Waikato Local Authority Shared Services (WLASS) / CoLAB LiDAR Data Capture Services
LiDAR Processing Report
Block A (Rev2)

Contract Number: AU411
Surveyed By: iXblue Pty Ltd / Ocean Infinity
Processing Completed By: Woolpert

Prepared For: Waikato Local Authority CoLAB

Document Date: 8 June 2023
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Document Revision

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## Revision History

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<td>3</td>
<td>Overlap flag methodology updated.</td>
<td>2.7</td>
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Figure 1: Waikato Survey Area
1 Introduction

Lidar survey projects are broken into three distinct phases. The survey commences with the data acquisition project phase. For matters pertaining to this phase of the project, refer to the document


The next phase of the project is the Geopositioning phase, which involves processing the raw sensor and trajectory data to produce a set of point clouds for each flight line.

The point clouds have several geometric optimizations performed, to optimise the relative and absolute spatial accuracy levels.

At completion of the Geopositioning phase, the point cloud geometry is final, and the point cloud classification and production generation project phases follow.

For matters pertaining to this phase of the project, refer to the documents

- AU411_Lidar_Geopos_QAQC_Reports_Waikato_Blocks_15062022
- AU411_Lidar_Geopos_QAQC_Reports_Waikato_Entirety_09092022

The following report covers the data processing project phase and describes the data processing methods used for the lidar classification and product generation, along with the QAQC procedures and results.

This report illustrates compliance with the LINZ PGF specifications sections 6 – 9.

This report pertains to the coverage of Block A, as illustrated in yellow in Figure 1 - Waikato Survey.

1.1 Revision 1

The dataset was originally uploaded by AAM / Woolpert on 06 December 2022. This was transferred to WRC the following day (07 December 2022). Two tiles were missed and the LAS, DSM and DEM for these products were provided on 14 December 2022 along with Shapefiles and tile index's to suit. Another tiling issue relating to either corrupt files and/or zipping errors was identified and an extra six tiles were supplied on 23 December 2023.

WRC and LINZ then carried out QAQC on the provided dataset. This concluded on January 21, 2023. A spreadsheet was provided and used for tracking the identified issues. This spreadsheet was shared with AAM/ Woolpert and formed the core document (along with shp and gdb files as examples) to use for the fixes and reprovision of the dataset. This spreadsheet underwent a number of revisions tracking the data and was supported by a technical meeting (07 February 2023) between WRC staff, Ocean Infinity and AAM / Woolpert.

The spreadsheet “WRC_Raised_Defect_Tracking_Block_A_v001_20230222-AAM-Responses” detailing the issues and associated fixes has been provided in Appendix B.

The reprovision of Block A was provided after hours on Friday 17 February 2023. This was transferred to WRC on Monday 20 February 2023.

On the 23rd of February AAM uploaded extra coastal tiles that were not covered by the LINZ PGF tile layout or contract. These were initially identified by WRC and AAM found extra tiles that contained land and were added to the request. A total of 57 tiles were provided in their various formats. This was
transferred to WRC on the same day. There were some download errors and was resupplied Monday 27 February 2023.

It is noted that some of the items on the Tracking sheets were related to general comments, these were reviewed in greater depth than the individual tiles of concern and changes were made where identified and required.

1.2 Revision 2

The dataset was returned for further rework. This was supported by the spreadsheet ‘AU411 WRC_Raised_Defect_Tracking_Block_A_v002_20230316’ supplied by WRC in association with LINZ. The new revision was resupplied by Woolpert Australia to Ocean Infinity on Wednesday 24 May. A Transfer to WRC and LINZ was initiated on the same day.

The total number of supplied LAS tiles:
- 8976

DEM and DSMs supplied over updated tiles. Tile count differs on purpose; resupply of failed format only that had export issue:
- 2239 DEMs
- 2241 DSMs

As highlighted previously there is no capture over these additional requested tiles (no products generated):
BA36_2105
BA36_2205
BA34_1317

As requested the DEMs and DSMs are flattened to the tile extents even if they aren’t completely covered by capture. This includes tiles BA34_1217, BA34_1218, BA34_1317 and BA34_1318, amongst others.

The following Images are supplied showing how feedback was addresses:

Additional Bridge break line tile BA34_4930

![Figure 2: Tile BA34_4930 Prior to break line](image)
Boulder/vegetation classification in tile BA34_1935.

Figure 3: Tile BA34_4930 After addition of break line

Figure 4: Boulder/vegetation classification in tile BA34_1935 – Original Side profile

Figure 5: Boulder/vegetation classification in tile BA34_1935 – Original DEM
Figure 6: Boulder/vegetation classification in tile BA34_1935 – After editing Side profile

Figure 7: Boulder/vegetation classification in tile BA34_1935 – After editing DEM
Noise in tile BA34_2732

Figure 8: Tile BA34_2732 Prior to editing

Figure 9: Tile BA34_2732 Post editing
Noise in tile BC36_2813

Figure 10: Tile BC36_2813 prior to editing

Figure 11: Tile BC36_2813 post editing
DSM-DEM difference example highlighting difference exists over cliffs

**Figure 12:** Tiles BA35_1000_3446, BA35_1000_3447, BA35_1000_3546, BA35_1000_3547

**Figure 13:** Same location in DEM
Swath matching as identified in ‘I28 GEOMETRIC RESULT POINTS.gpkg’

Figure 14: Prior to repair

Figure 15: After editing
2 LiDAR Data Processing and Handling

The LiDAR data processing method is described in the Project Method Statement, AU411-FOR-008-R5 Project Method Statement_WLASS. The following sections elaborate further but focus on adherence with compliance to the Linz PGF Specification (JAN 2020).


QAQC steps for various workflow tasks have been tracked and recorded and included as an embedded document within Appendix 1.

2.1 The ASPRS LAS File format

LINZ PGF specification 6.1 requires that all point deliverables are required to be fully compliant with LAS Specification Version 1.4, using Point Data Record Format (PDRF) 6, 7, 8, 9 or 10 (referred to as LAS v1.4).

For this project, LAS 1.4 with PDRF 6 is to be delivered.

The LAS files created during the project during the Geopositioning phase and subsequent data cleaning and deliverable products are in ASPRS LAS 1.4 format, with PDRF 6. This was specified during the creation of the project in TerraScan, as shown in a representative image in the figure below:

![Figure 16: LAS 1.4 being specified during project – example](image-url)
The correct format of LAS is illustrated by use of LASTools, which shows the LAS files are in 1.4 format in the figure below.

![LASTools output showing LAS 1.4 format](image)

**Figure 18: Confirmation of LAS 1.4 being the file format of handover laser point files using LASTools**

To verify that the project deliverables are in the correct LAS file format/version with PDRF, LP360 File Analyst was used. File Analyst performs exhaustive testing on the LAS file header and data records, and outputs the analysis results to an excel spreadsheet. As there are many tiles in the project area, the analysis results from LP360 are included as an imbedded document within Appendix A.

### 2.2 Time stamp of navigational data

LINZ PGF specification 6.2 requires that Each Global Navigation Satellite System (GNSS) aircraft positional measurement must be time stamped using Adjusted Global Positioning System (GPS) Time, at a precision enough to allow unique timestamps for each LiDAR pulse.

For this project, LAS 1.4 with PDRF 6 has been delivered including, with Global Encoding bit set to 1. An example of how adjusted GPS time is visualized and monitored is illustrated in Figure 5: LAS point attributes being shown as class, flightline, GPS time stamp, Northing and Easting (left-to-right).

To verify GPS time is set to adjusted GPS time, LP360 File Analyst was used. File Analyst performs exhaustive testing on the LAS file header and data records, and outputs the analysis results to an excel spreadsheet. The Lidar technical manager reviewed this analysis to ensure that all deliverable LAS files are compliant.

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*IXblue / OI Project No: 411 LiDAR Processing Report – Block A – Rev2*
As there are many tiles in the project area, the analysis results from LP360 are included as an imbedded document within Appendix A. Figure 5 below shows representative examples of LAS point attributes being shown as class, flightline, GPS time stamp, Northing and Easting (left-to-right).

![Representative examples of LAS point attributes](image)

**Figure 19: Representative examples of LAS point attributes**

### 2.3 Datums and coordinate reference system

LINZ PGF specification 6.3 requires that the required datum for latitude, longitude, and ellipsoid heights is the New Zealand Geodetic Datum 2000. The required vertical datum for normal-orthometric heights is NZVD2016 (Reference 9). Projected data products are to be delivered in NZTM2000 projection (Reference 10) with NZVD2016 normal-orthometric heights.

The Survey Datums, Ground Control, Check Points and Lidar Geopositioning sections of the Project Methodology Statement describes in detail how the data is transformed and connected to the required project datum.

To verify that the correct datum information is recorded in the LAS 1.4 header, LP360 File Analyst was used. File Analyst performs exhaustive testing on the LAS file header and data records, and outputs the analysis results to an excel spreadsheet. The Lidar Phase Manager reviewed this analysis to ensure that all deliverable LAS files have the correct CRS applied in the header.

As there are many tiles in the project area, the analysis results from LP360 are included as an imbedded document within Appendix A.
2.4 Geometric Calibration

Following initial sensor data processing, a formal reduction process was performed on the data. Laser point position was calculated by associating the SBET position to each laser point return time, scan angle, intensity, etc. Raw laser point cloud data was created for the whole project area in LAS format. Line-to-line calibrations were then performed for system attitude parameters (pitch, roll, heading), mirror flex (scale) and GPS/IMU drift.

Statistical reports were generated for comparison and used to make the necessary adjustments to remove any residual systematic error. These calibration adjustments were performed using a combination of automated and manual corrections to the data to develop the geometrically calibrated data set to be utilized for all downstream processes.

2.5 Positional accuracy validation

LINZ PGF specification 6.4 details the positional accuracy verification methods. The Vendor is expected to apply best practice in assessing the project accuracy and achieving compliance with this specification. Before classifying and developing derivative products from the point cloud, the relative vertical, local vertical and horizontal accuracies of the point cloud must be verified. The Vendor must deliver a detailed report of the validation processes used.

Validation of the point cloud positional accuracies is the primary outcome of the Lidar Geopositioning workflow phase, using surveyed ground control & check points. The assessments methods and results of the positional accuracy validation is be reported in the LiDAR Geopositioning QA/QC Report.

2.6 Use of the LAS withheld flag

LINZ PGF specification 6.5 requires that outliers, noise points, geometrically unreliable points near the extreme edge of the swath, and other points the Vendor deems unusable must be identified using the Withheld Flag, as defined in the LAS Specification.

Points classified as low noise (coverage class 7) and high noise (coverage class 18) will have the LAS withheld flag set.

To verify that the withheld flag has been correctly set, LP360 File Analyst was used. File Analyst performs exhaustive testing on the LAS file header and data records, and outputs the analysis results to an excel spreadsheet. The Lidar Phase Manager reviewed this analyst to ensure that the Las withheld flag is correctly applied. As there are many tiles in the project area, the analysis results from LP360 are included as an imbedded document within Appendix A.

2.7 Use of the LAS v1.4 Overlap Flag

LINZ PGF specification 6.6 requires identifying overage points is not required unless requested by the Contract Authority. However, if overage points are explicitly identified using LAS v1.4, they must be identified using the overlap flag.

Classification of the overlap points was done using TerraScan in Microstation. A macro step was created which allowed for points to be classified with the overlap bit by cutting the scan angle at zero degrees.
The step used for the project dataset is illustrated in the figure below. This allowed for the overlap points to be withheld from DEM, DSM and intensity imagery generation. Figure 6 below shows Settings used when cutting overlap in Microstation. Note that the 'Action' is on "Set overlap bit.

![Microstation Settings](image)

Figure 20: Settings used when cutting overlap in Microstation.

Verification of appropriate overlap flag application is performed using LP360 File Analyst. File Analyst performs exhaustive testing on the LAS file header and data records, and outputs the analysis results to an excel spreadsheet. The Lidar Phase Manager reviewed this analysis to ensure that all deliverable LAS files are compliant. As there are many tiles in the project area, the analysis results from LP360 are included as an imbedded document within Appendix A.

### 2.8 Point Classification

LINZ PGF specification 6.7 requires Lidar points are classified to the following coverage classes:

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<td>1</td>
<td>Processed, but unclassified</td>
</tr>
<tr>
<td>2</td>
<td>Ground</td>
</tr>
<tr>
<td>3</td>
<td>Low vegetation &lt;2m</td>
</tr>
<tr>
<td>4</td>
<td>Medium vegetation</td>
</tr>
<tr>
<td>5</td>
<td>High vegetation &gt;8m</td>
</tr>
<tr>
<td>6</td>
<td>Building</td>
</tr>
<tr>
<td>7</td>
<td>Low noise</td>
</tr>
<tr>
<td>8</td>
<td>Water</td>
</tr>
<tr>
<td>17</td>
<td>Bridge deck</td>
</tr>
<tr>
<td>18</td>
<td>High noise</td>
</tr>
</tbody>
</table>

Table 1: Point Classifications
Point cloud classification is performed by automated classification algorithms developed by Woolpert’s senior Lidar analysts and reviewed by the Lidar technical manager.

A first run automatic classification was carried out on the raw LiDAR points using TerraSolid’s TerraScan software to classify the LiDAR points into ground hits and non-ground hits. This results in a greater than 80% correct classification. Some of the steps used within this macro can be found within the screenshot below (Figure 7), including 5 of the 8 ground classification steps used on this data set.

![Figure 21: Automatic classification macro developed for the project area.](image)

As documented by TerraSolid, the ground routine classifies ground points by creating a triangulated surface model iteratively. The routine is best suited for classifying ground in airborne laser data sets and in data sets where there is mainly natural terrain. For classifying ground in mobile data sets where the majority of ground is on hard surfaces, such as roads, use the Hard surface routine instead of the ground routine.

The routine is sensitive to low error points in the point cloud. Therefore, you should run one or more classification steps using the Low points routine before classifying ground. A more complex classification strategy is required for classifying ground in photogrammetric point clouds.

The ground routine starts by selecting local low points that are confident hits on the ground. The initial point selection is controlled with the Max building size parameter. If the maximum building size is, for example, set to 60.0 m, the routine assumes that any 60 by 60 m area has at least one point on the ground level and that the lowest point is on the ground level.

Then, the routine builds a surface model (TIN) from the initial ground points. The triangles in this initial model are mostly below the ground level and only the vertices are touching the ground. In the following iterations, the routine molds the model upwards by adding more and more points. Each added point makes the model following the true ground surface more closely.

The iteration parameters of the routine determine how close a point must be to a triangle plane for being accepted as ground point and added to the model. Iteration angle is the maximum angle between a point, its projection on the triangle plane and the closest triangle vertex. This is the main parameter controlling how many points are classified into the ground class. The smaller the iteration angle, the less eager the routine is to follow variation in the ground level, such as small undulations in terrain or points on low vegetation. Use a smaller angle value (close to 4.0) in flat terrain and a bigger value (close to 10.0) in mountainous terrain.

Iteration distance makes sure that the iteration does not make big jumps upward if triangles are large.
This avoids ground points that are too high, for example within low vegetation or on low buildings.

![Figure 22: Illustration of iteration angle and iteration distance parameters in the ground routine.](image)

Figure 22: Illustration of iteration angle and iteration distance parameters in the ground routine.

![Figure 23: A smaller iteration distance value avoids classification of ground points on low objects.](image)

Figure 23: A smaller iteration distance value avoids classification of ground points on low objects.

The iteration angle can be reduced automatically if the triangles become small. This reduces the eagerness to classify more ground points inside small triangles and thus, avoids unnecessary point density of the ground model thus avoiding redundancy of inclusion of unnecessary ground points.

Related to this it is common to see default classified points within a classified ground point cloud surface. The iteration angle inside small triangles approaches zero if the longest triangle edge is shorter than a given Edge length value. Furthermore, the iteration can be stopped completely if triangle edges are shorter than a given limit.

After completion of the automated classification, a strenuous manual classification was carried out over the required area to edit the points thus minimizing gross classification errors that may have occurred in the automatic classification process.

Each block’s data was checked in a systematic approach to reduce missing important features. Orthogonal views with background orthoimagery, and profile views are used to review the performance of the automatic classification results.

Tools such as ‘Classify using brush’, ‘Classify above line’ and ‘Add Point to Ground’ (all found within TerraScan) were used during manual classification, to achieve classification accuracy meeting project specifications. Before handover files were created, checks were done on the project’s points by viewing statistics within TerraScan as illustrated in the figure below.
Figure 24: Statistics showing the classes of all the LAS points within the project area (original).

```
Figure 24: Statistics showing the classes of all the LAS points within the project area (original).

```

Figure 25: Statistics showing the classes of all the LAS points within the project area (latest).

```
Figure 25: Statistics showing the classes of all the LAS points within the project area (latest).

```
To keep track of the data cleaning process, a hatching method was used on the DGN within Microstation. It allows the cleaners to systematically mark each tile which has been fully checked and editing, making sure the whole data set has been initially covered.

Figure 26: The green diagonal hatching seen above shows blocks which have been fully checked.

Figure 27: The diagonal hatching seen above shows how the progress was tracked.
To verify that only the required coverage classes are present & populated, LP360 File Analyst performs exhaustive testing on the LAS data records, and outputs the analysis results to an excel spreadsheet. Lidar Analysts review this data to ensure that all deliverable LAS files are compliant with the specification coverage classes. Point cloud QAQC/editing is performed by trained Lidar Technicians, under the supervision the Lidar Phase Manager and followed by a dedicated QA/QC team.

### 2.9 Classification Accuracy

LINZ PGF specification 6.8 requires that non-withheld points must be classified to a classification accuracy level of 2%. No non-withheld points are to remain as class 0.

Realtime Digital Elevation models are generated using Terrascan/Terramodeler are used to verify ground classified points and lidar technicians review the DEMs to find anomalies such as spikes or pits that imply misclassified points and make corrections.

During DEM review profiles are cut across tiles where potential issues are detected. The Lidar Technician scans the profile view to identify if an issue exists and modifies the classification of points as required.

10% of the data tiles are subject to review by a senior analysis or project manager.

After data cleaning was completed, a comprehensive DEM review is performed to visualize the data over large areas for the purpose of identifying anomalies or areas for further investigation. Any potential errors were identified as shown in the red polygons below and later addressed via additional manual editing.

Figure 28: The polygons are areas for further investigation
The indicated areas were revisited and manually classified as appropriate. Below is an example of an issue identified for further investigation. Multiple revisions of the point cloud were performed to address issues common to the terrain and vegetation cover found within the project AOI. Rugged terrain and heavy vegetation across areas within the AOI commonly created unavoidable laser penetration difficulties as well as areas within the DEM that appear to have a rough surface.

The figures below illustrate such and occurrence. Issues were identified concerning what appeared to be excess noise in areas of gullies. After investigating it was determined the gully areas in question are densely vegetated and located within steep terrain. The sparseness of the consistent ground penetration and steepness of terrain led to points being classified as noise during ground filtering. Additional filtering steps were taken to reclassify points into ground from noise class. The additional ground points added from noise provide improvement to the DEM quality as the points classified from noise to ground were sparsely distributed due to dense vegetation.

![Figure 29: Example overhead image of DEM over cliffs](image)

![Figure 30: LAS point cloud profile view from previous figure](image)
2.10 Classification Consistency

LINZ PGF specification 6.9 requires that point classification must be consistent across the entire project. Noticeable variations in the character, texture, or quality of the classification between tiles, swaths, flights, or other unnatural divisions are grounds for rejection of the entire deliverable.

As with classification accuracy there is no analytical means of measuring compliance. As such the classification consistency is reviewed via visual means. To mitigate against inconsistent classification, the following controls were employed:

• Systematic geometric issues that may lead to swath-based inconsistencies are identified by the Lidar Geopositioning process, as documented in the Project Method Statement, specifically in the intraswath, interswath & absolute accuracy analysis steps. Data swaths that do not pass this stage do not progress to later classification steps.
• The automated classification process is a series of classification algorithm tools applied in a macro. The macro is designed and optimised to yield high classification accuracy across the variety of land cover types within the project area. Applying the one, optimised and flexible classification macro delivers consistent classification across the entire project area.

• To avoid tile edge artefacts, all tile-based workflow steps utilise a buffer of lidar points from surrounding tiles. This allows for a better classification of both ground and vegetation points.

• Lidar Technicians are trained to deliver consistent results and use the same visualisation methods/ aids. They are supervised by the Lidar Phase Manager and the 10% of classified point cloud tiles are peer reviewed by a dedicated QAQC team.

• DEM tiles are run after classification has been completed to review possible errors in Ground classification.

• Bridges are checked against a bridge shapefile (supplied by LINZ) to correctly identify and classify the bridges.

2.11 Classification Consistency – Bridges

As mentioned above the dataset was compared against the LINZ bridge shapefile. There was discussion between Ocean Infinity, WRC, Woolpert and AAM around the differentiation of bridges versus culverts. The subject is somewhat open to interpretation. It is noted that the classification of Bridges (or not) has implications for Water flow modelling and hydroflattening. The following images are a visual representation of some of the aspects discussed.

Below example shows DEM Triangulations where a bridge has been removed

![Figure 33: Tile DEM_AZ34_4944 with LINZ bridge centreline](image)

Below examples are bridges edited in the LAS files, but which were not highlighted in the LINZ Shapefile.
Below examples are bridges highlighted in the LINZ Shapefile which were determined not to be bridges.
Below examples are highlighted in the LINZ Shapefile which were subject to different determinations.

*Figure 37: This is a road cut into the slope rather than a bridge. Tile BC35_1000_1423*

*Figure 38: Bridge in the LINZ shapefile that has been classified to class 17 but is really a culvert. No breakline added. Tile BC36_1000_2807*

*Figure 39: Bridge in the LINZ shapefile that is a culvert and is therefore not edited to class 17. Tile BC35_1000_3023.*
Figure 40: Bridge that shows in LINZ Shapefile but determined to be a ford rather than a bridge.
Tile BC35_1000_2145

Below is an example of Ground Surface with bridge classified.

Figure 41: Tile DEM_BA34_1250
3 LiDAR Hydro-Flattening QAQC

LINZ PGF specification 7.0 details at length the requirements for Hydro flattening of Digital Elevation Models.

The methods for Hydro Break line Digitization, Hydro-Flattening and Hydro-Flattening quality control are described in the Lidar Processing and Data presentation section of the Project Method Statement.

Hydro-flattening generation methods will be detailed in the Processing Report.

The pertinent parts of the specification and the means of identifying the required hydro-flattening features are as follows:

• Permanent islands 5,000 m² or larger must be delineated
• Islands of 5000m² will be included as hole features within the parent hydro-flattening polygon.
• Inland ponds and lakes – water bodies of 10,000m² or greater at the time of collection must be flattened
• Lake polygon features will be precisely digitized using lidar point cloud with supporting background intensity imagery and supported by open-source imagery as reference.
• Inland streams and rivers of >= 30m nominal width (width of water flow in a single channel at time of capture) must be flattened
• Streams/rivers that fulfil the minimum distance requirement will be identified by visual inspection of the point cloud.

Hydro-flattening was performed upon the project dataset, and hydro break lines were used during the creation of digital elevation models. Hydro Flattening digitizing are performed by Lidar technicians, under the supervision of the Lidar technical manager. The hydrological features were digitised in Microstation using a combination of manual and automatic digitizing ('Display boundary' function in TerraModeler). Stream islands that were 5 000m² or larger in size.

Figure 42: Example of a hydro-flattened DEM Coastal Tile DEM_B36_0650.
When hydro-flattening a stream, the following process is used:

Identify a possible stream feature. Measure the width of the stream from bank to bank, and if greater than 30m wide, begin digitizing the feature. If the stream varies in width, the discretion of the geospatial specialist is applied.

Once the stream outline was completed, and that it was confirmed to be a polygon, a shapefile was imported into ArcMap and a centreline was created using the ‘Create Centreline’ script, which generates a centreline based on the stream polygon.

The centrelines were then checked for errors which may have occurred during its creation. It was then exported to Microstation where the centreline was then dropped to a surface (created by surrounding ground points). The tool ‘Force Downstream Flow’ was used to enforce correct elevations for the centreline, ensuring that each point’s height was equal to or less than that of the point before it.

Figure 43: Example of Bridge with LINZ bridge centreline

Figure 44: Same location as above DEM. Laser with the Ground and Bridge classes (red) visible. Shows that the bridge has been classified.
The correct order of point heights was then checked by exporting the co-ordinates out as a text file which would be used for the creation of a new centreline shapefile. Figure 18 shows the example excerpt of river points used to create the centreline after downstream flow was enforced. Figure 19 shows the example highlighted script was used to generate the centreline for the stream within the project’s survey.

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After the new centreline had been created, it was conflated with the stream’s shape using LP360 within ArcMap. This matched up the elevation of the stream’s outline with that of the centreline. The new stream shape was attached to a DGN and opened in Microstation, exported as co-ordinates, and then read into the project. These points along with ground points were used to output lattice models which show the results of the hydro-flattening. Stream-island break line points were also included to ensure the correct modelling of the stream and its features.
The following settings were used for lattice model creation:

![Image of lattice model settings](image)

*Figure 47: Settings used to export lattice models.*

The product undergoes QC by the Lidar Phase Manager and is reviewed for any omissions or blunders. The following project specification are checked against:

- All Hydrologic break lines developed for use in hydro-flattening are in non-tiled ESRI feature class in polylineZ or polygonZ shape file format.
- Water bodies (ponds, lakes, and reservoirs), wide streams and rivers (“double-line”), and other non-tidal water bodies are to be hydro-flattened within the DEM. The resulting pond and lake surfaces will be flat and double line rivers will be flat level bank-to-bank and be gradient.
- It is noted when hydro-flattening streams, significant breaks in water elevation as well as varying degrees of bends in the stream direction will create a triangulated appearance in the DEM. These affects will be minimized to an appropriate extent.
- The entire water surface edge must be at or below the immediately surrounding terrain.
- Hydro-flattening break line feature class use the NZTM2000 projection and NZVD0216 height datum.
- Hydro-flattening has applied to all streams that are nominally wider than 30 metres wide, and to all non-tidal boundary waters bordering the project area regardless of size.
- Hydro-flattening shall be applied to all water impoundments, natural or man-made, that are nominally larger than 10000m² in area.
- Stream channels should break at road crossings (culvert locations). These road fills should not be removed from the DEM.
- Streams and rivers should NOT break at elevated bridges. Bridges are removed from the DEM. When the identification of a feature such as a bridge or culvert cannot be made reliably, the feature should be regarded as a culvert.

A peer review of the Hydro flattening break line data products as well as the hydro-flattened DEM is performed on 10% of the dataset by an independent analyst or project manager.
To distribute and track the progress amongst the editing & QAQC team, an ArcSDE tracker (multiuser database) is employed.

During the QA/QC, it was identified there will be instances of vegetation classifications contained within waterbody polygons. After investigation it was determined much of this occurs from overhanging vegetation from the outside of the hydro features. Occasionally there are instances of vegetation within waterways which is related to islands falling below the required threshold for collection. Additional processing steps were taken to limit the amount of vegetation that exists within the waterway while retaining the overhanging vegetation. This processing step primarily involved classification based on XYZ proximity to existing digitized hydro/island lines. After this process was performed some vegetation classified lidar points will still be present in the waterway.
Additionally, during QC data review, it was discovered rocks and boulders within rivers are occasionally classified as vegetation. This is typically observed in high relief areas where water flows down steep terrain, i.e., rapids/white-water. Rivers tend to narrow in these areas and will not likely be caught during the aforementioned processing step based on proximity to linework. These points will continue to be classified as vegetation.

Figure 50: Point cloud – boulder filled stream

Figure 51: Imagery – boulder filled stream
Figure 52: Example of hydroflattened DEMs: DEM_BB36_1704 and DEM_BB36_1705

Figure 53: Difference between DSM and DEM indicating consistent ocean heights
4 LiDAR Deliverables QAQC

Section 8 of the LINZ PGF specification details the project reporting, metadata requirements & deliverable requirements.

4.1 Reporting and metadata

4.1.1 Project reports

The following details the reports being delivered for this section of the project:

- Collection Report detailing mission planning and flight logs, including dates of collection
- Details of quality control tests, and conformance against Linz specifications
  - Refer to AU411_WLASS-Collection_Report-10052021.pdf
- Survey Report detailing the collection of all ground control, including the following:
  - Control points used to calibrate and process the LiDAR and derivative data
  - Check sites used to validate the LiDAR point data or any derivative product
  - Refer to AU411-R1-Waikato LiDAR Ground Control Report of Survey.pdf
- Geopositioning QA/QC Report, detailing analysis, accuracy assessment and validation of the following:
  - Point cloud data, including a summary of relative (smooth surface repeatability and overlap consistency) and non-vegetated vertical and horizontal local accuracy.
  - QA/QC analysis of the vertical and horizontal local accuracy assessment will include a table of the product data compared to each check site.
  - Refer to AU411_Lidar_Geopos_QAQC_Reports_Waikato_Blocks_15062022
  - AU411_Lidar_Geopos_QAQC_Reports_Waikato_Entirety_09092022.
- Processing Report (This Document) detailing:
  - Classification and product generation procedures including methodology used for break line collection, hydro-flattening break line collection, hydro-flattening processing, DEM & DSM creation, and deliverable generation.
  - Details of quality control tests, and conformance against each of the relevant Linz specifications including:
    - Workflow QAQC checklist
    - Pre-Delivery QAQC worksheet as an embedded document

4.1.2 Extents

LINZ PGF specification 8.1.3 requires that a geo-referenced, digital spatial representation of the detailed extents of each delivered dataset.

The data for Block A was captured using Leica TerrainMapper sensors 513 and 559, flown on days 5th, 15th, 24th, 25th, 27th 29th January 2021 and days, 12th, 18th of February 2021 and days 11th, 12th, 22nd, 23rd, 24th of March 2021. The extent of Block A can be seen in Figure 25. The flight lines relating to the area can be seen in Figure 28.

This extent was created by creating a surface in Microstation based on all points collected during the survey flight. The tool “Display boundary” was then used to generate the extent, which was then exported into a shapefile and assigned with the necessary horizontal and vertical co-ordinate system.
Another new Shapefile `Waikato_Block-Delivery_Final_NZTM_20230222` was provided to rectify a rounding error on tiles. The AOI changed minimally and is reflected in the figure below.

*Figure 54: Extent of deliverable data for Block A*
4.1.3 Flight Lines

LINZ PGF specification 8.1.3 requires that Flightline shapefiles as Esri polylines are required. Each flightline must be assigned a unique File Source ID that is equal to the Point Source ID assigned to each point collected during that flightline.

The Sensor trajectory was imported into Terrascan and edited to split the trajectory into discrete flight lines. Each flight line was then assigned discrete flight line ID, in accordance with the project flight plan. Each Lidar point was assigned a flight line ID by matching against its trajectory, using the Adjusted GPS time stored in both the trajectory and lidar point. The trajectories were exported to ESRI shape file format with a File Source ID attribute populated with the trajectory flight line ID value. This process will ensure that specification 8.1.3 is adhered to.

The image below shows the extend of the area covered.

![Figure 55: Flight lines for 4ppm2 data coverage over Block A (Original)](image-url)
4.2 Classified point cloud tiles

LINZ PGF specification 8.2 details the requirement for the point cloud deliverables, and how adherence to the specifications is measured is listed below. Point cloud deliverable generation methods will be detailed in the Processing Report. Deliverable QC checks are performed both by Lidar technicians, under the supervision of the Lidar Phase Manager and followed by a review of 10% of the data by an independent analyst or project manager:

(a) Data from all project swaths, returns, and collected points, fully calibrated, adjusted to ground, and classified, by tiles. Project swaths exclude calibration swaths, crossties, and other swaths not used in product generation.

(b) Data is provided in the NZTM2000 coordinate system and the NZVD2016 vertical datum.

(c) Fully compliant LAS v1.4, Point Data Record Format (PDRF) 6-10. All files must have the same PDRF.

(d) Each point includes a Point Source ID linking it to the flight line File Source ID.

(e) Correct and properly formatted georeferenced information (EPSG: 2193 + 7839) as Open Geospatial Consortium (OGC) Well Known Text (WKT) included in all LAS file headers.

(f) File Source ID set to 0 for tiled LAS files.

(g) GPS times recorded as Adjusted GPS Time at a precision sufficient to allow unique timestamps for each pulse.

(h) Points are provided in the order in which they were collected.
(i) Height values reported to three decimal places (nearest mm). (While not significant for accuracy, this supports numerical processing and reduces the number of identical values caused by rounding.)

(j) Intensity values, normalised to 16-bit by multiplying the value by 65,536/ (intensity range of the sensor) per LAS v1.4. This will result in an intensity range of 0-65,536.

(k) Classification as required by the Contract Authority (Table 4 at a minimum).

(l) Tiled delivery, without overlap, per the project tiling scheme in Section 9 – Tiles.

(m) Files named per Section 9 – Tiles.

The point cloud tiles created for handover underwent multiple alterations before finalization. After the LAS tiles were created in Microstation, LASTools was used to assign the correct global encoding (17), system identifier and file source ID (0). WKT was also added to the LAS metadata, as illustrated in the figure below. The correct height values were also confirmed in LASTools ensuring that three decimal places were being used. The tiles were also named according to the required naming convention which is discussed in Section 6.

![Figure 57: WKT of a LAS file shown by LASTools.](image)

Intensity valued scaled from a range of 100 – 10000 output by HxMap, to full 16-bit dynamic range. Translation value = -100 Scale value = 6.5535

Once the point cloud was classified and was inspected manually in Microstation, the LAS files were loaded into LP360. The global coding, file source ID, WKT, VLRs, file format and LAS version were compared against to the LINZ specifications and after passing QA/QC, the files were renamed in accordance with the LINZ specifications. A condensed version of the LP360’s results can be found in the table below. A complete listing of the output from LP360 is included as an embedded document in Appendix A.
Additionally, a pre-delivery script which invokes LASTools was run on all tiles. The script output was imported into a custom Excel Worksheet, which checked specification compliance. For a complete listing of analysis refer to Section 6.1 of this document.

### 4.3 Elevation models

LINZ PGF specification 8.3 details requirements for raster surface model deliverables. The specification and how adherence to the specifications is measured is listed below. Deliverable QC checks are performed both by Lidar technicians, under the supervision the Lidar Phase Manager and followed by a review of 10% of the data by an independent analyst or project manager.

#### Table 2: Representative output from LP360 illustrating LAS file specification compliance

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</tr>
<tr>
<td>CL2_BA34_2021_1000_0236.las</td>
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<td>1.4</td>
<td>LASF 0</td>
<td>TRUE</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
(a) Grid spacing: 1m cell size.
(b) Generated to the limits of the project area
(c) Raster format: Geotiff (.tif)
(d) Geo-reference information (EPSG 2193) in each raster file.
(e) Tiled delivery without overlap.
(f) NOT clipped using polylines for land-water boundaries from national databases (for example coastlines, river or lake boundaries) as these can be inaccurate and subject to continual geomorphic change.
(g) Tiles with no edge artefacts or mismatch. A quilted appearance in the overall surface can be grounds for rejection of the entire deliverable - whether the rejection is caused by differences in processing quality or character among tiles, swaths, flights, or other unnatural divisions.
(h) Void areas (for example, areas outside the project area but within the project tiling scheme such as offshore water) coded using “NODATA” value equal to -9999. This value must be identified in the appropriate location within the raster file header.
(i) Constrained with any additional break lines required by the Contract Authority, such as stopbanks, streams, and narrower rivers.
(j) Provided in the NZTM2000 coordinate system and the NZVD2016 vertical datum. Additional vertical datums may be specified by the Contract Authority.

4.3.1 Bare-Earth Digital Elevation Models (DEM)

LINZ PGF specification 8.3.1 details additional requirements for Digital Elevation Models. The Bare-Earth DEM is the bare earth that has been classified and edited to remove vegetation and man-made structures within the bounds of the classification accuracy requirements. It must also include or conform to the following:

(a) Based on Classification level 2 or better ground return points.
(b) Hydro-flattening as outlined in Section 7 - Hydro-Flattening.
(c) Bridges removed from the surface, while culverts are treated as ground
(d) Method for removal of buildings, structures or other ground cover/vegetation and interpolation techniques documented.

The Digital Elevation Models were created using a combined model based on both ground surface points and break line points. These break line points were created during the hydro-flattening process mentioned in Section 4. By using these classes, a true representation of the ground points can be achieved while still maintaining a smooth water surface which gradually follows the terrain.

To generate DEMs, LAS format data files are loaded into TerraScan, only loading in class 2 points and breaklines. Additional data is referenced to avoid tile edge artefacts. Following import, TerraScan-Export Lattice Model command is used to create a grid file with uniform distances between points from one or more selected point classes. For each grid point, the lattice model file stores XY coordinates and elevation. Within the Export Lattice Models command we utilize “Triangulated model Z” to export the DEM tiffs. This triangulated model Z derives an elevation value that is calculated from a TIN
model of the lidar points using ground and breakline classifications.

The elevation grid is generated as a TerraScan Lattice model using the following settings:

- Grid Method = TIN Model (Triangulated model z)
- Grid Spacing = 1 meter

Following Lattice model export, the data was processed using Esri to produce GeoTiff files.

The tiles were loaded into LP360 to check the metadata of the images during both production and QA/QC of the deliverables. A Representative version of LP360’s findings is found in the table below. A complete listing of the LP360 results is included as an embedded document in Appendix 1.

<table>
<thead>
<tr>
<th>File</th>
<th>Format</th>
<th>NoData Value</th>
<th>BPB</th>
<th>Bands</th>
<th>Data Type</th>
<th>Pixel Size</th>
<th>Coordinate System</th>
</tr>
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<td>FLOAT</td>
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</tr>
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<td>FLOAT</td>
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<td>-9999</td>
<td>32</td>
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<tr>
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<td>-9999</td>
<td>32</td>
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<td>FLOAT</td>
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<td>FLOAT</td>
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</tr>
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<td>FLOAT</td>
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<td>1</td>
<td>FLOAT</td>
<td>1</td>
<td>EPSG: 2193</td>
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<td>FLOAT</td>
<td>1</td>
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<td>1</td>
<td>FLOAT</td>
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</tr>
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<td>FLOAT</td>
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<tr>
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<td>FLOAT</td>
<td>1</td>
<td>EPSG: 2193</td>
</tr>
</tbody>
</table>

Table 3: Condensed output from LP360 illustrating DEM file specification compliance

### 4.3.2 Digital Surface Models (DSM)

LINZ PGF specification 8.3.2 details additional requirements for Digital Surface Models. The DSM is the heights of the top of the highest feature at each gridpoint, including ground, vegetation, and man-made structures. The DSM is based on first return points after removal of noise.

LAS format data files are loaded into Terrascan only loading in First, First-of-many and Single returns. Additional data is loaded to avoid tile edge artefacts. Only coverage classed 1 to 6 & 17 points will be
used in generation of Digital Surface Models. The elevation grid is generated as a TerraScan Lattice Model using the following settings:

- Grid Method = Binning (Maximum Value – DSM)
- Grid Spacing = 1 metre

Following Lattice model export, the data was processed using Esri to produce GeoTiff files.

To meet the request to produce a DSM representative of the heights of the top of the highest feature at each grid point while incorporating hydro features, the hydro features used to create the DEM deliverables were included to produce a hydro flattened DSM.

Hydro-flattened DEM tiles are overlaid against the DSM tiles to identify and fill gaps in the data (such as the river), and then the tiles were exported in Geotiff format including settings for the datums and null data specifications, using the tile grid to clip & name the data files. The DSM deliverables undergo a visual spot check using Globalmapper.

In areas where valid data gaps (e.g. waterbodies) do not meet the LINZ specification for hydro-flattening the surface model will triangulate across these voids to the nearest point per pixel (highest for DSM & lowest for DEM). No intervention is made to flatten or constrain these areas.

Digital surface models are created by combining points with only a single return, and points that have the first return of many (returns) and are then used to generate the DSM model. Figure 28 is an excerpt of one of the DSM tiles created for the project area.

![Excerpt from DSM_BB34_2021_1000_3346](image-url)
The tiles created are in GeoTiff floating 32-bit format and have been adjusted to display a NoData value of -9999 (Figure 29). The composite DSM was produced in 32-bit GeoTiff format as requested and both the tiles and the composite had the correct horizontal and vertical co-ordinate systems assigned to the metadata in ArcMap.

![Image](image.png)

*Figure 59: Script used in ArcMap to achieve a NoData value of -9999.*

![Image](image.png)

*Figure 60: Properties of the composite DSM file showing its format and NoData value*

After these files were amended, they were loaded into LP360 to check the necessary metadata of the imagery. The results from LP360 can be found in the table below. A complete listing of the LP360 results are included as an embedded document in Appendix 1.

<table>
<thead>
<tr>
<th>File</th>
<th>Format</th>
<th>NoData Value</th>
<th>BPB</th>
<th>Bands</th>
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<th>Coordinate System</th>
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</tr>
</tbody>
</table>

*Table 4: Condensed output from LP360 illustrating DSM file specification compliance*
4.4 Break lines

LINZ PGF specification 8.4 details requirements for hydro-flattening break lines. Delivery of break lines representing all hydro-flattened features in a project is required. Additional break lines may also be required by the Contract Authority. These are to be delivered as ESRI Shape files (.shp) using the NZTM2000 projection.

Refer to section 7.0 of this document. The workflow methods will be documented in the project Processing Report. The digitized hydro features were included in the handover data set, under the Vector deliverable section. They are in shapefile (.shp) format and are in the NZTM2000 projection.

Stream and stream-island, lake and lake island break lines were delivered, with ocean features falling under the "Lake" feature category due to its uniform height. In figure 31 the geometry type is set to a polygon shape and has vertical and horizontal co-ordinate sets as well as Z values.

![Figure 61: Stream break line properties in ArcMap.](image)

4.5 GNSS data

GNSS data is not a required deliverable for this project.

4.6 Backed up project source data

LINZ PGF specification 8.6 details the requirements for archival and storage of the project data. Raw project source data, such as native format LiDAR files and point cloud swaths, are NOT required for delivery; however, a copy has been provided to CoLAB. It is acknowledged that the Vendor must hold a copy of all relevant raw project data, for a minimum of five years beyond the final delivery of the project deliverables. The vendor must provide this data, with unrestricted copyright, to the Contract Authority on request. The vendor may charge a reasonable access and distribution charge in such instances.

Woolpert and Ocean Infinity will archive all raw & processed data collected for 5 years following project completion.
4.7 Contours

Contours with an interval of 0.5m will be generated for all project area.

Note Contours will be generated at Project conclusion to ensure there are no line breaks between blocks.

Contours will be generated from the DEM. Contour methodology is undergoing internal discussion and will be agreed with all parties prior to their generation.
LiDAR QA Tiles

LINZ PGF specification 9.1 & 9.2 detail the requirements for project tiles geometry & naming convention.

(a) NZTopo50 subtitles based on NZTM2000 coordinates. The 1-m gridded raster products and point clouds must be delivered at 1:1000 nominal scale (2500 720m high x 480m wide subtiles per full NZTopo50 sheet).

(b) The origin of the raster tiles must be placed on a whole metre coordinate value of the southwest corner of each tile (for example, 5429500 mN_17490300mE).

(c) The tiled deliverables must edge-match seamlessly and without gaps.

(d) The tiled deliverables must conform to the project tiling scheme without overlap.

(e) File naming must conform with the naming convention described in section 9.2.

A Tile Index must be provided in ESRI shape file format. The file name must be included as an attribute in the Tile Index file.

The Client supplied tiling grid shape file will be used as the tile clipping polygon when exporting the deliverable products. The shape file will have an attribute added for each deliverable type as specified in section 9.2. This attribute will contain the required tile name for each deliverable. This shape file will be used as the means of extracting all project data deliverables, so that the geometric aspects for specification 9.1, and the naming requirements of section 9.2 are fulfilled.

Deliverable QC checks have been performed both by Lidar technicians, under the supervision the Lidar Phase Manager and followed by a dedicated QA/QC team:

5.1 LAS Tiles QAQC - LASQC

Prior to delivery, Lidar data tiles have undergone a final analysis, using a custom developed Pre-Delivery QAQC tool called LASQC. This tool uses LASTools ‘Lasinfo’ in a batchscript called LASExtract, which collates information regarding each tile into an Excel worksheet. The tool analysis and reports compliance on the following items:

- File naming accuracy
- Check to ensure lidar points fall inside the extents bounded by the NZTOPO50/1:1000 tile name
- Adjusted GPS time falling with correct extents for the survey
- LAS file format, version, file source ID, point data record format & scale factor
- Point counts by return, illustrating presence of multiple returns
- Average point density for the tile, excluding overlap
- Presence of the overlap (not applicable to all tiles) & withheld flags
- Minimum, maximum & average intensity values.
- Height above ground for building, low, medium & high vegetation classes
Note it should be noted that this analysis is not accurate in steep terrain due to the different methods used for triangulation of between Terrascan & LASTools.

- Check for presence of correct ESPG Codes for geodetic & vertical datums, and map projection
- Raster Overviews for Point Source ID, Intensity, Point Density and Overlap Analysis

These analysis results will be included as an attachment referenced in Appendix A.

5.2 File naming

Project deliverables have been named in accordance with the project specification illustrated in Table 5.

<table>
<thead>
<tr>
<th>Naming Convention for point clouds, DEMs, and other tiled products</th>
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</thead>
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<table>
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<td>CL2-Point Cloud Classification Level 2</td>
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</tr>
<tr>
<td>DEM-Bare Earth Digital Elevation Model</td>
<td></td>
</tr>
<tr>
<td>DSN-Digital Surface Model</td>
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<tr>
<td>DTM-Digital Terrain Model</td>
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<tr>
<td>UNC-Unclassified Point Cloud</td>
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</tr>
<tr>
<td>INT-Intensity Image</td>
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<tr>
<td>CHM – Canopy Height Model</td>
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<tr>
<td>IMG-Aerial photography</td>
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<tbody>
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<td>etc.</td>
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For example: DEM_BK34_2016_1000_4118.tif

Table 5: File Naming
5.3 Delivery Folder

The project deliverables are structured in the following manner:

- **raster**
  - dsm_tiles – Digital Surface Models geotiff format tiles
  - dem_tiles – Digital Elevation Models geotiff format tiles
  - las – Lidar Point Cloud Las 1.4 format tiles

- **vector**
  - **contours**
    - contours_smoothness_25.gdb – 50cm Contours Geodatabase
  - **shapefiles**
    - hydroflattening_shapefiles
    - stream – Hydro-flattening break line bank line strings
    - stream_islands – Hydro-flattening island break line line strings
    - data_extent – Project data extent shape file
    - flightline_index – Project flight lines shape files
    - tile_index – Project tile index shape files
    - control_points – Ground control shape files

- **report** – Project report PDF format
6 Setbacks and Solutions

During the production of the data sets for the preceding blocks, setbacks were encountered, with a varying impact on production time. Along with these setbacks, new methods of production were created to account for any necessary changes to improve the quality of the data set or save time when amending the data set. These setbacks impacted the delivery date of Block A and other areas.

6.1 Missing ground points under vegetation and low vegetation classification difficulties

During the processing of all Waikato Blocks it is noted there are areas of dense vegetation which limit and often prevent laser penetration to the ground surface. In these situations, it is common for data voids to appear in the DEM surface. In addition, low lying dense vegetation has caused difficulty in assessing the true ground surface. In these situations, it can be difficult to discern if points are part of the ground surface or the lowest part of low-lying vegetation. In these situations, it is common for the ground surface profile to transition to what may or may not be the lowest part of low-lying vegetation. During manual editing, these situations are monitored with the objective being to make the best interpretation of ground.

6.2 Production Delays to Block A

During production, it was determined a new technical team within Woolpert’s US and Australian offices was necessary to continue production on the project. This handover from the previous team created project delivery delays as the new team became familiar with the project specifications as well as to address quality assurance workflow requests made by the prime contractor.

6.3 Review Process

Due to uncertainty of deliverable quality and issues associated with the processing procedure Ocean Infinity implemented a layered review process. Woolpert provided the initial DEM and DSM supply along with a results folder. These folders and files were forwarded to Cyient, an independent contractor, for a 100% review. The results of this review were vetted by Ocean Infinity and passed onto Woolpert for their review, comment and repair where deemed necessary. The process has been tracked by a modified LINZ QAQC spreadsheet.

6.4 Data Resupply

After the initial complete supply of data this was followed by extensive QAQC from WRC and LINZ, a number of errors and improvements were required. These were managed and resupplied and tracked using another spreadsheet (Appendix B).
7 Results Acceptance & Signoff

An acceptance and signoff of the project QAQC supervisory review is listed below.

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Table 6: Processing Results Acceptable Signoff

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Appendix A: Lidar Quality Assurance Results

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Provided as separate Documents -
Appendix B

Provided as separate excel spreadsheets.

WRC_Raised_Defect_Tracking_Block_A_v001_20230222-AAM-Responses
AU411 WRC_Raised_Defect_Tracking_Block_A_v002_20230322
Document Control

Woolpert Inc. Representative

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<tr>
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<tr>
<td>Position</td>
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<tr>
<td>Address</td>
<td>333 North Alabama St. Suite 200</td>
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Ocean Infinity Supervisor

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<tr>
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Ocean Infinity Project Manager

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<tr>
<th>Name</th>
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<tr>
<td>Email</td>
<td><a href="mailto:luke.leydon@oceaninfinity.com">luke.leydon@oceaninfinity.com</a></td>
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Client Representative

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<tr>
<td>Address</td>
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1 Introduction

Lidar survey projects are broken into three distinct phases. The survey commences with the data acquisition project phase. For matters pertaining to this phase of the project, refer to the document


The next phase of the project is the Geopositioning phase, which involves processing the raw sensor and trajectory data to produce a set of point clouds for each flight line.

The point clouds have several geometric optimizations performed, to optimise the relative and absolute spatial accuracy levels.

At completion of the Geopositioning phase, the point cloud geometry is final, and the point cloud classification and production generation project phases follow.

For matters pertaining to this phase of the project, refer to the documents

- AU411_Lidar_Geopos_QAQC_Reports_Waikato_Blocks_15062022
- AU411_Lidar_Geopos_QAQC_Reports_Waikato_Entirety_09092022

The following report covers the data processing project phase and describes the data processing methods used for the lidar classification and product generation, along with the QAQC procedures and results.

This report illustrates compliance with the LINZ PGF specifications sections 6 – 9.

This report pertains to the coverage of Block B - Remainder, as illustrated in yellow in Figure 1 - Waikato Survey.

This report has been revised after the data was resupplied on Saturday 29 October 2022. The initial provision of data failed QAQC by Waikato Regional Council (WRC). A defect tracking spreadsheet was created and amended over the period between initial supply and resupply. In total there were 31 defect issues identified and dealt with. Thanks goes to the WRC Team of Bryan Clements, Dan Borman and Ross Martin for their hard work and perseverance.

This report was further revised after V2 of the defect spreadsheet was provided by WRC and issues addressed by Woolpert / AAM. A copy has been included in the Appendices.
2 LiDAR Data Processing and Handling

The LiDAR data processing method is described in the Project Method Statement, AU411-FOR-008-R5 Project Method Statement_WLASS. The following sections elaborate further but focus on adherence with compliance to the Linz PGF Specification (JAN 2020).


QAQC steps for various workflow tasks have been tracked and recorded and included as an embedded document within Appendix 1.

2.1 The ASPRS LAS File format

LINZ PGF specification 6.1 requires that all point deliverables are required to be fully compliant with LAS Specification Version 1.4, using Point Data Record Format (PDRF) 6, 7, 8, 9 or 10 (referred to as LAS v1.4).

For this project, LAS 1.4 with PDRF 6 is to be delivered.

The LAS files created during the project during the Geopositioning phase and subsequent data cleaning and deliverable products are in ASPRS LAS 1.4 format, with PDRF 6. This was specified during the creation of the project in TerraScan, as shown in a representative image in the figure below:

![Figure 2: LAS 1.4 being specified during project](image-url)

---

IXblue / OI Project No: 411 LiDAR Processing Report – Block B Remainder – Rev3
Figure 3: Project settings used in TerraScan project when importing points into the project.

The correct format of LAS is illustrated by use of LASTools, which shows the LAS files are in 1.4 format in the figure below.

![Attributes to store](image)

Figure 4: Confirmation of LAS 1.4 being the file format of handover laser point files using LASTools

To verify that the project deliverables are in the correct LAS file format/version with PDRF, LP360 File Analyst was used. File Analyst performs exhaustive testing on the LAS file header and data records, and outputs the analysis results to an excel spreadsheet. As there are many tiles in the project area, the analysis results from LP360 are included as an imbedded document within Appendix A.

2.2 Time stamp of navigational data

LINZ PGF specification 6.2 requires that Each Global Navigation Satellite System (GNSS) aircraft positional measurement must be time stamped using Adjusted Global Positioning System (GPS) Time, at a precision enough to allow unique timestamps for each LiDAR pulse.

For this project, LAS 1.4 with PDRF 6 has been delivered including, with Global Encoding bit set to 1.

An example of how adjusted GPS time is visualized and monitored is illustrated in Figure 5: LAS point attributes being shown as class, flightline, GPS time stamp, Northing and Easting (left-to-right).

To verify GPS time is set to adjusted GPS time, LP360 File Analyst was used. File Analyst performs exhaustive testing on the LAS file header and data records, and outputs the analysis results to an excel spreadsheet. The Lidar technical manager reviewed this analysis to ensure that all deliverable LAS files are compliant. As there are many tiles in the project area, the analysis results from LP360 are included...
as an imbedded document within Appendix A. Figure 5 below shows representative examples of LAS point attributes being shown as class, flightline, GPS time stamp, Northing and Easting (left-to-right).

![Figure 5: Representative examples of LAS point attributes]

**2.3 Datums and coordinate reference system**

LINZ PGF specification 6.3 requires that the required datum for latitude, longitude, and ellipsoid heights is the New Zealand Geodetic Datum 2000. The required vertical datum for normal-orthometric heights is NZVD2016 (Reference 9). Projected data products are to be delivered in NZTM2000 projection (Reference 10) with NZVD2016 normal-orthometric heights.

The Survey Datums, Ground Control, Check Points and Lidar Geopositioning sections of the Project Methodology Statement describes in detail how the data is transformed and connected to the required project datum.

To verify that the correct datum information is recorded in the LAS 1.4 header, LP360 File Analyst was used. File Analyst performs exhaustive testing on the LAS file header and data records, and outputs the analysis results to an excel spreadsheet. The Lidar Phase Manager reviewed this analysis to ensure that all deliverable LAS files have the correct CRS applied in the header. As there are many tiles in the project area, the analysis results from LP360 are included as an imbedded document within Appendix A.

**2.4 Geometric Calibration**

Following initial sensor data processing, a formal reduction process was performed on the data.
Laser point position was calculated by associating the SBET position to each laser point return time, scan angle, intensity, etc. Raw laser point cloud data was created for the whole project area in LAS format. Line-to-line calibrations were then performed for system attitude parameters (pitch, roll, heading), mirror flex (scale) and GPS/IMU drift. Statistical reports were generated for comparison and used to make the necessary adjustments to remove any residual systematic error. These calibration adjustments were performed using a combination of automated and manual corrections to the data to develop the geometrically calibrated data set to be utilized for all downstream processes.

### 2.5 Positional accuracy validation

LINZ PGF specification 6.4 details the positional accuracy verification methods. The Vendor is expected to apply best practice in assessing the project accuracy and achieving compliance with this specification. Before classifying and developing derivative products from the point cloud, the relative vertical, local vertical and horizontal accuracies of the point cloud must be verified. The Vendor must deliver a detailed report of the validation processes used.

Validation of the point cloud positional accuracies is the primary outcome of the Lidar Geopositioning workflow phase, using surveyed ground control & check points. The assessments methods and results of the positional accuracy validation is be reported in the LiDAR Geopositioning QA/QC Report.

### 2.6 Use of the LAS withheld flag

LINZ PGF specification 6.5 requires that outliers, noise points, geometrically unreliable points near the extreme edge of the swath, and other points the Vendor deems unusable must be identified using the Withheld Flag, as defined in the LAS Specification.

Points classified as low noise (coverage class 7) and high noise (coverage class 18) will have the LAS withheld flag set.

To verify that the withheld flag has been correctly set, LP360 File Analyst was used. File Analyst performs exhaustive testing on the LAS file header and data records, and outputs the analysis results to an excel spreadsheet. The Lidar Phase Manager reviewed this analyst to ensure that the Las withheld flag is correctly applied. As there are many tiles in the project area, the analysis results from LP360 are included as an imbedded document within Appendix A.

### 2.7 Use of the LAS v1.4 Overlap Flag

LINZ PGF specification 6.6 requires identifying overage points is not required unless requested by the Contract Authority. However, if overage points are explicitly identified using LAS v1.4, they must be identified using the overlap flag.

Classification of the overlap points was done using TerraScan in Microstation. A macro step was created which allowed for points to be classified with the overlap bit by cutting the scan angle at zero degrees. The step used for the project dataset is illustrated in the figure below. This allowed for the overlap points to be withheld from DEM, DSM and intensity imagery generation. Figure 6 below shows Settings used when cutting overlap in Microstation. Note that the ‘Action’ is on “Set overlap bit.
Verification of appropriate overlap flag application is performed using LP360 File Analyst. File Analyst performs exhaustive testing on the LAS file header and data records, and outputs the analysis results to an excel spreadsheet. The Lidar Phase Manager reviewed this analysis to ensure that all deliverable LAS files are compliant. As there are many tiles in the project area, the analysis results from LP360 are included as an imbedded document within Appendix A.

### 2.8 Point Classification

LINZ PGF specification 6.7 requires Lidar points are classified to the following coverage classes:

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<td>18</td>
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Table 1: Point Classifications
Point cloud classification is performed by automated classification algorithms developed by Woolpert’s senior Lidar analysts and reviewed by the Lidar technical manager.

A first run automatic classification was carried out on the raw LiDAR points using TerraSolid’s TerraScan software to classify the LiDAR points into ground hits and non-ground hits. This results in a greater than 80% correct classification. Some of the steps used within this macro can be found within the screenshot below (Figure 7), including 5 of the 8 ground classification steps used on this data set.

![Figure 7: Automatic classification macro developed for the project area.](image)

As documented by TerraSolid, the ground routine classifies ground points by creating a triangulated surface model iteratively. The routine is best suited for classifying ground in airborne laser data sets and in data sets where there is mainly natural terrain. For classifying ground in mobile data sets where the majority of ground is on hard surfaces, such as roads, use the Hard surface routine instead of the ground routine.

The routine is sensitive to low error points in the point cloud. Therefore, you should run one or more classification steps using the Low points routine before classifying ground. A more complex classification strategy is required for classifying ground in photogrammetric point clouds.

The ground routine starts by selecting local low points that are confident hits on the ground. The initial point selection is controlled with the Max building size parameter. If the maximum building size is, for example, set to 60.0 m, the routine assumes that any 60 by 60 m area has at least one point on the ground level and that the lowest point is on the ground level.

Then, the routine builds a surface model (TIN) from the initial ground points. The triangles in this initial model are mostly below the ground level and only the vertices are touching the ground. In the following iterations, the routine molds the model upwards by adding more and more points. Each added point makes the model following the true ground surface more closely.

The iteration parameters of the routine determine how close a point must be to a triangle plane for being accepted as ground point and added to the model. Iteration angle is the maximum angle between a point, its projection on the triangle plane and the closest triangle vertex. This is the main parameter controlling how many points are classified into the ground class. The smaller the iteration angle, the less eager the routine is to follow variation in the ground level, such as small undulations in terrain or points on low vegetation. Use a smaller angle value (close to 4.0) in flat terrain and a bigger value (close to 10.0) in mountainous terrain.

Iteration distance makes sure that the iteration does not make big jumps upward if triangles
are large. This avoids ground points that are too high, for example within low vegetation or on low buildings.

![Figure 8: Illustration of iteration angle and iteration distance parameters in the ground routine.](image)

![Figure 9: A smaller iteration distance value avoids classification of ground points on low objects.](image)

The iteration angle can be reduced automatically if the triangles become small. This reduces the eagerness to classify more ground points inside small triangles and thus, avoids unnecessary point density of the ground model thus avoiding redundancy of inclusion of unnecessary ground points. Related to this it is common to see default classified points within a classified ground point cloud surface. The iteration angle inside small triangles approaches zero if the longest triangle edge is shorter than a given Edge length value. Furthermore, the iteration can be stopped completely if triangle edges are shorter than a given limit. After completion of the automated classification, a strenuous manual classification was carried out over the required area to edit the points thus minimizing gross classification errors that may have occurred in the automatic classification process.

Each block’s data was checked in a systematic approach to reduce missing important features. Orthogonal views with background orthoimagery, and profile views are used to review the performance of the automatic classification results.

Tools such as ‘Classify using brush’, ‘Classify above line’ and ‘Add Point to Ground’ (all found within TerraScan) were used during manual classification, to achieve classification accuracy meeting project specifications. Before handover files were created, checks were done on the project’s points by viewing statistics within TerraScan as illustrated in the figure below.
<table>
<thead>
<tr>
<th>Class #</th>
<th>Class</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Unclassified</td>
<td>30686649</td>
</tr>
<tr>
<td>2</td>
<td>Ground</td>
<td>19756365059</td>
</tr>
<tr>
<td>3</td>
<td>Low Veg</td>
<td>1066086938</td>
</tr>
<tr>
<td>4</td>
<td>Medium Veg</td>
<td>2894068914</td>
</tr>
<tr>
<td>5</td>
<td>High Veg</td>
<td>4954331584</td>
</tr>
<tr>
<td>6</td>
<td>Building</td>
<td>79988352</td>
</tr>
<tr>
<td>9</td>
<td>Water</td>
<td>15286408</td>
</tr>
<tr>
<td>17</td>
<td>Bridge Deck</td>
<td>556184</td>
</tr>
<tr>
<td>W7</td>
<td>Witheld Low Noise</td>
<td>1673690020</td>
</tr>
<tr>
<td>W18</td>
<td>Witheld High Noise</td>
<td>50629487</td>
</tr>
<tr>
<td>O1</td>
<td>Overlap Unclassified</td>
<td>9850325</td>
</tr>
<tr>
<td>O2</td>
<td>Overlap Ground</td>
<td>7622487971</td>
</tr>
<tr>
<td>O3</td>
<td>Overlap Low Veg</td>
<td>403539841</td>
</tr>
<tr>
<td>O4</td>
<td>Overlap Medium Veg</td>
<td>1025451110</td>
</tr>
<tr>
<td>O5</td>
<td>Overlap High Veg</td>
<td>1751872720</td>
</tr>
<tr>
<td>O6</td>
<td>Overlap Building</td>
<td>28537166</td>
</tr>
<tr>
<td>O17</td>
<td>Overlap Bridge</td>
<td>177654</td>
</tr>
<tr>
<td>OW7</td>
<td>Overlap/Witheld Low Noise</td>
<td>894838077</td>
</tr>
<tr>
<td>OW18</td>
<td>Overlap/Witheld High Noise</td>
<td>10621542</td>
</tr>
</tbody>
</table>

Figure 10: Statistics showing the classes of all the LAS points within the project area.

To keep track of the data cleaning process, a hatching method was used on the DGN within Microstation. It allows the cleaners to systematically mark each tile which has been fully checked and editing, making sure the whole data set has been initially covered.
Figure 11: The green diagonal hatching seen above shows blocks which have been fully checked.

Figure 12: The diagonal hatching seen above shows how the progress was tracked

To verify that only the required coverage classes are present & populated, LP360 File Analyst performs exhaustive testing on the LAS data records, and outputs the analysis results to an excel spreadsheet. Lidar Analysts review this data to ensure that all deliverable LAS files are compliant with the specification coverage classes. Point cloud QAQC/editing is performed by trained Lidar Technicians, under the supervision the Lidar Phase Manager and followed by a dedicated QA/QC team.

2.9 Classification Accuracy

LINZ PGF specification 6.8 requires that non-withheld points must be classified to a classification accuracy level of 2%. No non-withheld points are to remain as class 0.

Realtime Digital Elevation models are generated using Terrascan/Terramodeler are used to verify ground classified points and lidar technicians review the DEMs to find anomalies such as spikes or pits that imply misclassified points and make corrections.

During DEM review profiles are cut across tiles where potential issues are detected. The Lidar Technician scans the profile view to identify if an issue exists and modifies the classification of points as required.

10% of the data tiles are subject to review by a senior analysis or project manager.
After data cleaning was completed, a comprehensive DEM review is performed to visualize the data over large areas for the purpose of identifying anomalies or areas for further investigation. Any potential errors were identified as shown in the red polygons below and later addressed via additional manual editing.

![Red polygons indicating areas for further investigation](image)

*Figure 13: The polygons are areas for further investigation*

The indicated areas were revisited and manually classified as appropriate. Below is an example of an issue identified for further investigation. Multiple revisions of the point cloud were performed to address issues common to the terrain and vegetation cover found within the project AOI. Rugged terrain and heavy vegetation across areas within the AOI commonly created unavoidable laser penetration difficulties as well as areas within the DEM that appear to have a rough surface.

The figures below illustrate such and occurrence. Issues were identified concerning what appeared to be excess noise in areas of gullies. After investigating it was determined the gully areas in question are densely vegetated and located within steep terrain. The sparseness of the consistent ground penetration and steepness of terrain led to points being classified as noise during ground filtering. Additional filtering steps were taken to reclassify points into ground from noise class. The additional ground points added from noise provide improvement to the DEM quality as the points classified from noise to ground were sparsely distributed due to dense vegetation.
Figure 14: Example overhead image of DEM Interpolation

Figure 15: LAS point cloud view from previous figure
Figure 16: Example overhead image of DEM interpolation

Figure 17: LAS Point cloud view from previous figure
2.10 Classification Consistency

LINZ PGF specification 6.9 requires that point classification must be consistent across the entire project. Noticeable variations in the character, texture, or quality of the classification between tiles, swaths, flights, or other unnatural divisions are grounds for rejection of the entire deliverable.

As with classification accuracy there is no analytical means of measuring compliance. As such the classification consistency is reviewed via visual means. To mitigate against inconsistent classification, the following controls were employed:

- Systematic geometric issues that may lead to swath-based inconsistencies are identified by the Lidar Geopositioning process, as documented in the Project Method Statement, specifically in the intraswath, interswath & absolute accuracy analysis steps. Data swaths that do not pass this stage do not progress to later classification steps.
- The automated classification process is a series of classification algorithm tools applied in a macro. The macro is designed and optimised to yield high classification accuracy across the variety of land cover types within the project area. Applying the one, optimised and flexible classification macro delivers consistent classification across the entire project area.
- To avoid tile edge artefacts, all tile-based workflow steps utilise a buffer of lidar points from surrounding tiles. This allows for a better classification of both ground and vegetation points.
- Lidar Technicians are trained to deliver consistent results and use the same visualisation methods/aids. They are supervised by the Lidar Phase Manager and the 10% of classified point cloud tiles are peer reviewed by a dedicated QAQC team.
- DEM tiles are run after classification has been completed to review possible errors in Ground classification.
- Bridges are checked against a bridge shapefile (supplied by LINZ) to correctly identify and classify the bridges.

2.11 Classification Consistency – Priority and Non-Priority blocks

Within the Waikato project area, the areas named Priority Area B and Priority Area E were processed in advance of the larger associated blocks of Remainder Area B and Remainder Area E.

While the priority blocks were processed to the New Zealand National Aerial Lidar Base Specification, some noticeable consistency variation was evident between the priority and associated areas.

The differences consisted of variation of classification in the ground, default, and noise classes as well as some tonal differences between the intensity balancing between blocks. Additional processing was performed within the priority areas to reduce this variation and develop a more consistent product across delivery areas.

The additional processing does not affect the useability of the data and maintains a product within the specifications of the project; however it is noted there are occasional and slight differences in classification density and intensity tone between the priority areas and remainder areas. This has for the most part been mitigated by resupplying the data after it had its intensity compared and balanced against Block B Remainder. The Histogram has been balanced the same as much as possible.
3 LiDAR Hydro-Flattening QAQC

LINZ PGF specification 7.0 details at length the requirements for Hydro flattening of Digital Elevation Models.

The methods for Hydro Break line Digitization, Hydro-Flattening and Hydro-Flattening quality control are described in the Lidar Processing and Data presentation section of the Project Method Statement.

Hydro-flattening generation methods will be detailed in the Processing Report.

The pertinent parts of the specification and the means of identifying the required hydro-flattening features are as follows:

- Permanent islands 5,000 m² or larger must be delineated
- Islands of 5000m² will be included as hole features within the parent hydro-flattening polygon.
- Inland ponds and lakes – water bodies of 10,000m² or greater at the time of collection must be flattened
- Lake polygon features will be precisely digitized using lidar point cloud with supporting background intensity imagery and supported by open-source imagery as reference.
- Inland streams and rivers of >= 30m nominal width (width of water flow in a single channel at time of capture) must be flattened
- Streams/rivers that fulfil the minimum distance requirement will be identified by visual inspection of the point cloud.

Hydro-flattening was performed upon the project dataset, and hydro break lines were used during the creation of digital elevation models. Hydro Flattening digitizing are performed by Lidar technicians, under the supervision of the Lidar technical manager.

The hydrological features were digitised in Microstation using a combination of manual and automatic digitizing (‘Display boundary’ function in TerraModeler). Stream islands that were 5000m² or larger in size.

Figure 18: Example of a hydro-flattened stream with a stream-island.
When hydro-flattening a stream, the following process is used:

Identify a possible stream feature. Measure the width of the stream from bank to bank, and if greater than 30m wide, begin digitizing the feature. If the stream varies in width, the discretion of the geospatial specialist is applied.

Once the stream outline was completed, and that it was confirmed to be a polygon, a shapefile was imported into ArcMap and a centreline was created using the ‘Create Centreline’ script, which generates a centreline based on the stream polygon.

The centrelines were then checked for errors which may have occurred during its creation. It was then exported to Microstation where the centreline was then dropped to a surface (created by surrounding ground points). The tool ‘Force Downstream Flow’ was used to enforce correct elevations for the centreline, ensuring that each point’s height was equal to or less than that of the point before it.

The correct order of point heights was then checked by exporting the co-ordinates out as a text file which would be used for the creation of a new centreline shapefile. Figure 18 shows the example excerpt of river points used to create the centreline after downstream flow was enforced. Figure 19 shows the example highlighted script was used to generate the centreline for the stream within the project’s survey.

![Figure 19: Excerpt of river points used to create the centreline](image)
After the new centreline had been created, it was conflated with the stream’s shape using LP360 within ArcMap. This matched up the elevation of the stream’s outline with that of the centreline. The new stream shape was attached to a DGN and opened in Microstation, exported as co-ordinates, and then read into the project. These points along with ground points were used to output lattice models which show the results of the hydro-flattening. Stream-island break line points were also included to ensure the correct modelling of the stream and its features.

The following settings were used for lattice model creation:

The product undergoes QC by the Lidar Phase Manager and is reviewed for any omissions or blunders. The following project specification are checked against:
• All Hydrologic break lines developed for use in hydro-flattening are in non-tiled ESRI feature class in polylineZ or polygonZ shape file format.

• Water bodies (ponds, lakes, and reservoirs), wide streams and rivers ("double-line"), and other non-tidal water bodies are to be hydro-flattened within the DEM. The resulting pond and lake surfaces will be flat and double line rivers will be flat level bank-to-bank and be gradient.

• It is noted when hydro-flattening streams, significant breaks in water elevation as well as varying degrees of bends in the stream direction will create a triangulated appearance in the DEM. These affects will be minimized to an appropriate extent.

• The entire water surface edge must be at or below the immediately surrounding terrain.

• Hydro-flattening break line feature class use the NZTM2000 projection and NZVD0216 height datum

• Hydro-flattening has applied to all streams that are nominally wider than 30 metres wide, and to all non-tidal boundary waters bordering the project area regardless of size.

• Hydro-flattening shall be applied to all water impoundments, natural or man-made, that are nominally larger than 10000m² in area

• Stream channels should break at road crossings (culvert locations). These road fills should not be removed from the DEM.

• Streams and rivers should NOT break at elevated bridges. Bridges are removed from the DEM. When the identification of a feature such as a bridge or culvert cannot be made reliably, the feature should be regarded as a culvert.

A peer review of the Hydro flattening break line data products as well as the hydro-flattened DEM is performed on 10% of the dataset by an independent analyst or project manager. To distribute and track the progress amongst the editing & QAQC team, an ArcSDE tracker (multiuser database) is employed.

During the QA/QC, it was identified there will be instances of vegetation classifications contained within waterbody polygons. After investigation it was determined much of this occurs from overhanging vegetation from the outside of the hydro features. Occasionally there are instances of vegetation within waterways which is related to islands falling below the required threshold for collection. Additional processing steps were taken to limit the amount of vegetation that exists within the waterway while retaining the overhanging vegetation. This processing step primarily involved classification based on XYZ proximity to existing digitized hydro/island lines. After this process was performed some vegetation classified lidar points will still be present in the waterway.
Figure 22: Pre-filter, overhead view of ground and veg points with hydro lines

Figure 23: Post-filter, overhead view of ground and veg points with hydro lines

Additionally, during QC data review, it was discovered rocks and boulders within rivers are occasionally classified as vegetation. This is typically observed in high relief areas where water flows down steep terrain, i.e., rapids/white-water. Rivers tend to narrow in these areas and will not likely be caught during the aforementioned processing step based on proximity to linework. These points will continue to be classified as vegetation.
Figure 24: Point cloud – boulder filled stream

Figure 25: Imagery – boulder filled stream
4 LiDAR Deliverables QAQC

Section 8 of the LINZ PGF specification details the project reporting, metadata requirements & deliverable requirements.

4.1 Reporting and metadata

4.1.1 Project reports

The following details the reports being delivered for this section of the project:

- **Collection Report** detailing mission planning and flight logs, including dates of collection
- **Details of quality control tests, and conformance against Linz specifications**
  - Refer to AU411_WLASS-Collection_Report-10052021.pdf
- **Survey Report** detailing the collection of all ground control, including the following:
  - Control points used to calibrate and process the LiDAR and derivative data
  - Check sites used to validate the LiDAR point data or any derivative product
  - Refer to AU411-R1-Waikato LiDAR Ground Control Report of Survey.pdf
- **Geopositioning QA/QC Report**, detailing analysis, accuracy assessment and validation of the following:
  - Point cloud data, including a summary of relative (smooth surface repeatability and overlap consistency) and non-vegetated vertical and horizontal local accuracy.
  - QA/QC analysis of the vertical and horizontal local accuracy assessment will include a table of the product data compared to each check site.
  - Refer to AU411_Lidar_Geopos_QAQC_Reports_Waikato_Blocks_15062022
  - AU411_Lidar_Geopos_QAQC_Reports_Waikato_Entirety_09092022.

**Processing Report** (This Document) detailing:

- Classification and product generation procedures including methodology used for break line collection, hydro-flattening break line collection, hydro-flattening processing, DEM & DSM creation, and deliverable generation.
- Details of quality control tests, and conformance against each of the relevant Linz specifications including:
  - Workflow QAQC checklist
  - Pre-Delivery QAQC worksheet as an embedded document

4.1.2 Extents

LINZ PGF specification 8.13 requires that a geo-referenced, digital spatial representation of the detailed extents of each delivered dataset.

The data for Block B - Remainder was captured using Leica TerrainMapper sensors 513 and 559, flown on days 5th, 15th, 27th, 28th, 29th, 30th and 31st January 2021 and days 3rd, 12th, 16th, 17th, 18th, of February 2021 and days 11th, 13th, 21st, 22nd, 23rd, 24th, 25th of March 2021. The extent of Block B Remainder can be seen in Figure 25. The flight lines relating to the area can be seen in Figure 28.

Please note some of the flightlines and associated data that were overlapping with adjoining blocks have been withheld from the supply in this instance. Alternative Block ID shapefile was provided to Waikato on 08 September 2022. The areas have been withheld in order to supply a seamless data set when combined.
This extent was created by creating a surface in Microstation based on all points collected during the survey flight. The tool “Display boundary” was then used to generate the extent, which was then exported into a shapefile and assigned with the necessary horizontal and vertical co-ordinate system.

![Figure 26: Extent of deliverable data for Remainder B (yellow outline)](image)

Note Block B – Priority is on The Northwest Section of this AOI Bordered by yellow and red outlines

### 4.1.3 Flight Lines

LINZ PGF specification 8.1.3 requires that Flightline shapefiles as Esri polylines are required. Each flightline must be assigned a unique File Source ID that is equal to the Point Source ID assigned to each point collected during that flightline.

The Sensor trajectory was imported into Terrascan and edited to split the trajectory into discrete flight lines. Each flight line was then assigned discrete flight line ID, in accordance with the project flight plan. Each Lidar point was assigned a flight line ID by matching against its trajectory, using the Adjusted GPS time stored in both the trajectory and lidar point. The trajectories were exported to ESRI shape file format with a File Source ID attribute populated with the trajectory flight line ID value. This process will ensure that specification 8.1.3 is adhered to.

The image below shows the extend of the area covered.
4.2 Classified point cloud tiles

LINZ PGF specification 8.2 details the requirement for the point cloud deliverables, and how adherence to the specifications is measured is listed below. Point cloud deliverable generation methods will be detailed in the Processing Report. Deliverable QC checks are performed both by Lidar technicians, under the supervision of the Lidar Phase Manager and followed by a review of 10% of the data by an independent analyst or project manager:

(a) Data from all project swaths, returns, and collected points, fully calibrated, adjusted to ground, and classified, by tiles. Project swaths exclude calibration swaths, crossties, and other swaths not used in product generation.

(b) Data is provided in the NZTM2000 coordinate system and the NZVD2016 vertical datum.

(c) Fully compliant LAS v1.4, Point Data Record Format (PDRF) 6-10. All files must have the same PDRF.

(d) Each point includes a Point Source ID linking it to the flight line File Source ID.

(e) Correct and properly formatted georeferenced information (EPSG: 2193 + 7839) as Open Geospatial Consortium (OGC) Well Known Text (WKT) included in all LAS file headers.

(f) File Source ID set to 0 for tiled LAS files.
(g) GPS times recorded as Adjusted GPS Time at a precision sufficient to allow unique timestamps for each pulse.

(h) Points are provided in the order in which they were collected.

(i) Height values reported to three decimal places (nearest mm). (While not significant for accuracy, this supports numerical processing and reduces the number of identical values caused by rounding.)

(j) Intensity values, normalised to 16-bit by multiplying the value by \( \frac{65,536}{\text{intensity range of the sensor}} \) per LAS v1.4. This will result in an intensity range of 0-65,536.

(k) Classification as required by the Contract Authority (Table 4 at a minimum).

(l) Tiled delivery, without overlap, per the project tiling scheme in Section 9 – Tiles.

(m) Files named per Section 9 – Tiles.

The point cloud tiles created for handover underwent multiple alterations before finalization. After the LAS tiles were created in Microstation, LASTools was used to assign the correct global encoding (17), system identifier and file source ID (0). WKT was also added to the LAS metadata, as illustrated in the figure below. The correct height values were also confirmed in LASTools ensuring that three decimal places were being used. The tiles were also named according to the required naming convention which is discussed in Section 6.

![Figure 28: WKT of a LAS file shown by LASTools.](image)

Intensity valued scaled from a range of 100 – 10000 output by HxMap, to full 16-bit dynamic range. Translation value = -100 Scale value = 6.5535

Once the point cloud was classified and was inspected manually in Microstation, the LAS files were loaded into LP360. The global coding, file source ID, WKT, VLRs, file format and LAS version were compared against to the LINZ specifications and after passing QA/QC, the files were renamed in accordance with the LINZ specifications. A condensed version of the LP360's results can be found in the table below. A complete listing of the output from LP360 is included as an embedded document in Appendix A.
Additionally, a pre-delivery script which invokes LASTools was run on all tiles. The script output was imported into a custom Excel Worksheet, which checked specification compliance. For a complete listing of analysis refer to Section 6.1 of this document.

### 4.3 Elevation models

LINZ PGF specification 8.3 details requirements for raster surface model deliverables. The specification and how adherence to the specifications is measured is listed below. Deliverable QC checks are performed both by Lidar technicians, under the supervision the Lidar Phase Manager and followed by a review of 10% of the data by an independent analyst or project manager:

(a) Grid spacing: 1m cell size.
(b) Generated to the limits of the project area
(c) Raster format: Geotiff (.tif)
(d) Geo-reference information (EPSG 2193) in each raster file.
(e) Tiled delivery without overlap.
(f) NOT clipped using polylines for land-water boundaries from national databases (for example coastlines, river or lake boundaries) as these can be inaccurate and subject to continual geomorphic change.
(g) Tiles with no edge artefacts or mismatch. A quilted appearance in the overall surface can be grounds for rejection of the entire deliverable - whether the rejection is caused by differences in processing quality or character among tiles, swaths, flights, or other unnatural divisions.
(h) Void areas (for example, areas outside the project area but within the project tiling scheme such as offshore water) coded using “NODATA” value equal to -9999. This value must be identified in the appropriate location within the raster file header.

(i) Constrained with any additional break lines required by the Contract Authority, such as stopbanks, streams, and narrower rivers.

(j) Provided in the NZTM2000 coordinate system and the NZVD2016 vertical datum. Additional vertical datums may be specified by the Contract Authority.

4.3.1 Bare-Earth Digital Elevation Models (DEM)

LINZ PGF specification 8.3.1 details additional requirements for Digital Elevation Models. The Bare-Earth DEM is the bare earth that has been classified and edited to remove vegetation and man-made structures within the bounds of the classification accuracy requirements. It must also include or conform to the following:

(a) Based on Classification level 2 or better ground return points.

(b) Hydro-flattening as outlined in Section 7 - Hydro-Flattening.

(c) Bridges removed from the surface, while culverts are treated as ground

(d) Method for removal of buildings, structures or other ground cover/vegetation and interpolation techniques documented.

The Digital Elevation Models were created using a combined model based on both ground surface points and break line points. These break line points were created during the hydro-flattening process mentioned in Section 4. By using these classes, a true representation of the ground points can be achieved while still maintaining a smooth water surface which gradually follows the terrain.

To generate DEMs, LAS format data files are loaded into TerraScan, only loading in class 2 points and breaklines. Additional data is referenced to avoid tile edge artefacts. Following import, TerraScan-Export Lattice Model command is used to create a grid file with uniform distances between points from one or more selected point classes. For each grid point, the lattice model file stores XY coordinates and elevation. Within the Export Lattice Models command we utilize “Triangulated model Z” to export the DEM tiffs. This triangulated model z derives an elevation value that is calculated from a TIN model of the lidar points using ground and breakline classifications.

The elevation grid is generated as a TerraScan Lattice model using the following settings:

- Grid Method = TIN Model (Triangulated model Z)
- Grid Spacing = 1 meter

Following Lattice model export, the data was processed using Esri to produce GeoTiff files.

The tiles were loaded into LP360 to check the metadata of the images during both production and QA/QC of the deliverables. A Representative version of LP360’s findings is found in the table below. A complete listing of the LP360 results is included as an embedded document in Appendix 1.
4.3.2 Digital Surface Models (DSM)

LINZ PGF specification 8.3.2 details additional requirements for Digital Surface Models. The DSM is the heights of the top of the highest feature at each gridpoint, including ground, vegetation, and man-made structures. The DSM is based on first return points after removal of noise.

LAS format data files are loaded into Terrascan only loading in First, First-of-many and Single returns. Additional data is loaded to avoid tile edge artefacts. Only coverage classed 1 to 6 & 17 points will be used in generation of Digital Surface Models. The elevation grid is generated as a TerraScan Lattice Model using the following settings:

- Grid Method = Binning (Maximum Value – DSM)
- Grid Spacing = 1 metre

Following Lattice model export, the data was processed using Esri to produce GeoTiff files.

To meet the request to produce a DSM representative of the heights of the top of the highest feature at each grid point while incorporating hydro features, the hydro features used to create the DEM deliverables were included to produce a hydro flattened DSM.

Hydro-flattened DEM tiles are overlaid against the DSM tiles to identify and fill gaps in the data (such as the river), and then the tiles were exported in GeoTiff format including settings for the datums and null data specifications, using the tile grid to clip & name the data files. The DSM deliverables undergo a visual spot check using Globalmapper.

In areas where valid data gaps (e.g. waterbodies) do not meet the LINZ specification for hydro-flattening the surface model will triangulate across these voids to the nearest point per pixel (highest for DSM & lowest for DEM). No intervention is made to flatten or constrain these areas.

Digital surface models are created by combining points with only a single return, and points that have the first return of many (returns) and are then used to generate the DSM model. Figure 28 is an excerpt of one of the DSM tiles created for the project area.

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<td>EPSG: 2193</td>
</tr>
<tr>
<td>DEM_BC33_2021_1000_0343.tif</td>
<td>GTiff</td>
<td>-9999</td>
<td>32</td>
<td>1</td>
<td>FLOAT</td>
<td>1</td>
<td>EPSG: 2193</td>
</tr>
<tr>
<td>DEM_BC34_2021_1000_2326.tif</td>
<td>GTiff</td>
<td>-9999</td>
<td>32</td>
<td>1</td>
<td>FLOAT</td>
<td>1</td>
<td>EPSG: 2193</td>
</tr>
<tr>
<td>DEM_BC34_2021_1000_4237.tif</td>
<td>GTiff</td>
<td>-9999</td>
<td>32</td>
<td>1</td>
<td>FLOAT</td>
<td>1</td>
<td>EPSG: 2193</td>
</tr>
<tr>
<td>DEM_BD32_2021_1000_0729.tif</td>
<td>GTiff</td>
<td>-9999</td>
<td>32</td>
<td>1</td>
<td>FLOAT</td>
<td>1</td>
<td>EPSG: 2193</td>
</tr>
<tr>
<td>DEM_BD32_2021_1000_3043.tif</td>
<td>GTiff</td>
<td>-9999</td>
<td>32</td>
<td>1</td>
<td>FLOAT</td>
<td>1</td>
<td>EPSG: 2193</td>
</tr>
<tr>
<td>DEM_BD33_2021_1000_1509.tif</td>
<td>GTiff</td>
<td>-9999</td>
<td>32</td>
<td>1</td>
<td>FLOAT</td>
<td>1</td>
<td>EPSG: 2193</td>
</tr>
<tr>
<td>DEM_BD33_2021_1000_3618.tif</td>
<td>GTiff</td>
<td>-9999</td>
<td>32</td>
<td>1</td>
<td>FLOAT</td>
<td>1</td>
<td>EPSG: 2193</td>
</tr>
<tr>
<td>DEM_BD34_2021_1000_1025.tif</td>
<td>GTiff</td>
<td>-9999</td>
<td>32</td>
<td>1</td>
<td>FLOAT</td>
<td>1</td>
<td>EPSG: 2193</td>
</tr>
<tr>
<td>DEM_BD34_2021_1000_2025.tif</td>
<td>GTiff</td>
<td>-9999</td>
<td>32</td>
<td>1</td>
<td>FLOAT</td>
<td>1</td>
<td>EPSG: 2193</td>
</tr>
<tr>
<td>DEM_BD35_2021_1000_0104.tif</td>
<td>GTiff</td>
<td>-9999</td>
<td>32</td>
<td>1</td>
<td>FLOAT</td>
<td>1</td>
<td>EPSG: 2193</td>
</tr>
</tbody>
</table>
Figure 29: Excerpt from DSM_BD35_2021_1000_2144.

The tiles created are in GeoTiff floating 32-bit format and have been adjusted to display a NoData value of -9999 (Figure 29). The composite DSM was produced in 32-bit GeoTiff format as requested and both the tiles and the composite had the correct horizontal and vertical co-ordinate systems assigned to the metadata in ArcMap.

Figure 30: Script used in ArcMap to achieve a NoData value of -9999.

<table>
<thead>
<tr>
<th>Format</th>
<th>IMAGINE Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source Type</td>
<td>Generic</td>
</tr>
<tr>
<td>Pixel Type</td>
<td>floating point</td>
</tr>
<tr>
<td>Pixel Depth</td>
<td>32 Bit</td>
</tr>
<tr>
<td>NoData Value</td>
<td>-9999</td>
</tr>
</tbody>
</table>

Figure 31: Properties of the composite DSM file showing its format and NoData value

After these files were amended, they were loaded into LP360 to check the necessary metadata of the imagery. The results from LP360 can be found in the table below. A complete listing of the LP360 results are included as an embedded document in Appendix 1.
4.4 Break lines

LINZ PGF specification 8.4 details requirements for hydro-flattening break lines. Delivery of break lines representing all hydro-flattened features in a project is required. Additional break lines may also be required by the Contract Authority. These are to be delivered as ESRI Shape files (.shp) using the NZTM2000 projection.

Refer to section 7.0 of this document. The workflow methods will be documented in the project Processing Report. The digitized hydro features were included in the handover data set, under the Vector deliverable section. They are in shapefile (.shp) format and are in the NZTM2000 projection. Stream and stream-island, lake and lake island break lines were delivered, with ocean features falling under the “Lake” feature category due to its uniform height. In figure 31 the geometry type is set to a polygon shape and has vertical and horizontal co-ordinate sets as well as Z values.

<table>
<thead>
<tr>
<th>File</th>
<th>Format</th>
<th>NoData Value</th>
<th>Bands</th>
<th>Data Type</th>
<th>Pixel Size</th>
<th>Coordinate System</th>
</tr>
</thead>
<tbody>
<tr>
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<td>-9999</td>
<td>32</td>
<td>FLOAT</td>
<td>1</td>
<td>EPSG: 2193</td>
</tr>
<tr>
<td>DSM_BB33_2021_1000_4043.tiff</td>
<td>GTiff</td>
<td>-9999</td>
<td>32</td>
<td>FLOAT</td>
<td>1</td>
<td>EPSG: 2193</td>
</tr>
<tr>
<td>DSM_BC33_2021_1000_0034.tiff</td>
<td>GTiff</td>
<td>-9999</td>
<td>32</td>
<td>FLOAT</td>
<td>1</td>
<td>EPSG: 2193</td>
</tr>
<tr>
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<td>GTiff</td>
<td>-9999</td>
<td>32</td>
<td>FLOAT</td>
<td>1</td>
<td>EPSG: 2193</td>
</tr>
<tr>
<td>DSM_BC34_2021_1000_4237.tiff</td>
<td>GTiff</td>
<td>-9999</td>
<td>32</td>
<td>FLOAT</td>
<td>1</td>
<td>EPSG: 2193</td>
</tr>
<tr>
<td>DSM_BB32_2021_1000_0729.tiff</td>
<td>GTiff</td>
<td>-9999</td>
<td>32</td>
<td>FLOAT</td>
<td>1</td>
<td>EPSG: 2193</td>
</tr>
<tr>
<td>DSM_BB32_2021_1000_1034.tiff</td>
<td>GTiff</td>
<td>-9999</td>
<td>32</td>
<td>FLOAT</td>
<td>1</td>
<td>EPSG: 2193</td>
</tr>
<tr>
<td>DSM_BB33_2021_1000_1509.tiff</td>
<td>GTiff</td>
<td>-9999</td>
<td>32</td>
<td>FLOAT</td>
<td>1</td>
<td>EPSG: 2193</td>
</tr>
<tr>
<td>DSM_BB33_2021_1000_3618.tiff</td>
<td>GTiff</td>
<td>-9999</td>
<td>32</td>
<td>FLOAT</td>
<td>1</td>
<td>EPSG: 2193</td>
</tr>
<tr>
<td>DSM_BB34_2021_1000_1025.tiff</td>
<td>GTiff</td>
<td>-9999</td>
<td>32</td>
<td>FLOAT</td>
<td>1</td>
<td>EPSG: 2193</td>
</tr>
<tr>
<td>DSM_BB34_2021_1000_2025.tiff</td>
<td>GTiff</td>
<td>-9999</td>
<td>32</td>
<td>FLOAT</td>
<td>1</td>
<td>EPSG: 2193</td>
</tr>
<tr>
<td>DSM_BB35_2021_1000_0104.tiff</td>
<td>GTiff</td>
<td>-9999</td>
<td>32</td>
<td>FLOAT</td>
<td>1</td>
<td>EPSG: 2193</td>
</tr>
</tbody>
</table>

Table 4: LP360 Results example table

Figure 32: Stream break line properties in ArcMap.
4.5 GNSS data

GNSS data is not a required deliverable for this project.

4.6 Backed up project source data

LINZ PGF specification 8.6 details the requirements for archival and storage of the project data. Raw project source data, such as native format LiDAR files and point cloud swaths, are NOT required for delivery; however, a copy has been provided to CoLAB. It is acknowledged that the Vendor must hold a copy of all relevant raw project data, for a minimum of five years beyond the final delivery of the project deliverables. The vendor must provide this data, with unrestricted copyright, to the Contract Authority on request. The vendor may charge a reasonable access and distribution charge in such instances.

Woolpert and Ocean Infinity will archive all raw & processed data collected for 5 years following project completion.

4.7 Contours

Contours with an interval of 0.5m will be generated for project areas using Terramodeler and generated using the following settings:

Note Contours will be generated at Project conclusion to ensure there are no line breaks between blocks.

![Contour key points settings used in Terrascan.](image)

Once these contours are generated, they are extracted out as shapefiles and imported into Global Mapper and the attributes Elevation, INDEX2P5, INDEX10 & INDEX100 added. Each contour is then assigned a "Y" or "N" value depending on the elevation of that contour. These contours are then tiled out according to the LINZ tile specification, and once reviewed in ArcMap they are placed into a geodatabase using ArcGIS Pro for QA/QC and then delivery.
5 LiDAR QA Tiles

LINZ PGF specification 9.1 & 9.2 detail the requirements for project tiles geometry & naming convention.

(a) NZTopo50 subtitles based on NZTM2000 coordinates. The 1-m gridded raster products and point clouds must be delivered at 1:1000 nominal scale (2500 720m high x 480m wide subtiles per full NZTopo50 sheet).

(b) The origin of the raster tiles must be placed on a whole metre coordinate value of the south-west corner of each tile (for example, 5429500 mN_174 90300mE).

(c) The tiled deliverables must edge-match seamlessly and without gaps.

(d) The tiled deliverables must conform to the project tiling scheme without overlap.

(e) File naming must conform with the naming convention described in section 9.2.

A Tile Index must be provided in ESRI shape file format. The file name must be included as an attribute in the Tile Index file.

The Client supplied tiling grid shape file will be used as the tile clipping polygon when exporting the deliverable products. The shape file will have an attribute added for each deliverable type as specified in section 9.2. This attribute will contain the required tile name for each deliverable. This shape file will be used as the means of extracting all project data deliverables, so that the geometric aspects for specification 9.1, and the naming requirements of section 9.2 are fulfilled.

Deliverable QC checks have been performed both by Lidar technicians, under the supervision the Lidar Phase Manager and followed by a dedicated QA/QC team:

5.1 LAS Tiles QAQC - LASQC

Prior to delivery, Lidar data tiles have undergone a final analysis, using a custom developed Pre-Delivery QAQC tool called LASQC. This tool uses LASTools ‘Lasinfo’ in a batchscript called LASExtract, which collates information regarding each tile into an Excel worksheet. The tool analysis and reports compliance on the following items:

- File naming accuracy
- Check to ensure lidar points fall inside the extents bounded by the NZTOPO50/1:1000 tile name
- Adjusted GPS time falling with correct extents for the survey
- LAS file format, version, file source ID, point data record format & scale factor
- Point counts by return, illustrating presence of multiple returns
- Average point density for the tile, excluding overlap
- Presence of the overlap (not applicable to all tiles) & withheld flags
- Minimum, maximum & average intensity values.
- Height above ground for building, low, medium & high vegetation classes
Note it should be noted that this analysis is not accurate in steep terrain due to the different methods used for triangulation of between Terrascan & LASTools.

- Check for presence of correct ESPG Codes for geodetic & vertical datums, and map projection
- Raster Overviews for Point Source ID, Intensity, Point Density and Overlap Analysis

These analysis results will be included as an attachment referenced in Appendix A.

### 5.2 File naming

Project deliverables have been named in accordance with the project specification illustrated in Table 5.

<table>
<thead>
<tr>
<th>Naming Convention for point clouds, DEMs, and other tiled products</th>
</tr>
</thead>
<tbody>
<tr>
<td>[product]<em>[sheet]</em>[year]<em>[scale]</em>[tile]_[ext]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Product</th>
<th>DEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>CL2-Point Cloud Classification Level 2</td>
<td></td>
</tr>
<tr>
<td>DEM-Bare Earth Digital Elevation Model</td>
<td></td>
</tr>
<tr>
<td>DSN-Digital Surface Model</td>
<td></td>
</tr>
<tr>
<td>DTM-Digital Terrain Model</td>
<td></td>
</tr>
<tr>
<td>UNC-Unclassified Point Cloud</td>
<td></td>
</tr>
<tr>
<td>INT-Intensity Image</td>
<td></td>
</tr>
<tr>
<td>CHM – Canopy Height Model</td>
<td></td>
</tr>
<tr>
<td>IMG-Aerial photography</td>
<td></td>
</tr>
<tr>
<td>etc</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sheet</th>
<th>BK34</th>
<th>LINZ Topo50 identifier (4 characters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>2016</td>
<td>Year of survey commencement</td>
</tr>
<tr>
<td>Scale</td>
<td>1000</td>
<td>Nominal scale of NZTopo50 subtiles</td>
</tr>
<tr>
<td>Tile</td>
<td>4118</td>
<td>Row number (41), Column number (18) of tile with respect to an upper left origin</td>
</tr>
<tr>
<td>ext</td>
<td>tif</td>
<td>File extension according to format conventions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>las</td>
</tr>
<tr>
<td></td>
<td></td>
<td>tif</td>
</tr>
<tr>
<td></td>
<td></td>
<td>shp</td>
</tr>
<tr>
<td></td>
<td></td>
<td>etc</td>
</tr>
</tbody>
</table>

For example: DEM_BK34_2016_1000_4118.tif

*Table 5: File Naming*
5.3 Delivery Folder

The project deliverables are structured in the following manner:

```
raster
├───
│   └───
│       └───
│           └───
│               └───
│                   └───
│                       └───
│                               └───
│                                                   └───
│                                           dsm_tiles – Digital Surface Models geotiff format tiles
│                                           dem_tiles – Digital Elevation Models geotiff format tiles
las – Lidar Point Cloud Las 1.4 format tiles

vector
├───
│   └───
│       └───
│           └───
│               └───
│                   └───
│                               └───
│                                           └───
│                                               └───
│                                                   └───
│                                           contours_smoothness_25.gdb – 50cm Contours Geodatabase
shapefiles
│   └───
│       └───
│           └───
│               └───
│                   └───
│                               └───
│                                           └───
│                                               └───
│                                                   └───
│                                           hydroflattening_shapefiles
│   └───
│       └───
│           └───
│               └───
│                   └───
│                               └───
│                                           └───
│                                               └───
│                                                   └───
│                                           stream – Hydro-flattening break line bank line strings
│   └───
│       └───
│           └───
│               └───
│                   └───
│                               └───
│                                           └───
│                                               └───
│                                                   └───
│                                           stream_islands – Hydro-flattening island break line line strings
│   └───
│       └───
│           └───
│               └───
│                   └───
│                               └───
│                                           └───
│                                               └───
│                                                   └───
│                                           data_extent – Project data extent shape file
│   └───
│       └───
│           └───
│               └───
│                   └───
│                               └───
│                                           └───
│                                               └───
│                                                   └───
│                                           flightline_index – Project flight lines shape files
│   └───
│       └───
│           └───
│               └───
│                   └───
│                               └───
│                                           └───
│                                               └───
│                                                   └───
│                                           tile_index – Project tile index shape files
│   └───
│       └───
│           └───
│               └───
│                   └───
│                               └───
│                                           └───
│                                               └───
│                                                   └───
│                                           control_points – Ground control shape files
│   └───
│       └───
│           └───
│               └───
│                   └───
│                               └───
│                                           └───
│                                               └───
│                                                   └───
│                                           report – Project report PDF format
```
6 Setbacks and Solutions

During the production of the data sets for the Block B Remainder area, setbacks were encountered, with a varying impact on production time. Along with these setbacks, new methods of production were created to account for any necessary changes to improve the quality of the data set or save time when amending the data set.

6.1 Missing ground points under vegetation and low vegetation classification difficulties

During the processing of all Waikato Blocks it is noted there are areas of dense vegetation which limit and often prevent laser penetration to the ground surface. In these situations, it is common for data voids to appear in the DEM surface. In addition, low lying dense vegetation has caused difficulty in assessing the true ground surface. In these situations, it can be difficult to discern if points are part of the ground surface or the lowest part of low-lying vegetation. In these situations, it is common for the ground surface profile to transition to what may or may not be the lowest part of low-lying vegetation. During manual editing, these situations are monitored with the objective being to make the best interpretation of ground.

6.2 Production Delays to Block B

During production, it was determined a new technical team within Woolpert’s US and Australian offices was necessary to continue production on the project. This handover from the previous team created project delivery delays as the new team became familiar with the project specifications as well as to address quality assurance workflow requests made by the prime contractor.

6.3 Review Process

Due to uncertainty of deliverable quality and issues associated with the processing procedure Ocean Infinity implemented a layered review process. Woolpert provided the initial DEM and DSM supply along with a results folder. These folders and files were forwarded to Cyient, an independent contractor, for a 100% review. The results of this review were vetted by Ocean Infinity and passed onto Woolpert for their review, comment and repair where deemed necessary. The process has been tracked by a modified LINZ QAQC spreadsheet.

6.4 Delivery not Meeting Specification

The original supply of data included filenames that did not meet specification. This was rectified by a resupply. There was also an issue with missing Z values in the hydroflattening shapefiles – this too was resupplied. There was also issue where Woolpert have withheld parts of the AOI which intersect with adjoining AOI’s. An alternative block ID Shapefile has been provided.
6.5 Failure of QAQC undertaken by WRC

This data set was extensively QAQC’d by WRC staff. As previously mentioned, Thanks must go to this team for their work.

A defect tracking spreadsheet was created and amended over the period between initial supply and resupply. In total there were 31 defect issues identified and dealt with. This was an effective means of tracking the defects and their unique solutions.

A new LiDAR Manager – Luke Graham (AAM – A Woolpert Company) has been tasked with all the Waikato non-priority blocks, his input has had a positive influence on the project, and he has made changes to workflows and procedures which should not see the same issues reproduced in future deliveries.

It is noted that as of 10 November further defects have been found, added to the defect spreadsheet and repaired. WRC have advised they will be providing more feedback that will require more rework. As such, this report and appendices will be updated thereafter.

A further defect spreadsheet was provided (V2) the issues contained within were dealt with prior to the latest data supply. A copy with commentary has been included in the appendices.
7 Results Acceptance & Signoff

An acceptance and signoff of the project QAQC supervisory review is listed below.

<table>
<thead>
<tr>
<th>Assessment Criteria</th>
<th>Status</th>
<th>Completed By</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point cloud classification accuracy</td>
<td>Complete</td>
<td>Woolpert</td>
<td>10 August 2022</td>
</tr>
<tr>
<td>Point cloud classification consistency</td>
<td>Complete</td>
<td>Woolpert</td>
<td>20 August 2022</td>
</tr>
<tr>
<td>Point Cloud LAS tiled deliverables</td>
<td>Complete</td>
<td>Woolpert</td>
<td>20 August 2022</td>
</tr>
<tr>
<td>Hydro-flattened Digital Elevation Models</td>
<td>Complete</td>
<td>Woolpert</td>
<td>20 August 2022</td>
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<tr>
<td>Digital Survey Models</td>
<td>Complete</td>
<td>Woolpert</td>
<td>20 August 2022</td>
</tr>
<tr>
<td>Contours</td>
<td>Complete</td>
<td>Woolpert</td>
<td>20 August 2022</td>
</tr>
<tr>
<td>Extents, Flight Lines, Break lines, Tile Index</td>
<td>Complete</td>
<td>Woolpert</td>
<td>20 August 2022</td>
</tr>
<tr>
<td>Project Manager / Supervisor Signoff</td>
<td>Complete</td>
<td>Brian Foster</td>
<td>20 August 2022</td>
</tr>
<tr>
<td>Ocean Infinity Review</td>
<td>Complete</td>
<td>Luke Leydon</td>
<td>09 September 2022</td>
</tr>
</tbody>
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Table 6: Processing Results Acceptable Signoff

<table>
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<th>Date</th>
</tr>
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<td>Woolpert</td>
<td>29 October 2022</td>
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<tr>
<td>Point cloud classification consistency</td>
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<td>Woolpert</td>
<td>29 October 2022</td>
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<tr>
<td>Hydro-flattened Digital Elevation Models</td>
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<td>Woolpert</td>
<td>29 October 2022</td>
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<tr>
<td>Digital Survey Models</td>
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<td>Woolpert</td>
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<tr>
<td>Contours</td>
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<td>29 October 2022</td>
</tr>
<tr>
<td>Extents, Flight Lines, Break lines, Tile Index</td>
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<td>Luke Leydon</td>
<td>10 November 2022</td>
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</table>

Table 7: Processing Results Acceptable Signoff (Revision 1)

<table>
<thead>
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<th>Assessment Criteria</th>
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<th>Completed By</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point cloud classification accuracy</td>
<td>Complete</td>
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<td>29 October 2022</td>
</tr>
<tr>
<td>Point cloud classification consistency</td>
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Table 8: Processing Results Acceptable Signoff (Revision 2)
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*Table 9: Processing Results Acceptable Signoff (Revision 3)*
Appendix A: Lidar Quality Assurance Results

Provided as separate Documents

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