LiDAR Survey - Metadata Report

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WSA – Saskatchewan

Prepared for:
Water Security Agency
101-111 Fairford St East
Moose Jaw SK S6H 7X9

Prepared by:
KBM Resources Group
349 Mooney Ave.
Thunder Bay, ON P7B 5L5

WSA Contact:
Curtis Hallborg
Tel: 306-694-3942
Email: Curtis.Hallborg@wsask.ca

KBM Contact:
Ian Gillies
Tel: 807-629-3534
Email: igillies@kbm.ca

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1. PROJECT OVERVIEW

Saskatchewan Water Security Agency contracted KBM Resources Group to collect LiDAR covering multiple river valleys in Southeastern Saskatchewan, focussed on the Souris River Valley. Total area collected was approx. 600 km^2. The following is a report that outlines data acquisition, processing and accuracy assessment procedures used for delivered LiDAR. Data were acquired over the area on May 5th, 2018 and May 6th, 2018.

Project Area

Figure 1 is an overview of the project areas that cover approximately 600 km^2.

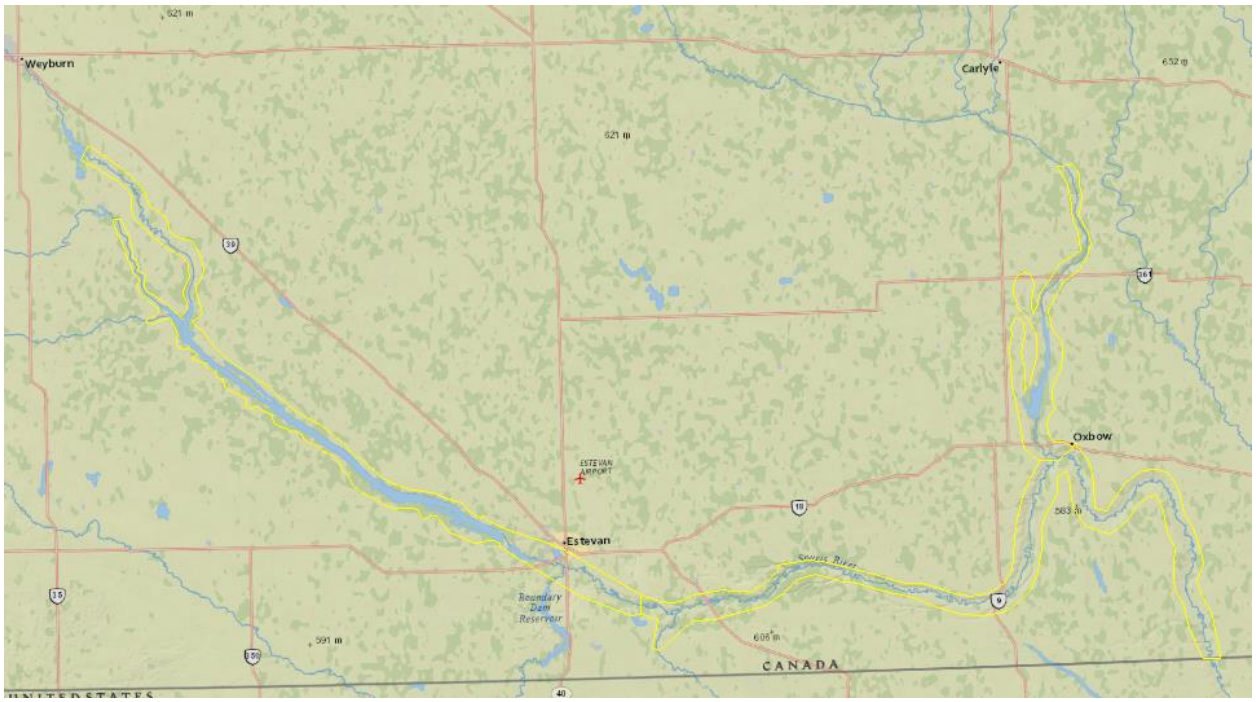


FIGURE 1: OVERVIEW OF SURVEY AREA

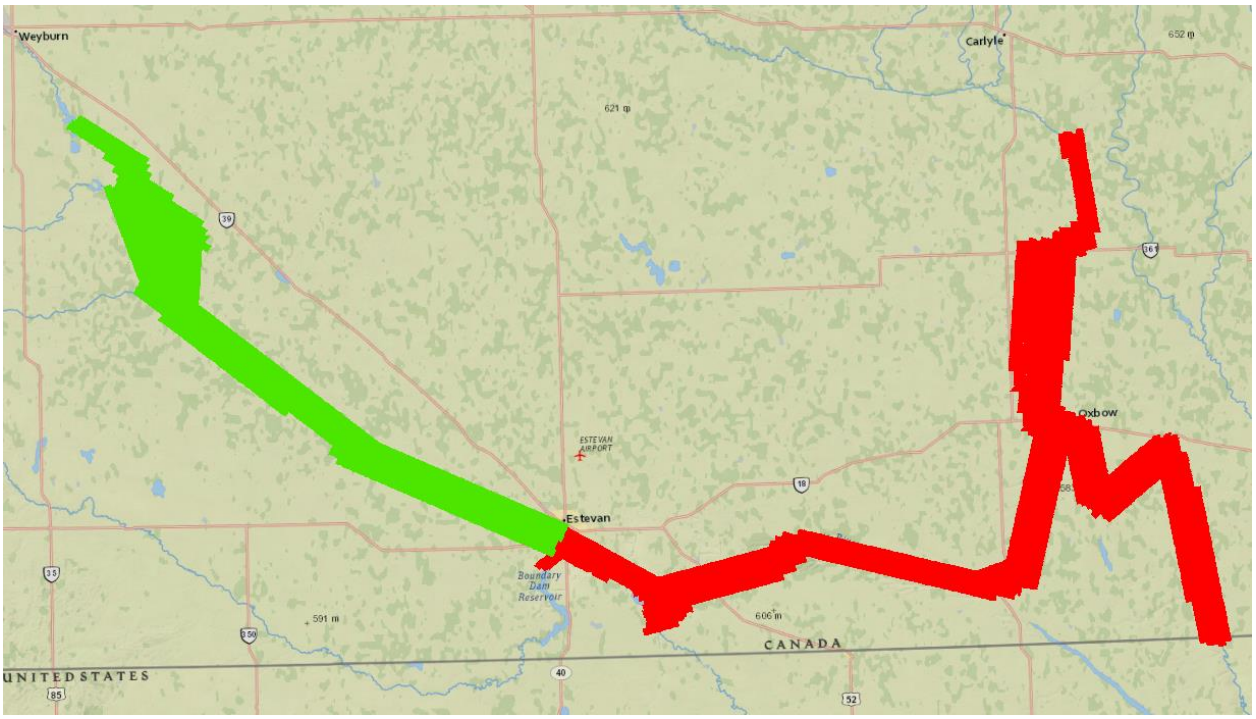
1. DATA ACQUISITION OVERVIEW

Data were acquired under favourable weather conditions over multiple sessions on May 5th and 6th 2018. Table 1 is a summary of acquisition sessions by date and time.

TABLE 1: SUMMARY OF DATA ACQUSITION SESSIONS

Date	Sess. No.	Start (UTC)	End (UTC)	Acquisition Details
05-05-2018	1	15:12:19	21:54:19	LiDAR Acquisition
05-05-2018	2	23:42:23	03:25:37	LiDAR Acquisition
05-06-2018	3	15:06:14	19:25:30	LiDAR Acquisition

FIGURE 2: DATA COLLECTION DATES (MAY 5TH IN RED, MAY 6TH IN GREEN)



1.1 Data Parameters

1.1.1 Geodetic parameters:

All positional data were processed to the following geodetic parameters:

Horizontal datum	: NAD83(CSRS), Epoch 2010.00
Vertical datum	: CGVD28
Projection	: UTM ZONE 13N
Units	: Metres

1.1.2 LiDAR data acquisition parameters:

LiDAR data were acquired using the following acquisition parameters:

LiDAR Scanner Serial Number	: 9998870
Scanner Model	: Riegl LMS-680i
Pulse Repetition Frequency (PRF)	: 400 kHz (267 kHz effective)
Scan Frequency (Lines per sec)	: 190 Hz
Flying Altitude (AGL)	: 757 m
Field of View	: 60° (±30°)
Flying Speed	: 119 knots
Flightline Overlap	: 20%+

2. DATA PROCESSING

2.1 Calibration

A complete and rigorous calibration for boresight and lens distortion offsets occurs two to three times a year or if equipment is changed or dismounted from the aircraft frame. The last calibration was performed on 09-FEB-2018. Roll, pitch, heading and scale offsets are also checked during the processing workflow after acquisition using overlapping features in opposing and/or perpendicular flight lines.

Positioning

The positioning workflow includes obtaining precise coordinates over a static ground point and positioning the aircraft trajectory. The following table summarizes the process:

Processing Step	Software used
A complete network consistency check between all active stations will performed prior to any kinematic positioning. If necessary additional KBM base stations in areas of marginal active network coverage will also be included.	GrafNet 8.7
Position the aircraft trajectory by combining aircraft attitude (roll, pitch and heading) recorded at 200 Hz with and differentially corrected GPS position at 1 Hz using the so-called tightly-coupled smart-base method. The processing output is a smoothed best estimate of trajectory (SBET) is generated by applying offsets to a common reference point to the processed kinematic solution.	Applanix PosPAC MMS 8.0

2.2 LiDAR point cloud processing

The LiDAR point cloud processing workflow includes extracting the range point-cloud from LiDAR sensor, transforming the point-cloud into real-world coordinates by combining the SBET with LiDAR ranges, checking and correcting relative and global offsets, tiling data into 1 km x 1km tiles, automated ground point extraction, de-noising, automated vegetation classification, building classification and quality checks. The following is a summary of each step in the workflow.

Processing Step	Software used
Extract discrete LiDAR returns from raw pulse waveform data with range, precise timestamp and other attributes such as intensity and scan angle.	RiAnalyze v6.0
Combine ranges and SBET using timestamps to generate a globally referenced LiDAR point cloud, apply a Geoid12A geoid correction to reference elevations as orthometric heights and export point cloud in LAS1.2 format. Three-dimensional projected grid positions, GPS timestamp, scan angle and flightline attributes are maintained. Data are checked for	Inpho LPMaster v8.0, TerraMatch v18

minor (< 0.030 m) relative and absolute vertical offsets and adjusted if necessary.	
Eliminate outliers such as multipath and mid-air returns; segment data into manageable 1 km x 1km tiles; *auto-classify* point cloud into ground points and unclassified classes.	LASTools v170122 and custom KBM software.
High-level overview and quality checks for blunders, relative accuracy, missing outliers or misclassification. Correct if required.	LAStools v170122 and Terrascan v18
Assess vertical accuracy and point density relative to control and project specifications.	LASTools v170122 and Terrascan v18

3. GROUND CONTROL

3.1 Survey Planning:

Consistent with industry best practices, all positioning time windows was planned based on optimal predicted PDOP (measure of loss of precision due to unfavourable GPS satellite geometry) and space weather (solar flares affect GPS signals). No GPS positioning was planned if predicted PDOP exceeded 4 or if K-index prediction exceeded 6.

3.2 Base Stations:

KBM used a combination of CAN-NET active stations and KBM-acquired base station data for control:

TABLE 2: BASE STATIONS

CAN-NET Station	Latitude	Longitude	Ellipsoidal h	Easting	Northing	Orthometric H	UTM Zone	Remarks
	(DMS - North/West Positive)		(m)	(m)	(m)	(m)		
WBRN	49 39 29.55290	103 50 06.77821	562.237	584066.027	5501281.299	581.047	UTM 13N	CANNET Active Control
EST3	49 08 49.92478	102 57 57.64373	565.754	648327.634	5445811.485	584.281	UTM 13N	CANNET Active Control
OXB01	49 13 11.20560	102 11 08.30914	493.192	704930.023	5455700.641	512.893	UTM 13N	KBM Base Station

The proposed technical approach is based on compliance with requirements of the ASPRS 2.5 cm accuracy class for control and 5 cm accuracy class (10 cm at 95% confidence) for deliverables, to meet or exceed requirements as laid out in Canadian Quality Level 1 (CQL1) Key Summary Requirements for Topographic Base Mapping (Federal Airborne LiDAR Data Acquisition Guideline Version 1.1), and outlined by ASPRS Positional Accuracy Standards for Digital Geospatial Data (Edition 1, Version 1.0 – November, 2014).

3.3 Ground Control Points:

In addition to base stations, 70 Kinematic check points were collected in 6 main zones throughout the project area using post-processed kinematic techniques. To comply with ASPRS specifications for LiDAR, kinematic points were acquired on hard open surfaces. Location of the collection zones is visible in Figure 2, full coordinates are listed in Table 3.

FIGURE 2: LOCATION OF GROUND CONTROL POINTS (ZONES IN RED, MULTIPLE POINTS IN EACH ZONE)

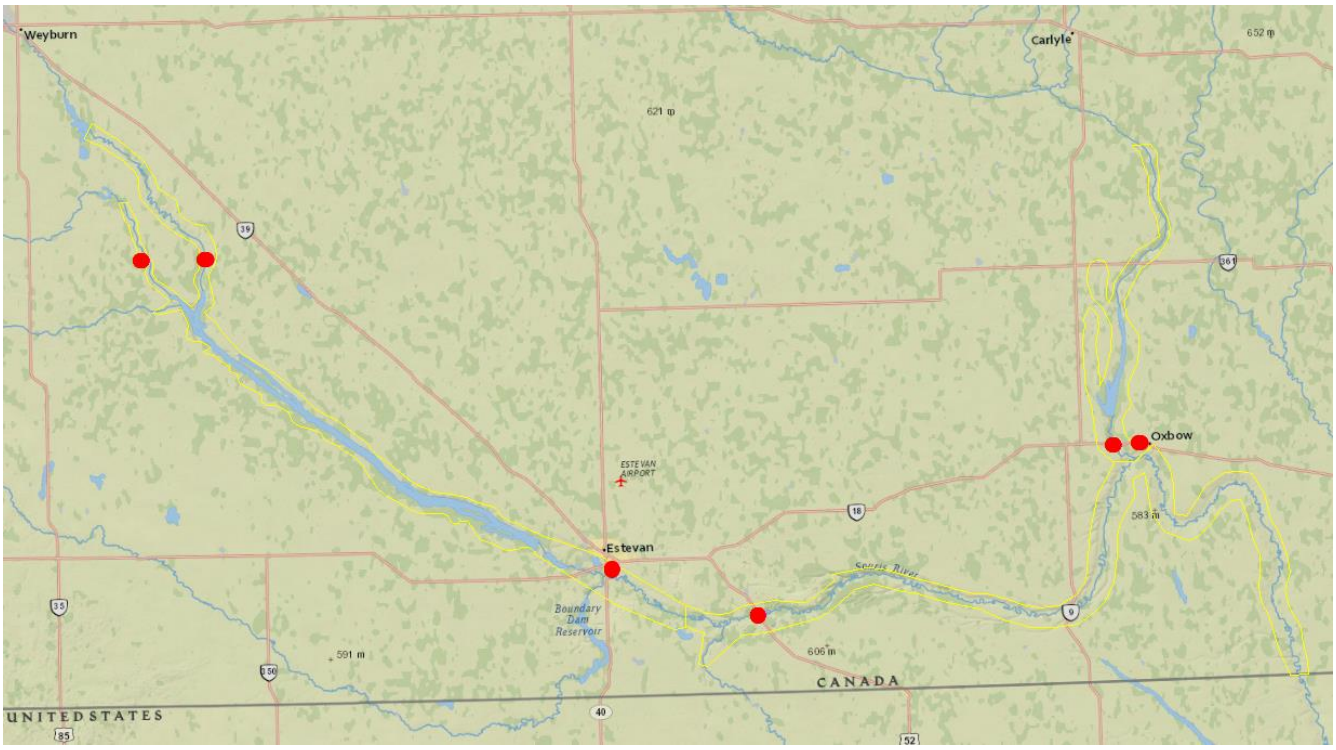


TABLE 3: GROUND CONTROL POINTS

Station	Easting (m)	Northing (m)	Orthometric H (m)	Station	Easting (m)	Northing (m)	Orthometric H (m)
WSA_WY01	602909.278	5476831.841	553.95	WSA_OXB36	704730.981	5457019.043	583.86
WSA_WY02	602923.182	5476831.875	553.968	WSA_OXB37	702021.342	5456751.547	526.429
WSA_WY03	602935.801	5476832.417	553.979	WSA_OXB38	702008.459	5456752.593	526.122
WSA_WY04	602954.004	5476832.622	553.987	WSA_OXB39	701998.475	5456753.584	525.92
WSA_WY05	602977.845	5476833.277	554.073	WSA_OXB40	701988.716	5456754.455	525.755
WSA_WY06	602992.809	5476833.63	554.279	WSA_OXB41	701976.024	5456754.868	525.59
WSA_WY07	603008.628	5476834.13	554.538	WSA_OXB42	701965.959	5456756.071	525.504
WSA_WY08	603032.762	5476834.588	555	WSA_OXB43	701959.189	5456756.842	525.49
WSA_WY09	603052.974	5476834.834	555.453	WSA_OXB44	701936.672	5456758.756	525.422
WSA_WY010	603078.515	5476835.33	556.308	WSA_OXB45	701889.269	5456762.462	525.813
WSA_WY011	603109.788	5476835.973	557.856	WSA_OXB46	701872.906	5456763.618	526.141
WSA_WY012	603147.037	5476836.761	560.311	WSA_EST47	663225.023	5438247.091	531.711
WSA_WY013	595966.996	5476704.355	562.928	WSA_EST48	663232.054	5438236.739	531.681
WSA_WY014	595966.99	5476704.353	562.93	WSA_EST49	663239.192	5438226.4	531.651
WSA_WY015	595978.69	5476704.321	562.866	WSA_EST50	663239.421	5438226.136	531.65
WSA_WY016	595993.1	5476704.455	562.818	WSA_EST51	663246.685	5438215.508	531.62
WSA_WY017	596010.78	5476704.888	562.906	WSA_EST52	663246.705	5438215.524	531.602
WSA_WY018	596024.78	5476705.026	563.026	WSA_EST53	663253.701	5438205.331	531.603
WSA_WY019	596027.145	5476705.121	563.038	WSA_EST54	663260.755	5438194.996	531.623
WSA_WY020	596039.692	5476705.598	563.158	WSA_EST55	663267.755	5438184.76	531.693
WSA_WY021	596055.412	5476705.736	563.304	WSA_EST56	663274.767	5438174.426	531.717
WSA_WY022	596067.52	5476705.921	563.459	WSA_EST57	663281.761	5438164.302	531.788
WSA_WY023	596080.048	5476706.068	563.598	WSA_EST58	663288.772	5438154.011	531.845
WSA_WY024	596090.979	5476706.23	563.702	WSA_EST59	663295.907	5438143.763	531.89
WSA_WY025	596105.444	5476706.481	563.777	WSA_EST60	663301.164	5438136.043	531.94
WSA_OXB26	704920.77	5456993.538	582.7	WSA_EST61	647325.62	5443256.596	539.823
WSA_OXB27	704909.197	5456996.568	582.79	WSA_EST62	647325.902	5443240.697	539.736
WSA_OXB28	704893.53	5456999.761	582.853	WSA_EST63	647325.744	5443225.338	539.72
WSA_OXB29	704873.389	5457003.098	582.906	WSA_EST64	647325.726	5443210.036	539.677
WSA_OXB30	704840.927	5457008.214	583.111	WSA_EST65	647326.04	5443195.566	539.817
WSA_OXB31	704823.332	5457010.726	583.263	WSA_EST66	647326.617	5443179.472	539.949
WSA_OXB32	704804.817	5457012.968	583.389	WSA_EST67	647327.39	5443163.774	539.837
WSA_OXB33	704784.259	5457015.182	583.506	WSA_EST68	647327.835	5443148.077	539.721
WSA_OXB34	704761.369	5457017.115	583.697	WSA_EST69	647327.979	5443132.588	539.6
WSA_OXB35	704745.968	5457018.125	583.781	WSA_EST70	647328.282	5443116.56	539.368

4 QUALITY CONTROL

4.1 LiDAR trajectory processing

5 Additional CANNET active control stations were used as Virtual Reference Stations (SmartBase) to position the GPS trajectories (see Table 4).

TABLE 4: VIRTUAL REFERENCE STATIONS

CAN-NET Station	Latitude	Longitude	Ellipsoidal h	Easting	Northing	Orthometric H	UTM Zone	Remarks
	(DMS - North/West Positive)		(m)	(m)	(m)	(m)		
DLOR	49 11 39.80536	100 29 40.33640	484.542	828207.241	5458842.662	505.902	UTM 13N	CANNET Active Control
NDGR	48 37 14.47311	103 55 59.20342	642.838	578625.156	5385840.054	660.511	UTM 13N	CANNET Active Control
REST	49 33 37.05827	101 05 37.65638	448.762	782456.718	5497077.369	470.436	UTM 13N	CANNET Active Control
STOU	49 40 15.48532	103 01 16.53637	612.916	642771.395	5503928.256	631.892	UTM 13N	CANNET Active Control
WBRN	49 39 29.55290	103 50 06.77821	562.237	584066.027	5501281.299	581.047	UTM 13N	CANNET Active Control

The quality of the base VRS network was checked before use to ensure that network misclosure was within ±0.020 m horizontally and ±0.030 m vertically.

The SBET solution was reprocessed or if necessary rejected under the following conditions within one minute of active airborne data acquisition:

- If forward/reverse combined separation exceeded 0.05 m for more than ten seconds.
- If an INS solution (before smoothing) lost phase ambiguity lock (i.e. deteriorated to fixed wide lane or float mode).
- If for any other reason a solved position's RMS exceeded the allowable error of 0.05 m horizontally and vertically.

XYZ (ENH) residuals for the two main base stations (REST, WBRN) are listed in Table 5:

TABLE 5: CONTROL POINT RESIDUALS

```
*****************************************************************
    CONTROL POINT RESIDUALS (ADJUSTMENT MADE)
*****************************************************************

STA. NAME     -- RE --    -- RN --    -- RH --
                 (m)         (m)         (m)
REST           -0.0070      0.0004     -0.0073
WBRN            0.0072     -0.0001      0.0071
              -------------------------------
RMS             0.0071      0.0003      0.0072
```

4.2 Ground Control Point processing

Ground control coordinates were reprocessed or, if necessary, rejected and reacquired in any one of the following conditions:

- Sigma values (x, y or z) at 95% confidence from CSRS-PPP exceeded 0.03 m
- More than 10% of observed epochs were rejected.
- Minimally constrained network misclosure exceeded 0.03 m for active control within 50 km

The following is a summary of LiDAR assessment against independently acquired kinematic checkpoints (summarized control results are listed in Table 6):

TABLE 6: LIDAR CONTROL SUMMARY AGAINST KINEMATIC VALIDATION CHECKPOINTS

Average dZ (signed)	:	+0.004 m
Average dZ (magnitude)	:	0.044 m
Maximum dZ	:	+0.080 m
Minimum dZ	:	-0.131 m
RMS	:	0.056 m
Std. deviation	:	0.057 m
Accuracy (95% CI)	:	0.15 m

TABLE 7: LIDAR CONTROL REPORT AGAINST KINEMATIC VALIDATION CHECKPOINTS

Station	Easting	Northing	Orthometric H	Lidar Z	dZ	Station	Easting	Northing	Orthomet	Lidar Z	dZ
	(m)	(m)	(m)	(m)	(m)		(m)	(m)	(m)	(m)	(m)
WSA_WY01	602909.3	5476832	553.95	553.95	0	WSA_OXB36	704731	5457019	583.86	583.89	0.03
WSA_WY02	602923.2	5476832	553.968	553.97	0.002	WSA_OXB37	702021.3	5456752	526.429	526.45	0.021
WSA_WY03	602935.8	5476832	553.979	553.99	0.011	WSA_OXB38	702008.5	5456753	526.122	526.14	0.018
WSA_WY04	602954	5476833	553.987	554	0.013	WSA_OXB39	701998.5	5456754	525.92	525.96	0.04
WSA_WY05	602977.8	5476833	554.073	554.11	0.037	WSA_OXB40	701988.7	5456754	525.755	525.8	0.045
WSA_WY06	602992.8	5476834	554.279	554.3	0.021	WSA_OXB41	701976	5456755	525.59	525.64	0.05
WSA_WY07	603008.6	5476834	554.538	554.54	0.002	WSA_OXB42	701966	5456756	525.504	525.54	0.036
WSA_WY08	603032.8	5476835	555	555.01	0.01	WSA_OXB43	701959.2	5456757	525.49	525.53	0.04
WSA_WY09	603053	5476835	555.453	555.46	0.007	WSA_OXB44	701936.7	5456759	525.422	525.45	0.028
WSA_WY010	603078.5	5476835	556.308	556.33	0.022	WSA_OXB45	701889.3	5456762	525.813	525.86	0.047
WSA_WY011	603109.8	5476836	557.856	557.84	-0.016	WSA_OXB46	701872.9	5456764	526.141	526.18	0.039
WSA_WY012	603147	5476837	560.311	560.31	-0.001	WSA_EST47	663225	5438247	531.711	531.76	0.049
WSA_WY013	595967	5476704	562.928	562.89	-0.038	WSA_EST48	663232.1	5438237	531.681	531.75	0.069
WSA_WY014	595967	5476704	562.93	562.89	-0.04	WSA_EST49	663239.2	5438226	531.651	531.71	0.059
WSA_WY015	595978.7	5476704	562.866	562.83	-0.036	WSA_EST50	663239.4	5438226	531.65	531.71	0.06
WSA_WY016	595993.1	5476704	562.818	562.83	0.012	WSA_EST51	663246.7	5438216	531.62	531.68	0.06
WSA_WY017	596010.8	5476705	562.906	562.93	0.024	WSA_EST52	663246.7	5438216	531.602	531.68	0.078
WSA_WY018	596024.8	5476705	563.026	563.03	0.004	WSA_EST53	663253.7	5438205	531.603	531.68	0.077
WSA_WY019	596027.1	5476705	563.038	563.04	0.002	WSA_EST54	663260.8	5438195	531.623	531.69	0.067
WSA_WY020	596039.7	5476706	563.158	563.15	-0.008	WSA_EST55	663267.8	5438185	531.693	531.74	0.047
WSA_WY021	596055.4	5476706	563.304	563.29	-0.014	WSA_EST56	663274.8	5438174	531.717	531.77	0.053
WSA_WY022	596067.5	5476706	563.459	563.44	-0.019	WSA_EST57	663281.8	5438164	531.788	531.86	0.072
WSA_WY023	596080	5476706	563.598	563.56	-0.038	WSA_EST58	663288.8	5438154	531.845	531.9	0.055
WSA_WY024	596091	5476706	563.702	563.67	-0.032	WSA_EST59	663295.9	5438144	531.89	531.97	0.08
WSA_WY025	596105.4	5476706	563.777	563.74	-0.037	WSA_EST60	663301.2	5438136	531.94	532.01	0.07
WSA_OXB26	704920.8	5456994	582.7	582.73	0.03	WSA_EST61	647325.6	5443257	539.823	539.71	-0.113
WSA_OXB27	704909.2	5456997	582.79	582.83	0.04	WSA_EST62	647325.9	5443241	539.736	539.64	-0.096
WSA_OXB28	704893.5	5457000	582.853	582.87	0.017	WSA_EST63	647325.7	5443225	539.72	539.61	-0.11
WSA_OXB29	704873.4	5457003	582.906	582.94	0.034	WSA_EST64	647325.7	5443210	539.677	539.57	-0.107
WSA_OXB30	704840.9	5457008	583.111	583.14	0.029	WSA_EST65	647326	5443196	539.817	539.7	-0.117
WSA_OXB31	704823.3	5457011	583.263	583.29	0.027	WSA_EST66	647326.6	5443179	539.949	539.83	-0.119
WSA_OXB32	704804.8	5457013	583.389	583.39	0.001	WSA_EST67	647327.4	5443164	539.837	539.72	-0.117
WSA_OXB33	704784.3	5457015	583.506	583.52	0.014	WSA_EST68	647327.8	5443148	539.721	539.59	-0.131
WSA_OXB34	704761.4	5457017	583.697	583.71	0.013	WSA_EST69	647328	5443133	539.6	539.49	-0.11
WSA_OXB35	704746	5457018	583.781	583.82	0.039	WSA_EST70	647328.3	5443117	539.368	539.26	-0.108

4.3 Additional Quality Control

In addition to self-review at each step of the workflow, the following quality checks occur twice, once after pre-processing and later repeated at the final stage before delivery.

- Data Extent: Using a footprint of all available ground classified data, delivery extents are matched against extents stated in the project specification.
- Data Density – A data density raster is created to examine whether pulse distribution is even and every necessary area is covered.
- Positional Accuracy – Using validation control points LiDAR data are checked for accuracy (using ground points) to ensure stated specifications are met.