar	**BASE AIRPORT:**	Bozeman Int. (BZN)
LOCATION / AREA:	Stillwater, MT / BL02, 04, 06, 14, 15 & Reflights	**DATE:**	11 August 2016
AIRCRAFT:	Cessna 401 - N6255Q	**PILOT:**	Ray L.
SYSTEM:	Dual DragonEye	**OPERATOR:**	Dushan A.
MISSION ID:	P2016-012_StillwaterMT_1500m	**CLOUDS:**	Cloudy
BASE STATION:	NYE1	**WIND:**	20kts @ 220°

ENGINE START:	12:12	**ENGINE OFF:**	16:17	**ENGINE TIME:**	04:05
GNSS START:	-	**GNSS STOP:**	-		
TAKEOFF:	12:26	**TOUCHDOWN:**	16:14	**AIR TIME**	03:48

FL #	START TIME	END TIME	TOPO PRF | PWR		BATHY PWR CHII	REMARKS
025_FL1	15:30:13	15:31:17	180	55	-	Start BL02
026_FL3	15:35:10	15:36:07	180	55	-	Start BL09
027_FL2	15:40:37	15:41:45	180	55	-	Start BL08
028_FL4	15:45:37	15:46:36	180	55	-	Start BL17
	15:52:00					Close GNSS over NYE1

Section 7: Final Deliverables

The final lidar deliverables are listed below.

- LAS v1.4 classified point cloud
- LAS v1.4 raw unclassified point cloud flight line strips.
- Hydro Breaklines as ESRI GDB
- Bridge Breaklines as ESRI GDB
- Digital Elevation Model in ERDAS .IMG format
- 8-bit gray scale intensity images in .TIF format
- Tile Index provided as ESRI shapefile
- Project boundary as ESRI shape file
- Control Points provided as ESRI shapefile
- FGDC compliant metadata per product in XML format
- Lidar processing report in pdf format
- Survey report in pdf format