# 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 SHARED SERVICES CoLAB BETTER TOGETHER

Document Date: 8 June 2023

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## Document Revision

| Revision No | Issue Purpose | Prepared | Checked | Approved |
|---|---|---|---|---|
| 0 | Issue Block A LiDAR Processing Report | L Leydon | BF/MM | D Field |
| 1 | Revise | L Leydon | D Field | L Leydon |
| 2 | Revise with latest supply | L Leydon | D Field | L Leydon |
| | | | | |

## Approval for Issue

| Name | Signature | Date |
|---|---|---|
| Luke Leydon | Luke Leydon | 08 June 2023 |

# Revision History

| Item | Description of change | Section | Revision |
|---|---|---|---|
| 1 | Added extra section to introduction | 1.1, | 1 |
| 2 | Added Appendix B | Appendix B | 1 |
| 3 | Overlap flag methodology updated. | 2.7 | 1 |
| 4 | Figure 10 supplemented by additional figure (11) to reflect most recent supply. | Figure 10/11 | 1 |
| 5 | Figure 40 supplemented by additional figure (41) to reflect most recent supply | Figure 40/41 | 1 |
| 6 | Contours methodology changed to reflect AAM methodology | 4.7 | 1 |
| 7 | New flightline shapefile image added. | Figure 42/43 | 1 |
| 8 | Added extra section to introduction with supporting figures | 1.2 | 2 |
| 9 | New LP360 Tables added | Tables 2,3,4 | 2 |
| 10 | New Point Cloud Statistics added | Figure 25 | 2 |
| 11 | Contours methodology removed, under internal discussion, methodology to be presented to WRC and LINZ prior to generation | 4.7 | 2 |
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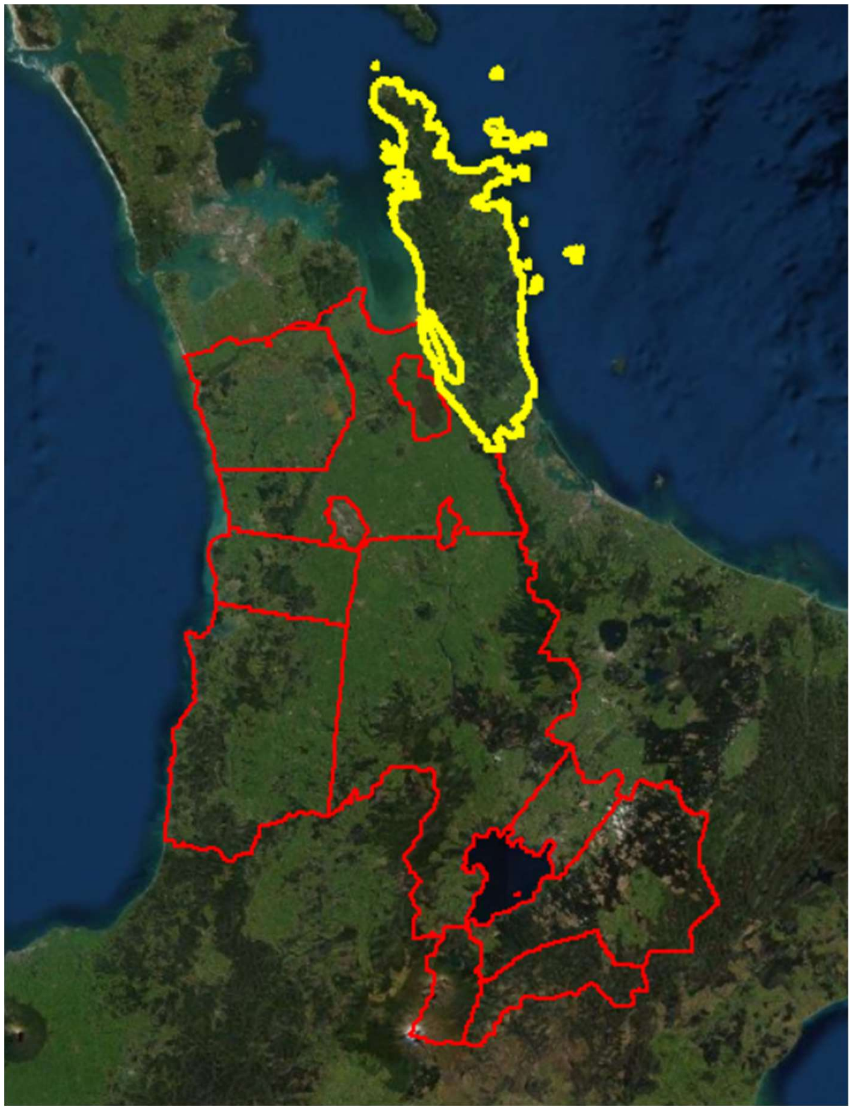

*Figure 1: Waikato Survey Area*

# 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

- AU411_WLASS-Collection_Report-10052021.pdf.

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 23$^{rd}$ 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

DEMs 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

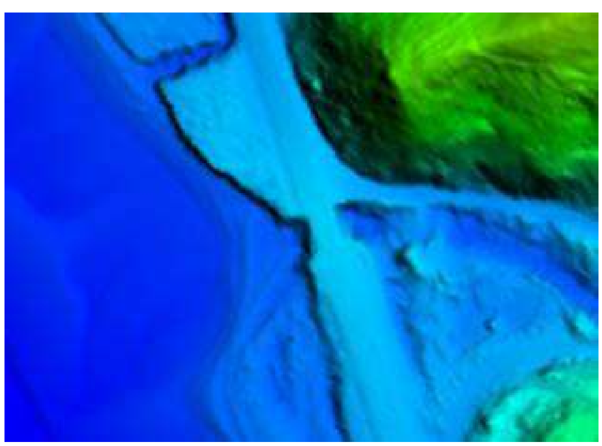

*Figure 2: Tile BA34_4930 Prior to break line*

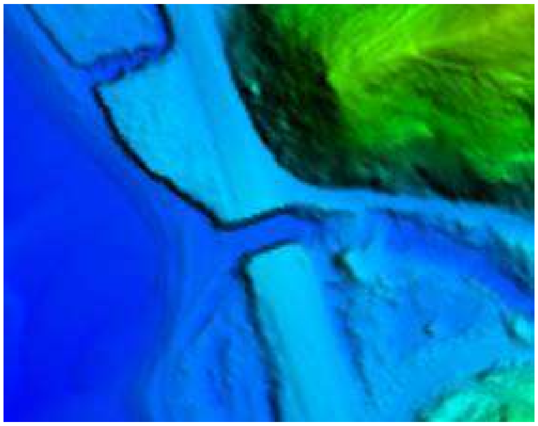

*Figure 3: Tile BA34_4930 After addition of break line*

Boulder/vegetation classification in tile BA34_1935.

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

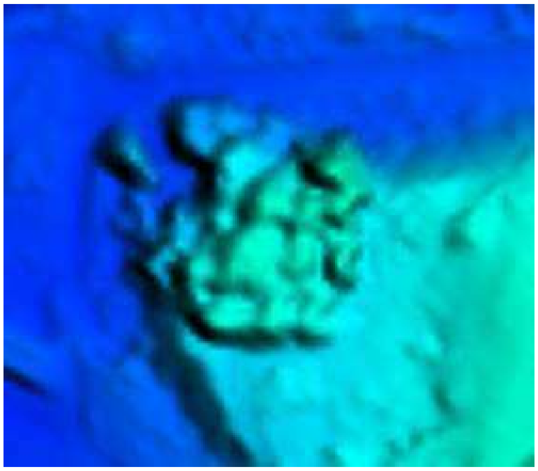

*Figure 5: Boulder/vegetation classification in tile BA34_1935 – Original DEM*

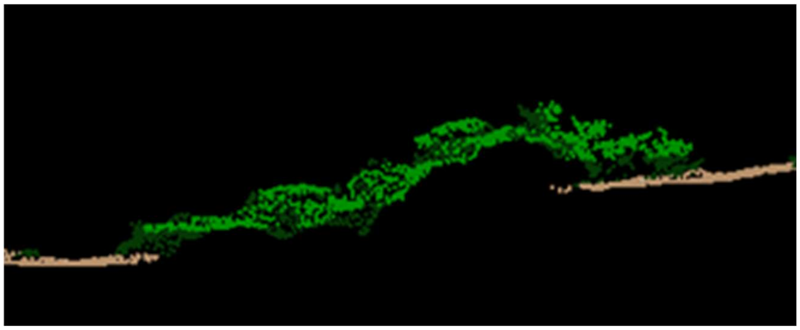

*Figure 6: Boulder/vegetation classification in tile BA34_1935 – After editing Side profile*

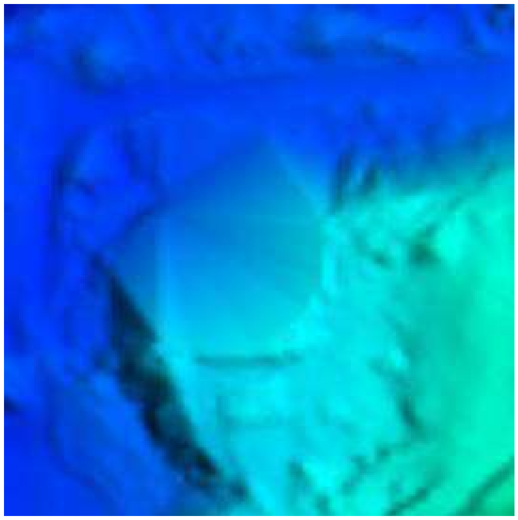

*Figure 7: Boulder/vegetation classification in tile BA34_1935 – After editing DEM*

Noise in tile BA34_2732

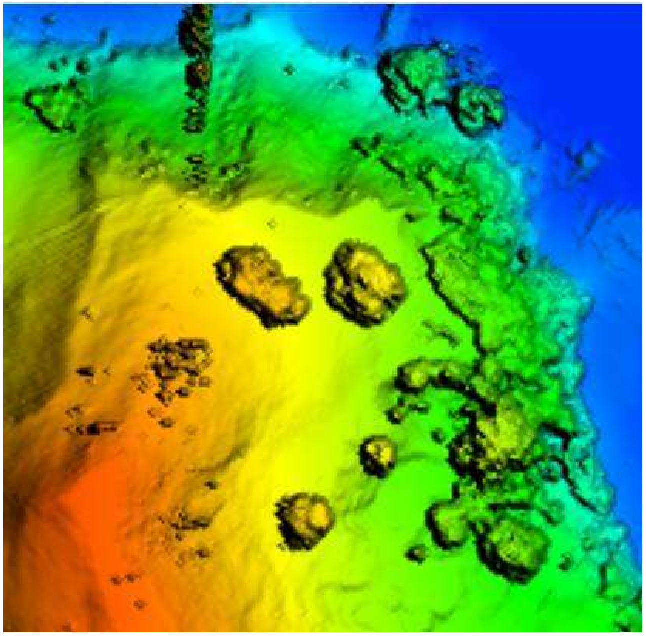

*Figure 8: Tile BA34_2732 Prior to editing*

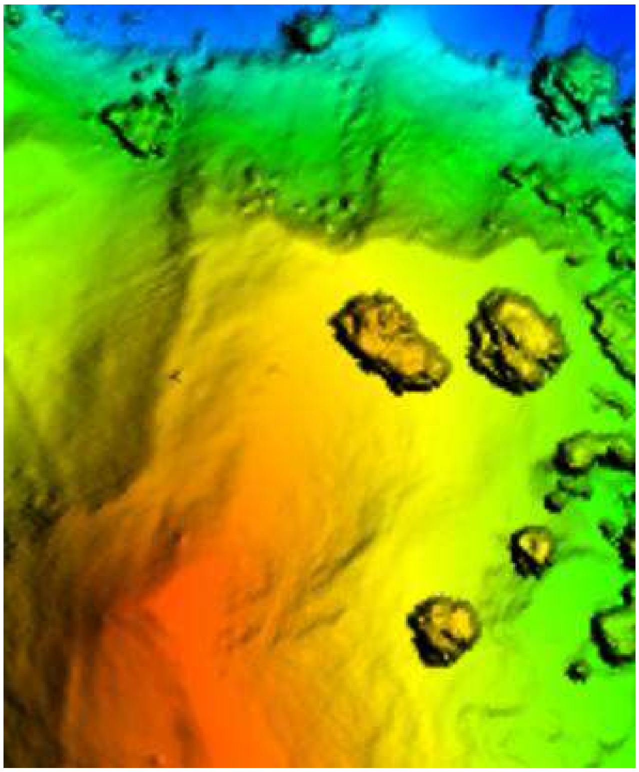

*Figure 9: Tile BA34_2732 Post editing*

Noise in tile BC36_2813

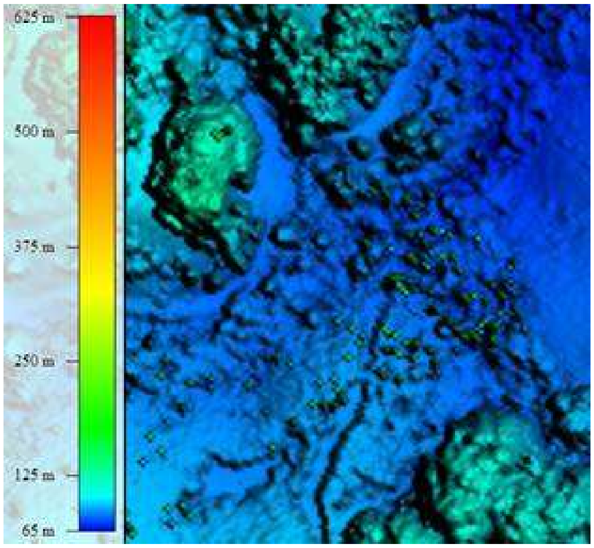


*Figure 10: Tile BC36_2813 prior to editing*

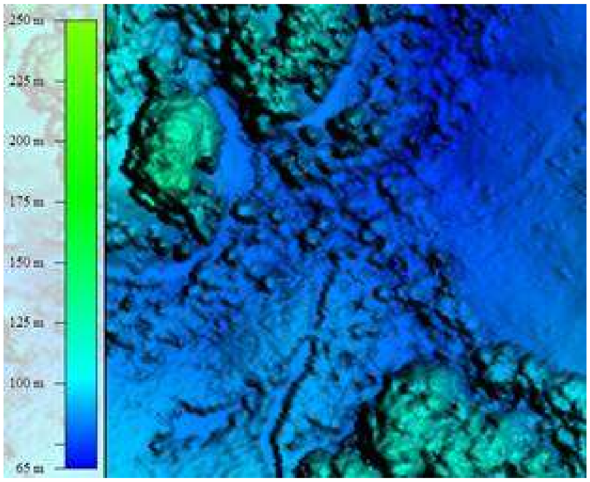


*Figure 11: Tile BC36_2813 post editing*

DSM-DEM difference example highlighting difference exists over cliffs

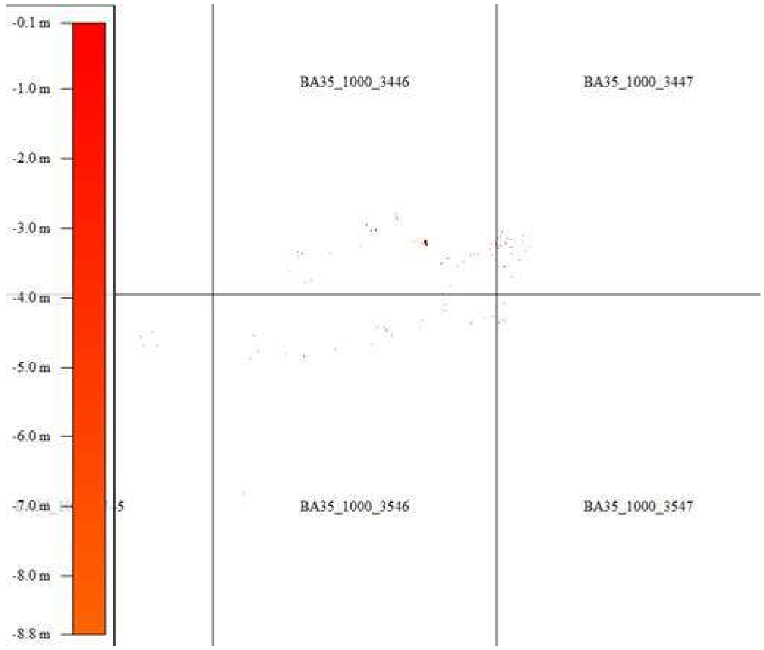


*Figure 12: Tiles BA35_1000_3446, BA35_1000_3447, BA35_1000_3546, BA35_1000_3547*

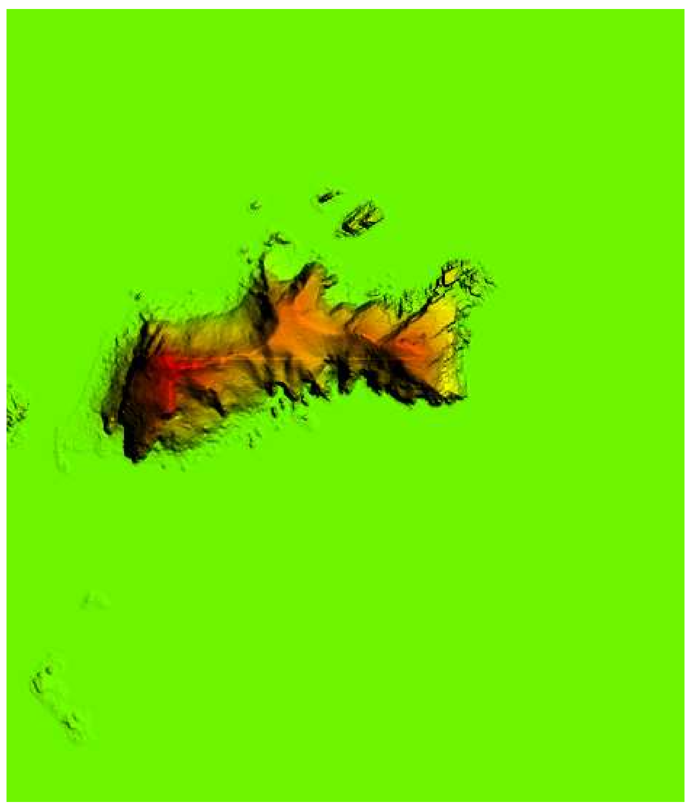

*Figure 13: Same location in DEM*

Swath matching as identified in '128 GEOMETRIC RESULT POINTS.gpkg'

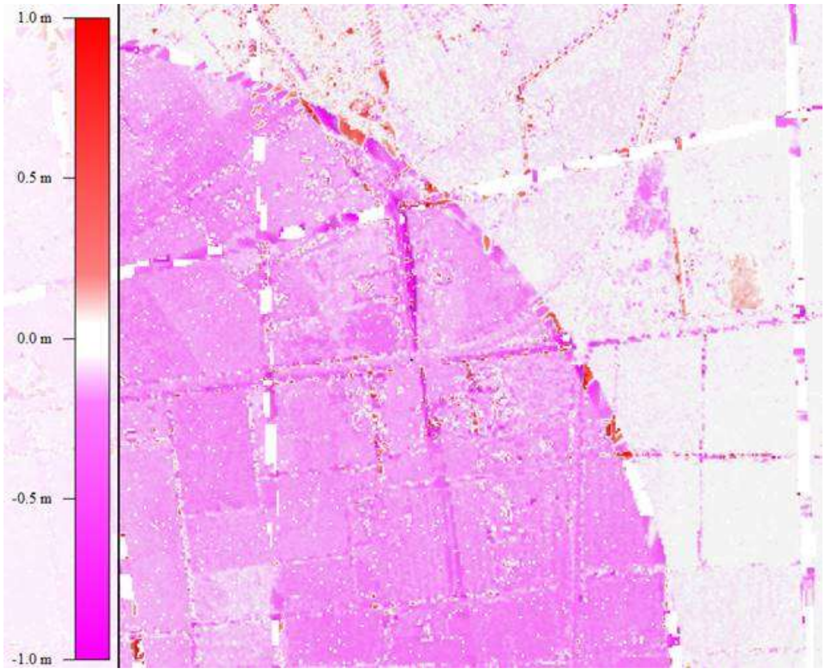


*Figure 14: Prior to repair*

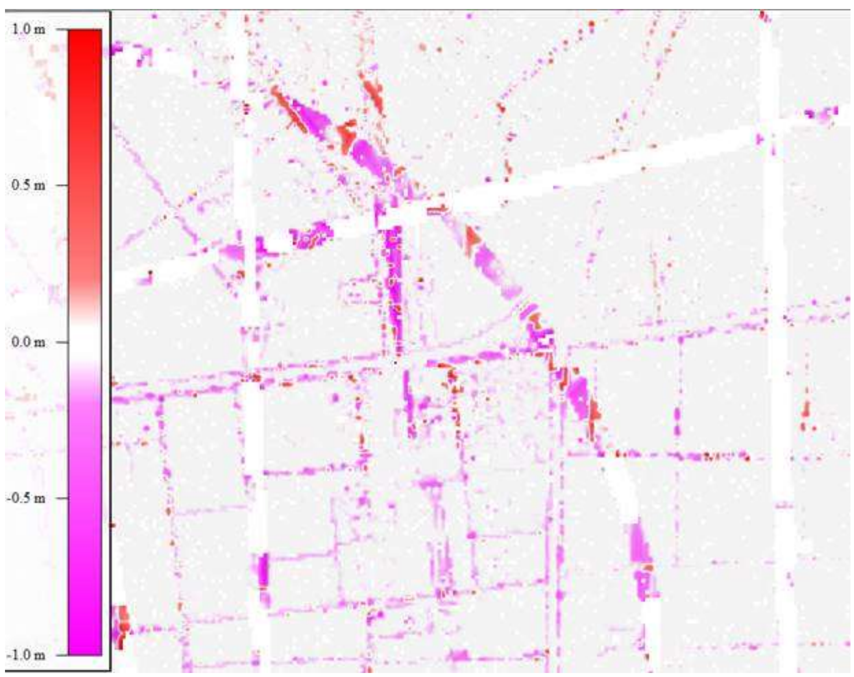


*Figure 15: After editing*

# 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).

https://www.linz.govt.nz/system/files_force/media/doc/pgf_version_new_zealand_national_aerial_lidar_base_specification.pdf?download=1

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:

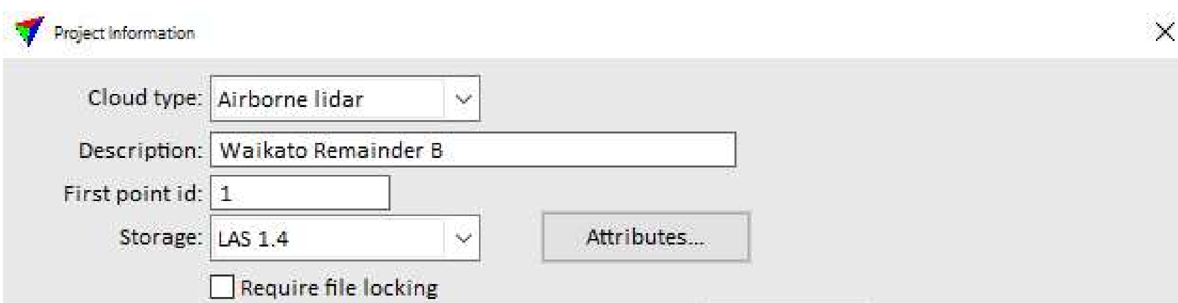


*Figure 16: LAS 1.4 being specified during project – example*

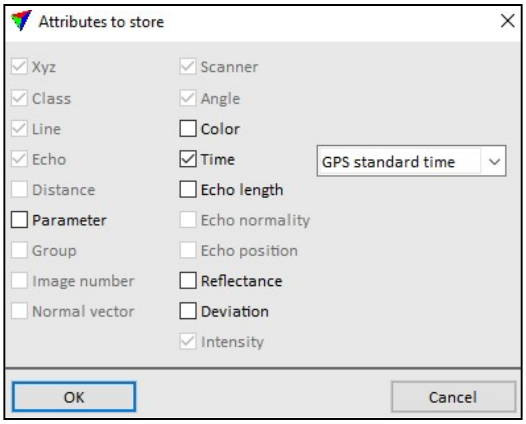


*Figure 17: Project settings used in TerraScan project when importing points into the project.*

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.

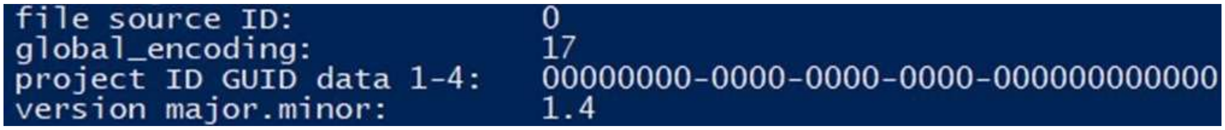


*Figure 18: Confirmation of LAS 1.4 being the file format of handover laser point files using LASTools*

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.

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)

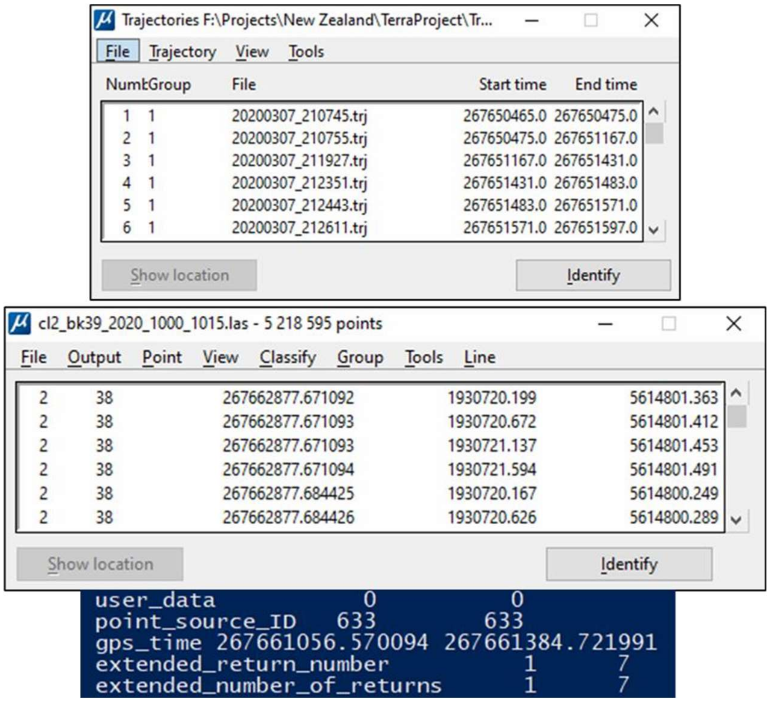


*Figure 19: Representative examples of LAS point attributes*

## 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.

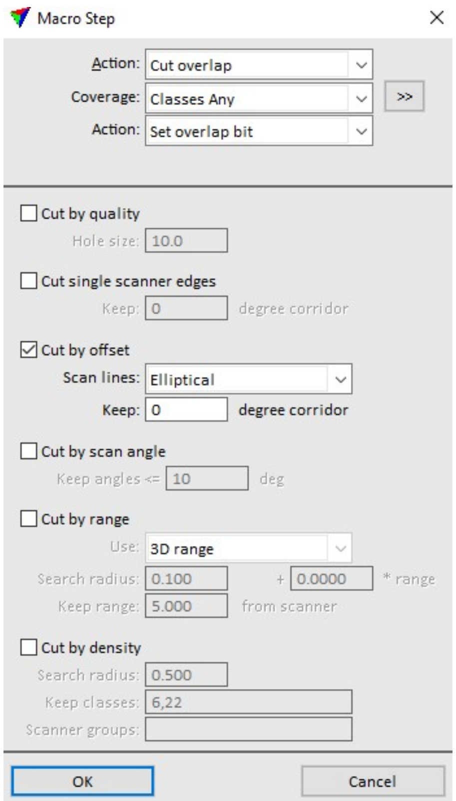


*Figure 20: Settings used when cutting overlap in Microstation.*

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:

| *Code* | *Description* |
|---|---|
| *1* | *Processed, but unclassified* |
| *2* | *Ground* |
| *3* | *Low vegetation <2m* |
| *4* | *Medium vegetation* |
| *5* | *High vegetation >8m* |
| *6* | *Building* |
| *7* | *Low noise* |
| *9* | *Water* |
| *17* | *Bridge deck* |
| *18* | *High noise* |

*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.

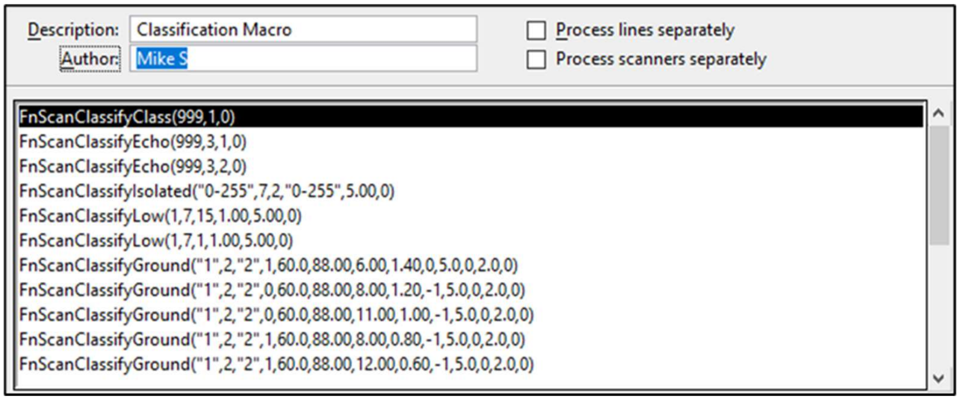


*Figure 21: Automatic classification macro developed for the project area.*

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.

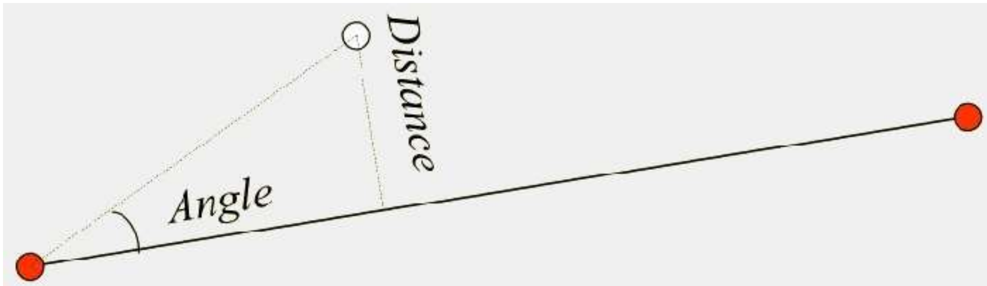


*Figure 22: Illustration of iteration angle and iteration distance parameters in the ground routine.*

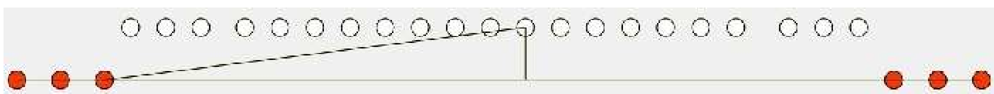

*Figure 23: A smaller iteration distance value avoids classification of ground points on low objects.*

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.

```
histogram of classification of points:
         59902  unclassified (1)
    8657753636  ground (2)
    2514117170  low vegetation (3)
   12439875394  medium vegetation (4)
   15508886711  high vegetation (5)
      71648553  building (6)
    1355999971  noise (7)
      27359166  water (9)
        443035  bridge deck (17)
      98241836  Reserved for ASPRS Definition (18)
 +-> flagged as extended overlap: 17641564162
  +--->          11538 of those are unclassified (1)
  +--->     4055437164 of those are ground (2)
  +--->     1068654592 of those are low vegetation (3)
  +--->     5160855005 of those are medium vegetation (4)
  +--->     6515360509 of those are high vegetation (5)
  +--->       33446882 of those are building (6)
  +--->      781862289 of those are noise (7)
  +--->        5670044 of those are water (9)
  +--->         219683 of those are bridge deck (17)
  +--->       20046456 of those are Reserved for ASPRS Definition (18)
```

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

```
histogram of classification of points:
         66714  unclassified (1)
    8904919481  ground (2)
    2438760442  low vegetation (3)
   12437483046  medium vegetation (4)
   15521697202  high vegetation (5)
      71642554  building (6)
    1181492747  noise (7)
      28601137  water (9)
        447964  bridge deck (17)
      97900577  Reserved for ASPRS Definition (18)
 +-> flagged as withheld:  1279393324
  +--->     1181492747 of those are noise (7)
  +--->       97900577 of those are Reserved for ASPRS Definition (18)
 +-> flagged as extended overlap: 16314331833
  +--->          12474 of those are unclassified (1)
  +--->     3615118188 of those are ground (2)
  +--->      992616004 of those are low vegetation (3)
  +--->     4964188526 of those are medium vegetation (4)
  +--->     6107579150 of those are high vegetation (5)
  +--->       28162806 of those are building (6)
  +--->      577858052 of those are noise (7)
  +--->        9142431 of those are water (9)
  +--->         173190 of those are bridge deck (17)
  +--->       19481012 of those are Reserved for ASPRS Definition (18)
```

*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.

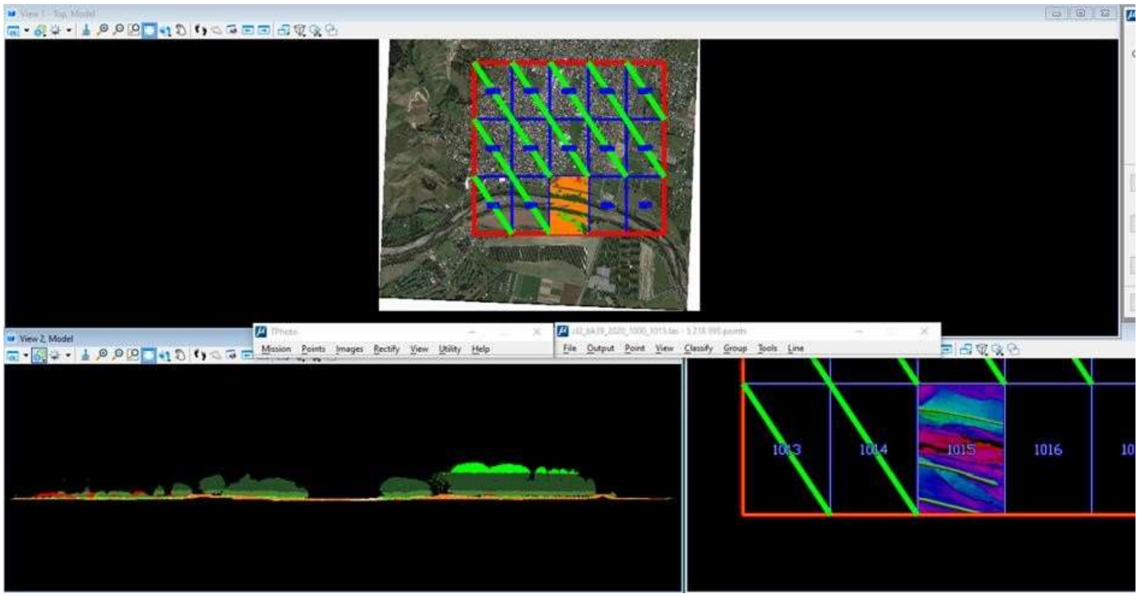


*Figure 26: The green diagonal hatching seen above shows blocks which have been fully checked.*

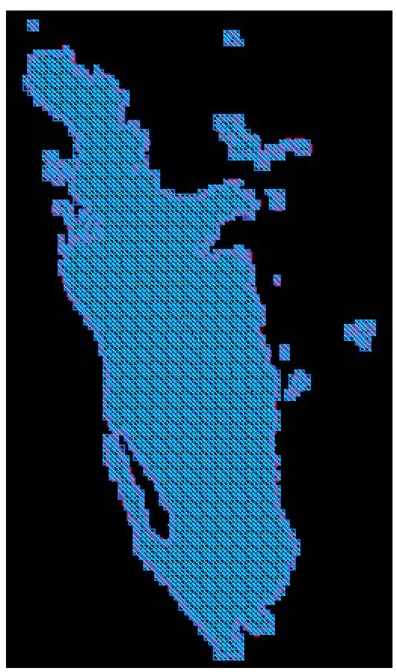

*Figure 27: The diagonal hatching seen above shows how the progress was tracked*

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.

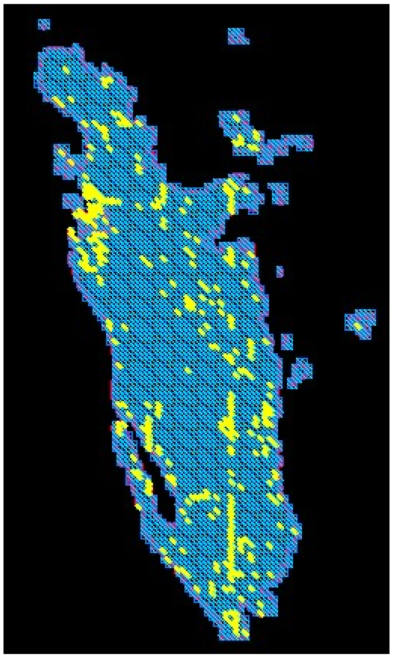

*Figure 28: The polygons are areas for further investigation*

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 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.

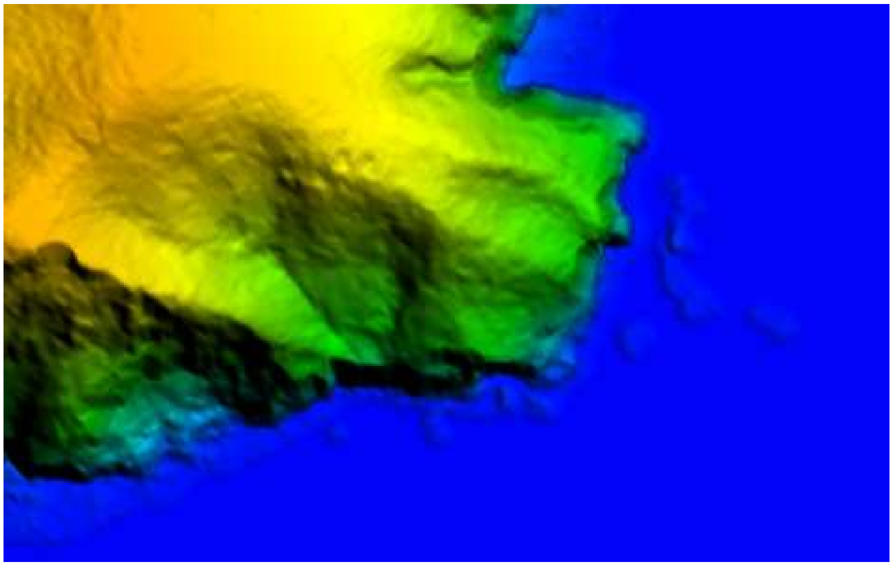

*Figure 29: Example overhead image of DEM over cliffs*

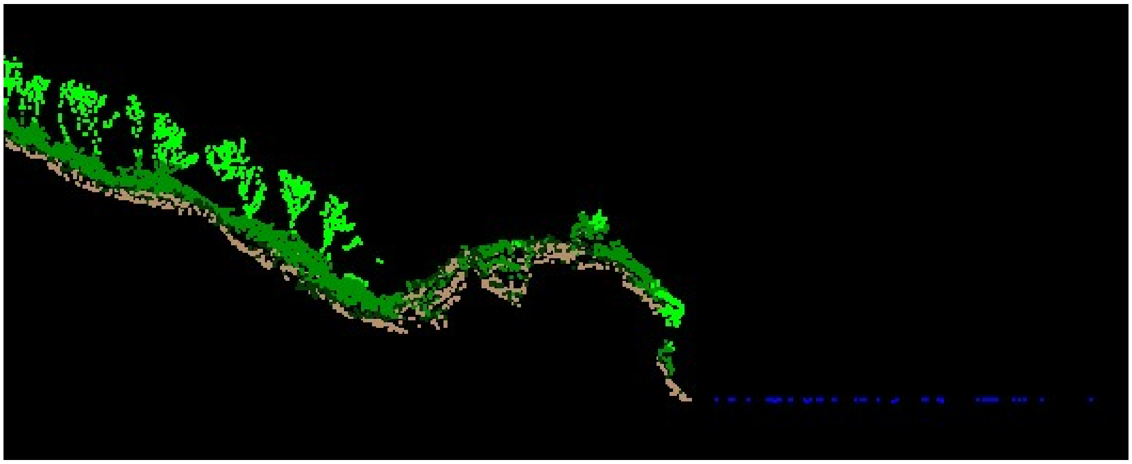

*Figure 30: LAS point cloud profile view from previous figure*

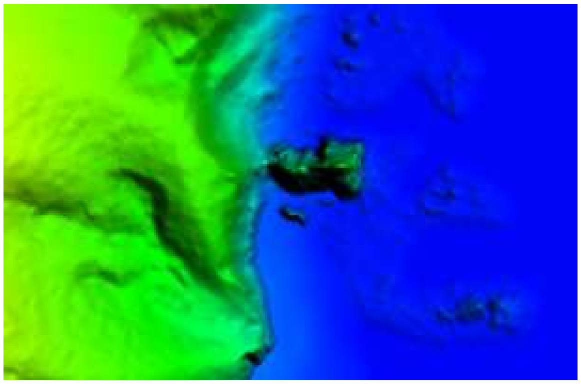

*Figure 31: Example overhead image of DEM interpolation*

*Figure 32: 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 – 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

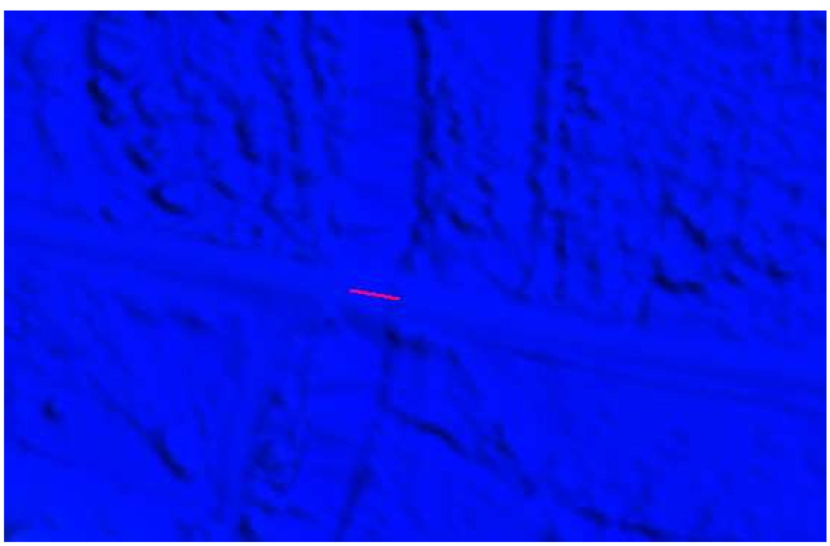

Figure 33: Tile DEM_AZ34_4944 with LINZ bridge centreline

Below examples are bridges edited in the LAS files, but which were not highlighted in the LINZ Shapefile.

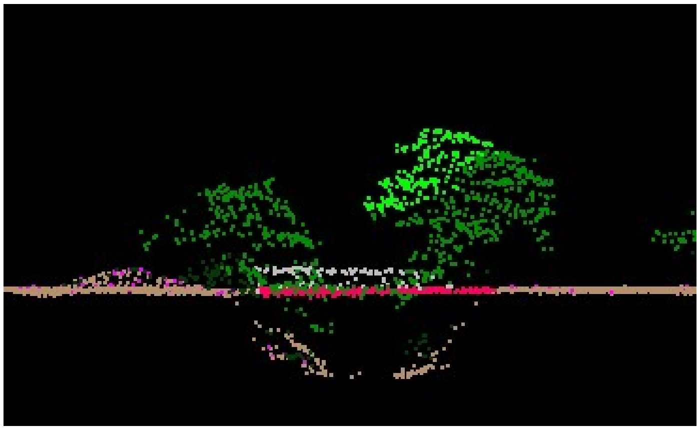

*Figure 34: Tile BA_35_1000_3720*

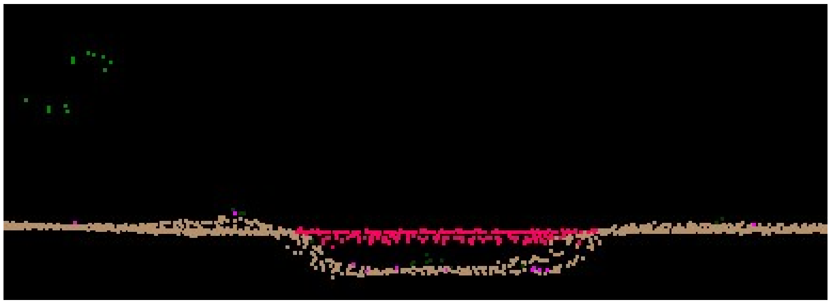

*Figure 35: Tile AZ34_1000_4011*

Below examples are bridges highlighted in the LINZ Shapefile which were determined not to be bridges.

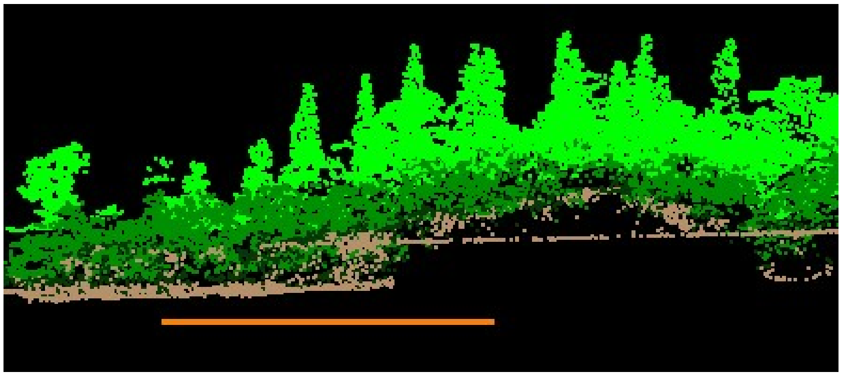

*Figure 36: A cutting through steep terrain. Tile BC35_1000_4038*

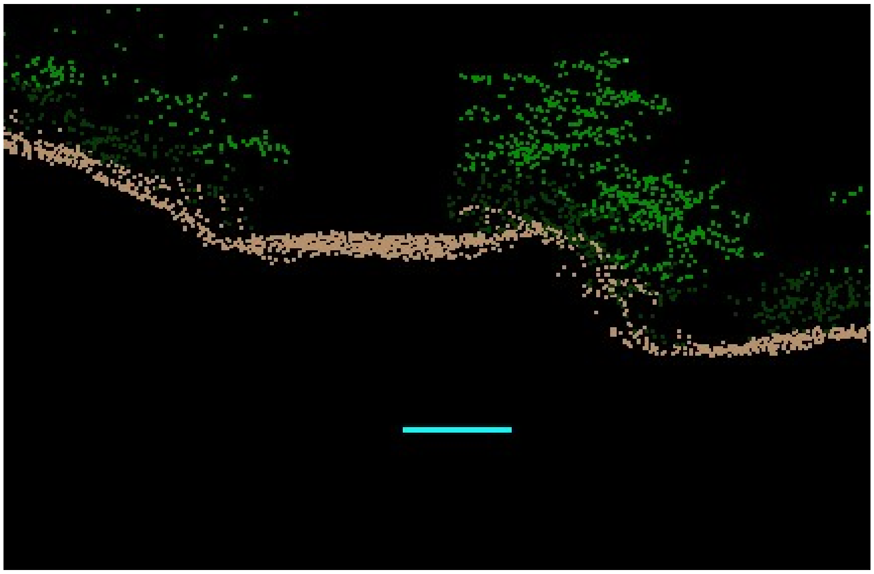

*Figure 37: This is a road cut into the slope rather than a bridge. Tile BC35_1000_1423*

Below examples are highlighted in the LINZ Shapefile which were subject to different determinations.

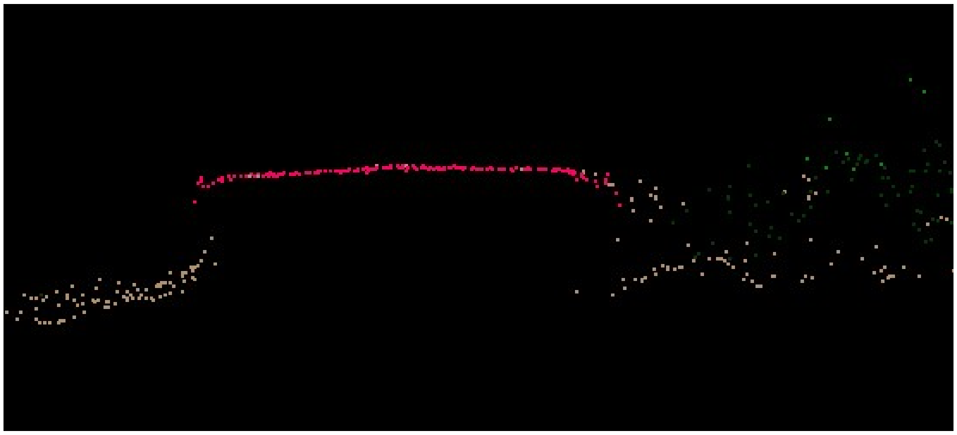

*Figure 38: Bridge in the LINZ shapefile that has been classified to class 17 but is really a culvert.*
No breakline added. Tile BC36_1000_2807

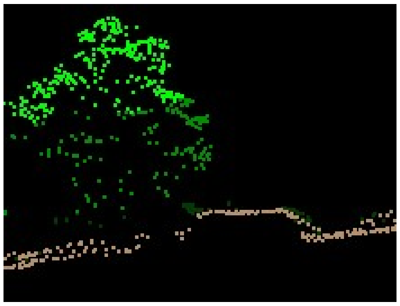

*Figure 39: Bridge in the LINZ shapefile that is a culvert and is therefore not edited to class 17.*
Tile BC35_1000_3023.

*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 000m$^2$ or larger in size.

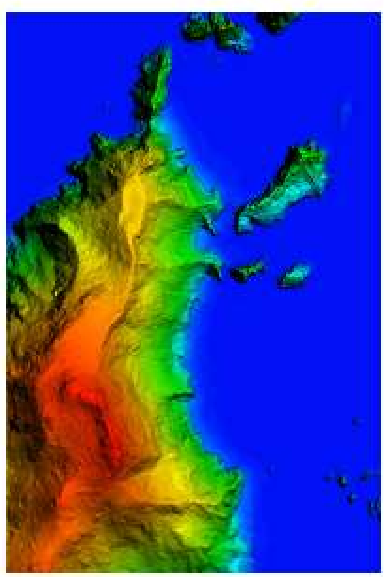

*Figure 42: Example of a hydro-flattened DEM Coastal Tile DEM_B36_0650.*

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.

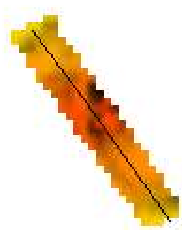

Figure 43: Example of Bridge with LINZ bridge centreline

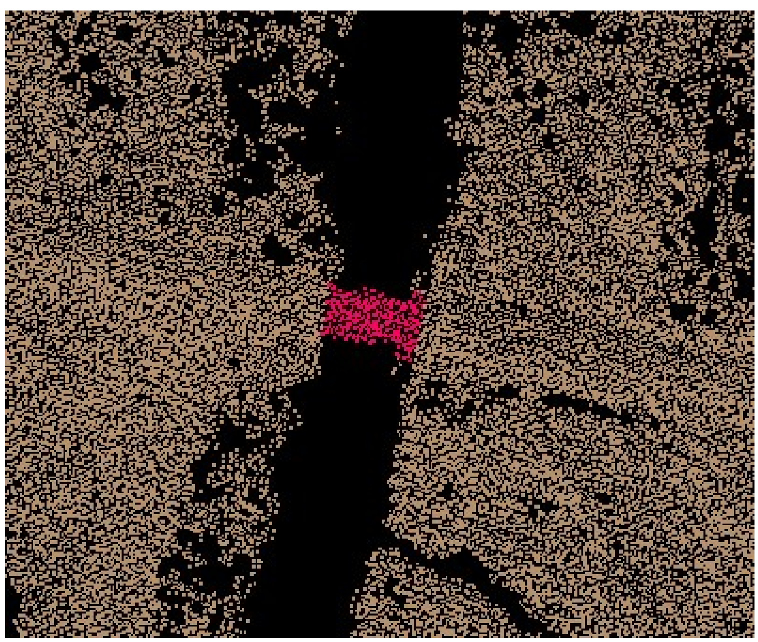

Figure 44: Same location as above DEM. Laser with the Ground and Bridge classes (red) visible.

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.

| | | | |
|---|---|---|---|
| 1 | 1929744.8358 | 5615128.2638 | 7.7096 |
| 2 | 1929746.0769 | 5615130.8498 | 7.6863 |
| 3 | 1929746.4280 | 5615131.5996 | 7.6796 |
| 4 | 1929746.5107 | 5615131.7727 | 7.678 |
| 5 | 1929746.7841 | 5615132.3591 | 7.6728 |
| 6 | 1929748.0794 | 5615135.0799 | 7.6483 |
| 7 | 1929748.5703 | 5615136.1455 | 7.6388 |
| 8 | 1929749.4246 | 5615138.0643 | 7.622 |
| 9 | 1929749.8587 | 5615139.0742 | 7.6132 |
| 10 | 1929750.6288 | 5615140.9327 | 7.5973 |
| 11 | 1929751.0393 | 5615141.7916 | 7.5896 |
| 12 | 1929751.5292 | 5615142.7809 | 7.5805 |
| 13 | 1929754.3861 | 5615148.3485 | 7.529 |
| 14 | 1929754.7868 | 5615149.1041 | 7.5219 |
| 15 | 1929754.7991 | 5615149.1267 | 7.5217 |
| 16 | 1929757.3347 | 5615152.1834 | 7.4808 |
| 17 | 1929757.8445 | 5615152.7752 | 7.4594 |

*Figure 45: Excerpt of river points used to create the centreline*

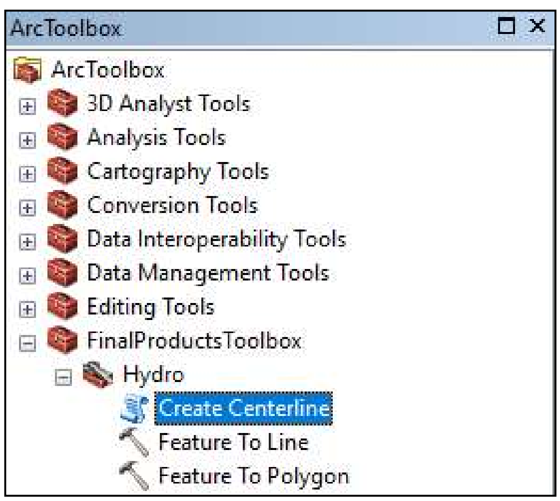


*Figure 46: Centreline for the stream within the project's survey*

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:

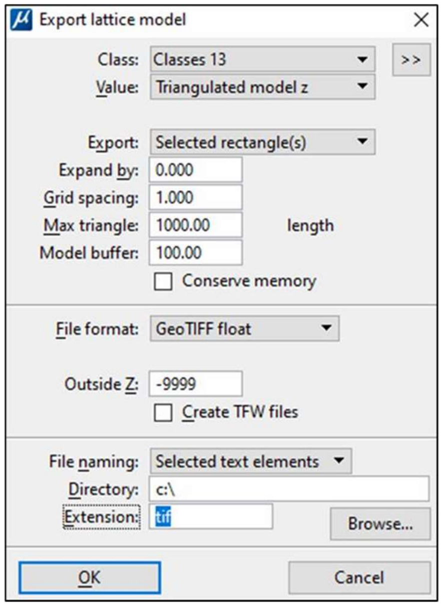


*Figure 47: Settings used to export lattice models.*

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.

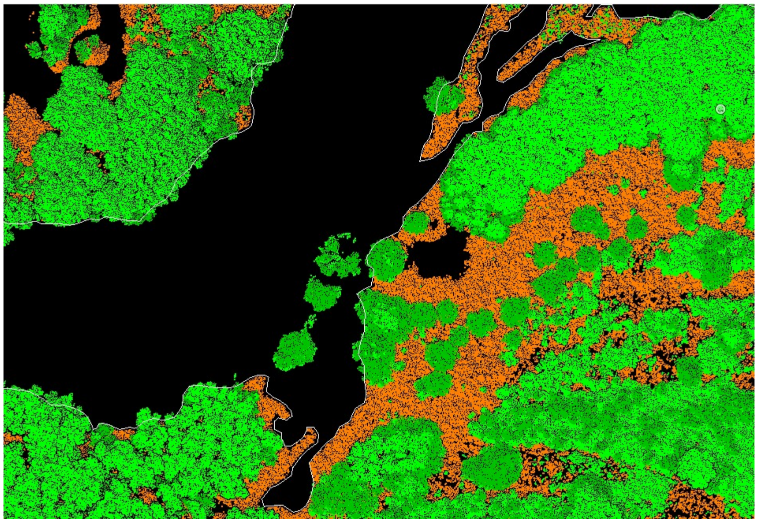

*Figure 48: Pre-filter, overhead view of ground and veg points with hydro lines*

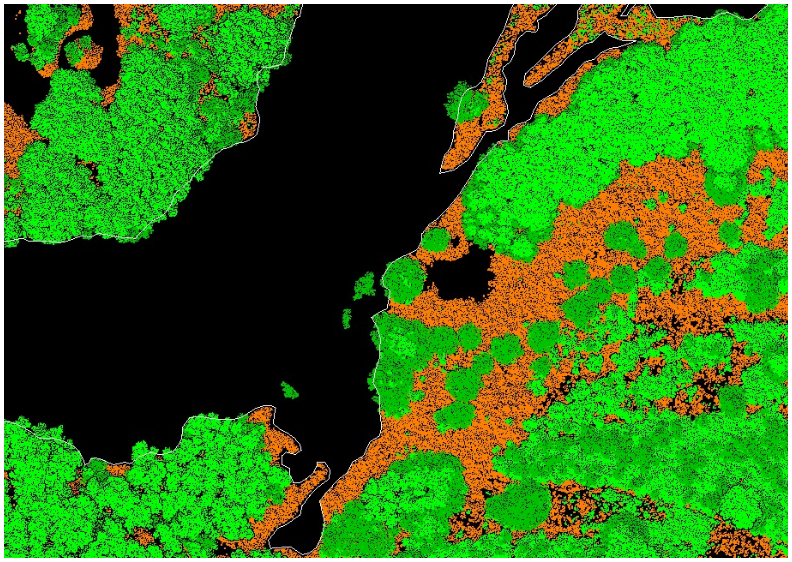

*Figure 49: Post-filter, overhead view of ground and veg points with hydro lines*

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 50: Point cloud – boulder filled stream*


*Figure 51: Imagery – boulder filled stream*

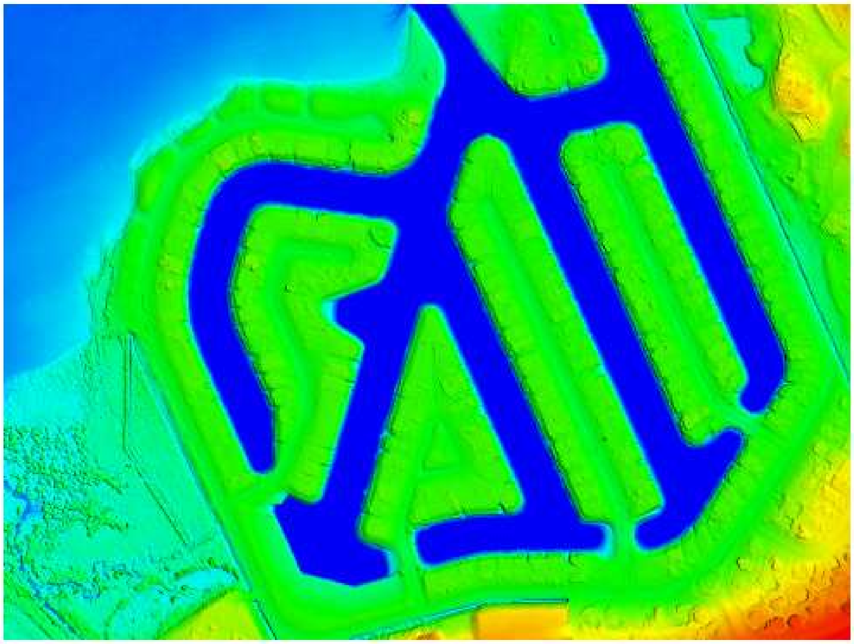

*Figure 52: Example of hydroflattened DEMs: DEM_BB36_1704 and DEM_BB36_1705*

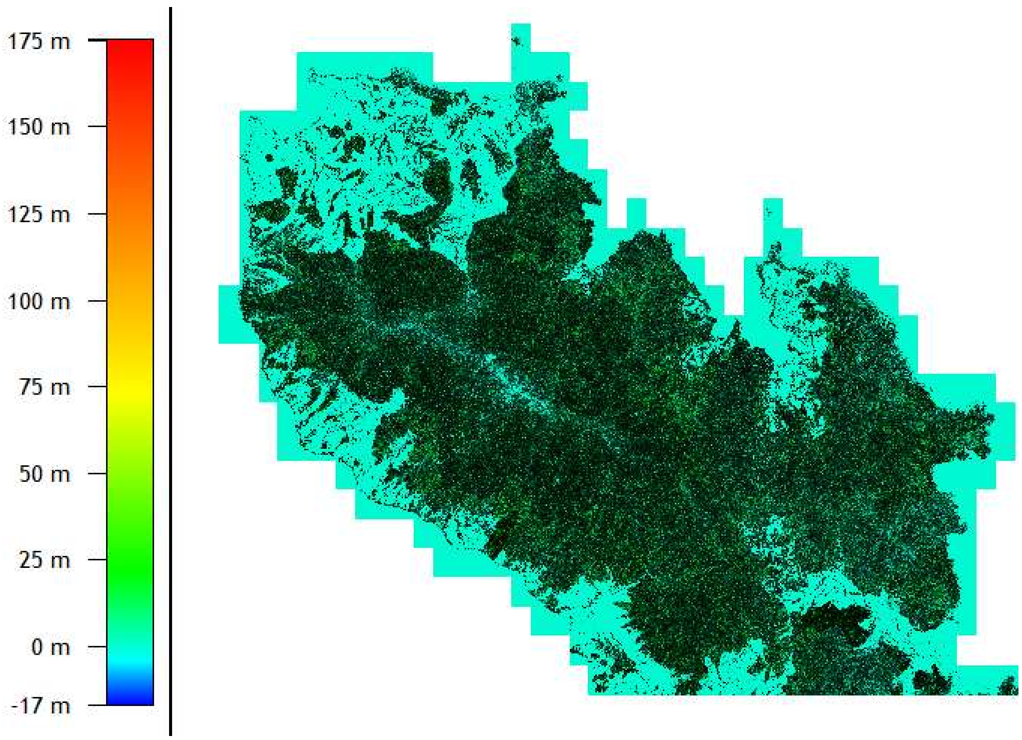


*Figure 53: Difference between DSM and DEM indicating consistent ocean heights*

# 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.

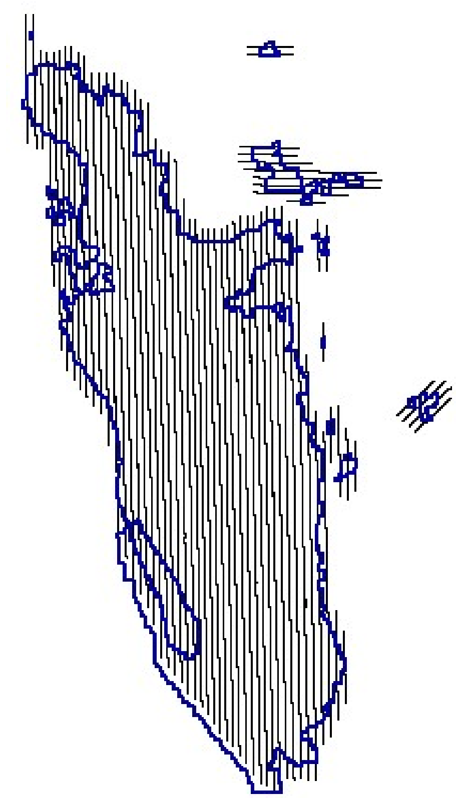

*Figure 55: Flight lines for 4ppm2 data coverage over Block A (Original)*

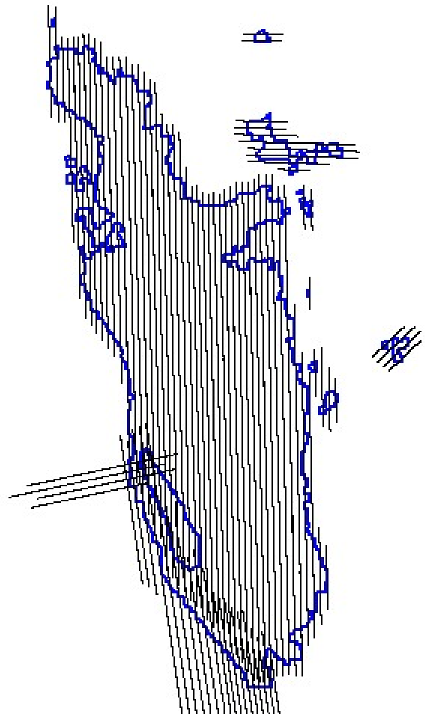

*Figure 56: Flight lines for 4ppm2 data coverage over Block A (Revised)*

## 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.*

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.

| File | Points | Coordinate System | Version | File Signature | File Source ID | CRS is WKT |
|---|---|---|---|---|---|---|
| CL2_BA34_2021_1000_0138.las | 2,977,555 | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 | 1.4 | LASF | 0 | TRUE |
| CL2_BA34_2021_1000_0139.las | 5,553,224 | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 | 1.4 | LASF | 0 | TRUE |
| CL2_BA34_2021_1000_0140.las | 3,818,768 | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 | 1.4 | LASF | 0 | TRUE |
| CL2_BA34_2021_1000_0141.las | 6,242,004 | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 | 1.4 | LASF | 0 | TRUE |
| CL2_BA34_2021_1000_0142.las | 4,590,987 | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 | 1.4 | LASF | 0 | TRUE |
| CL2_BA34_2021_1000_0143.las | 4,982,542 | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 | 1.4 | LASF | 0 | TRUE |
| CL2_BA34_2021_1000_0144.las | 5,327,000 | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 | 1.4 | LASF | 0 | TRUE |
| CL2_BA34_2021_1000_0145.las | 6,679,325 | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 | 1.4 | LASF | 0 | TRUE |
| CL2_BA34_2021_1000_0146.las | 9,951,623 | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 | 1.4 | LASF | 0 | TRUE |
| CL2_BA34_2021_1000_0147.las | 5,496,468 | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 | 1.4 | LASF | 0 | TRUE |
| CL2_BA34_2021_1000_0148.las | 7,864,446 | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 | 1.4 | LASF | 0 | TRUE |
| CL2_BA34_2021_1000_0149.las | 6,044,892 | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 | 1.4 | LASF | 0 | TRUE |
| CL2_BA34_2021_1000_0150.las | 5,780,460 | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 | 1.4 | LASF | 0 | TRUE |
| CL2_BA34_2021_1000_0231.las | 145,374 | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 | 1.4 | LASF | 0 | TRUE |
| CL2_BA34_2021_1000_0232.las | 1,022,439 | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 | 1.4 | LASF | 0 | TRUE |
| CL2_BA34_2021_1000_0233.las | 1,151,686 | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 | 1.4 | LASF | 0 | TRUE |
| CL2_BA34_2021_1000_0234.las | 3,148,049 | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 | 1.4 | LASF | 0 | TRUE |
| CL2_BA34_2021_1000_0235.las | 2,681,102 | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 | 1.4 | LASF | 0 | TRUE |
| CL2_BA34_2021_1000_0236.las | 4,925,163 | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 | 1.4 | LASF | 0 | TRUE |
| CL2_BA34_2021_1000_0237.las | 3,665,857 | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 | 1.4 | LASF | 0 | TRUE |

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

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 analysist 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.

| File | Format | NoData Value | BPB | Bands | Data Type | Pixel Size | Coordinate System |
|---|---|---|---|---|---|---|---|
| DEM_BB35_2021_1000_4824.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BB35_2021_1000_4825.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BB35_2021_1000_4826.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BB35_2021_1000_4827.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BB35_2021_1000_4828.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BB35_2021_1000_4829.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BB35_2021_1000_4830.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BB35_2021_1000_4901.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BB35_2021_1000_4902.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BB35_2021_1000_4913.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BB35_2021_1000_4914.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BB35_2021_1000_4915.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BB35_2021_1000_4916.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BB35_2021_1000_4917.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BB35_2021_1000_4918.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BB35_2021_1000_4919.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BB35_2021_1000_4920.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BB35_2021_1000_4921.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BB35_2021_1000_4922.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BB35_2021_1000_4923.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |

*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:

- o Grid Method = Binning (Maximum Value – DSM)
- o 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.

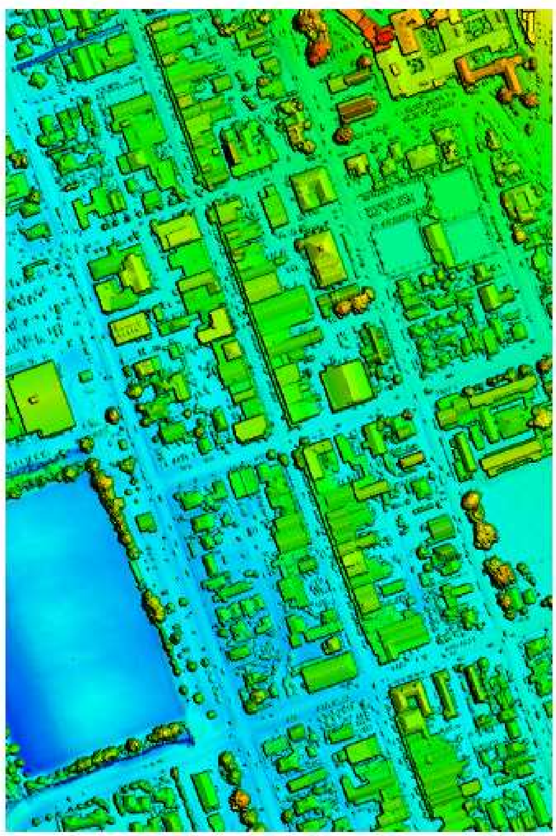

*Figure 58: Excerpt from DSM_BB34_2021_1000_3346*

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.

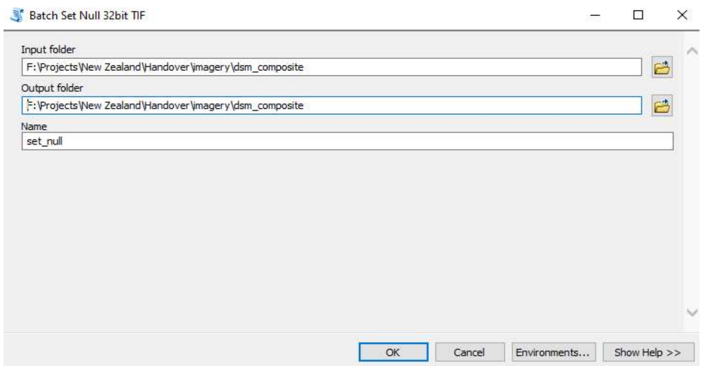


*Figure 59: Script used in ArcMap to achieve a NoData value of -9999.*

| | |
|---|---|
| Format | IMAGINE Image |
| Source Type | Generic |
| Pixel Type | floating point |
| Pixel Depth | 32 Bit |
| NoData Value | -9999 |

*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.

| File | Format | NoData Value | BPB | Bands | Data Type | Pixel Size | Coordinate System |
|---|---|---|---|---|---|---|---|
| DSM_BC35_2021_1000_0501.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BC35_2021_1000_0502.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BC35_2021_1000_0503.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BC35_2021_1000_0504.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BC35_2021_1000_0505.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BC35_2021_1000_0506.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BC35_2021_1000_0517.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BC35_2021_1000_0518.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BC35_2021_1000_0519.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BC35_2021_1000_0520.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BC35_2021_1000_0521.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BC35_2021_1000_0522.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BC35_2021_1000_0523.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BC35_2021_1000_0524.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BC35_2021_1000_0525.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BC35_2021_1000_0526.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |

*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.

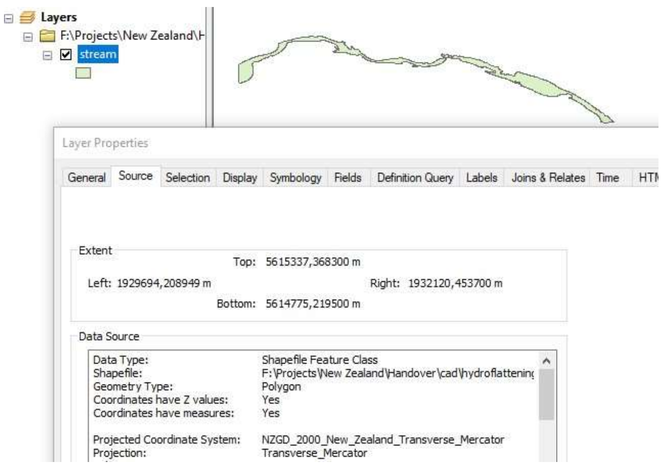


*Figure 61: Stream break line properties in ArcMap.*

## 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.

# 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_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.

| Naming Convention for point clouds, DEMs, and other tiled products<br>*[product]_[sheet]_[year]_[scale]_[tile].[ext]* | | |
|---|---|---|
| **Product** | *DEM* | **CL2-Point Cloud Classification Level 2**<br>**DEM-Bare Earth Digital Elevation Model**<br>**DSM-Digital Surface Model**<br>DTM-Digital Terrain Model<br>UNC-Unclassified Point Cloud<br>INT-Intensity image<br>CHM – Canopy Height Model<br>IMG-Aerial photography<br>etc |
| **Sheet** | *BK34* | LINZ Topo50 identifier (4 characters) |
| **Year** | *2016* | Year of survey commencement |
| **Scale** | *1000* | Nominal scale of NZTopo50 subtiles |
| **Tile** | *4118* | Row number (41), Column number (18) of tile with respect to an upper left origin |
| **ext** | *tif* | File extension according to format conventions<br>las<br>tif<br>shp<br>etc |
| *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-flatting break line bank line strings
│      │ └──stream_islands – Hydro-flatting 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.

| Result Acceptance | | | |
|---|---|---|---|
| Assessment Criteria | Status | Completed By | Date |
| Point cloud classification accuracy | Complete | Woolpert/ AAM | 07 December 2022 |
| Point cloud classification consistency | Complete | Woolpert/ AAM | 07 December 2022 |
| Point Cloud LAS tiled deliverables | Complete | Woolpert/ AAM | 07 December 2022 |
| Hydro-flattened Digital Elevation Models | Complete | Woolpert/ AAM | 07 December 2022 |
| Digital Survey Models | Complete | Woolpert/ AAM | 07 December 2022 |
| Contours | Complete | Woolpert/ AAM | 07 December 2022 |
| Extents, Flight Lines, Break lines, Tile Index | Complete | Woolpert/ AAM | 07 December 2022 |
| | | | |
| Project Manager / Supervisor Signoff | Complete | Brian Foster | 07 December 2022 |
| Ocean Infinity Review | Complete | Luke Leydon | 12 December 2022 |

*Table 6: Processing Results Acceptable Signoff*

| Result Acceptance | | | |
|---|---|---|---|
| Assessment Criteria | Status | Completed By | Date |
| Point cloud classification accuracy | Complete | Woolpert/ AAM | 24 May 2023 |
| Point cloud classification consistency | Complete | Woolpert/ AAM | 24 May 2023 |
| Point Cloud LAS tiled deliverables | Complete | Woolpert/ AAM | 24 May 2023 |
| Hydro-flattened Digital Elevation Models | Complete | Woolpert/ AAM | 24 May 2023 |
| Digital Survey Models | Complete | Woolpert/ AAM | 24 May 2023 |
| Contours | Complete | Woolpert/ AAM | 24 May 2023 |
| Extents, Flight Lines, Break lines, Tile Index | Complete | Woolpert/ AAM | 24 May 2023 |
| | | | |
| Project Manager / Supervisor Signoff | Complete | Brian Foster | 24 May 2023 |
| Ocean Infinity Review | Complete | Luke Leydon | 08 June 2023 |

*Table 7: Processing Results Acceptable Signoff (rev2)*

# Appendix A: Lidar Quality Assurance Results

Provided as separate Documents -

| | | | |
|---|---|---|---|
| LP360_Results_for_DEM | 17/05/2023 5:00 PM | Microsoft Excel W... | 236 KB |
| LP360_Results_for_DSM | 17/05/2023 5:11 PM | Microsoft Excel W... | 237 KB |
| LP360_Results_for_LAS_FINAL | 5/06/2023 5:07 PM | Microsoft Excel W... | 2,367 KB |

# 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

# Waikato Local Authority Shared Services (WLASS) / CoLAB LiDAR Data Capture Services

# LiDAR Processing Report Block B Priority (Rev3)

Contract Number: AU411

Surveyed By: iXblue Pty Ltd / Ocean Infinity Pty Ltd

Processing Completed By: Woolpert USA and Woolpert Australia

Prepared For: Colab (formerly WLASS)

Document Date: 22 June 2023

Ocean Infinity (Australia) Pty Ltd
ABN 61 128 811 978
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## Client Representative

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## Document Revision

| Revision No | Issue Purpose | Prepared | Checked | Approved |
|---|---|---|---|---|
| 0 | Issue Block B LiDAR Processing Report | L Leydon | BF/MM | D Field |
| 1 | Report amended | L Leydon | MM | D Field |
| 2 | Report amended for most recent supply | L Leydon | BF | D Field |
| 3 | Report amended for most recent supply | L Leydon | BF | D Field |

## Approval for Issue

| Name | Signature | Date |
|---|---|---|
| Luke Leydon | Luke Leydon | 22 June 2023 |

# Revision History

| Item | Description of change | Section | Revision |
|---|---|---|---|
| 1 | Revised DEM Methodology | 4.3.1 | 1 |
| 2 | Added to Introduction | 1 | 2 |
| 3 | Updated Pointcloud statistics | Figure 10, | 2 |
| 4 | Updated LAS, DEM, DSM LP360 tables | Table 2, Table 3, Table 4 | 2 |
| 5 | Added to 6.4 Delivery not meeting specification with example figures of how data was corrected | 6.4 | 2 |
| 6 | New appendices | Appendices | 2 |
| 7 | Added to Introduction | 1 | 3 |
| 8 | Updated Point cloud statistics | Figure 10 | 3 |
| 9 | Updated LAS, DEM, DSM LP360 tables | Table 2, Table 3, Table 4 | 3 |
| 10 | Added Section 2.9.1 Changes to Classification Accuracy and Filters post LINZ and WRC QA | 2.91 | 3 |
| 11 | Removed Contours methodology, to be confirmed and discussed with WRC prior to generation | 4.7 | 3 |
| 12 | Added 6.4.1 Delivery not Meeting Specification – Previous rendition | 6.4.1 | 3 |
| 13 | New results sign off table | Table 9 | 3 |
| 14 | New Appendices | Appendices | 3 |
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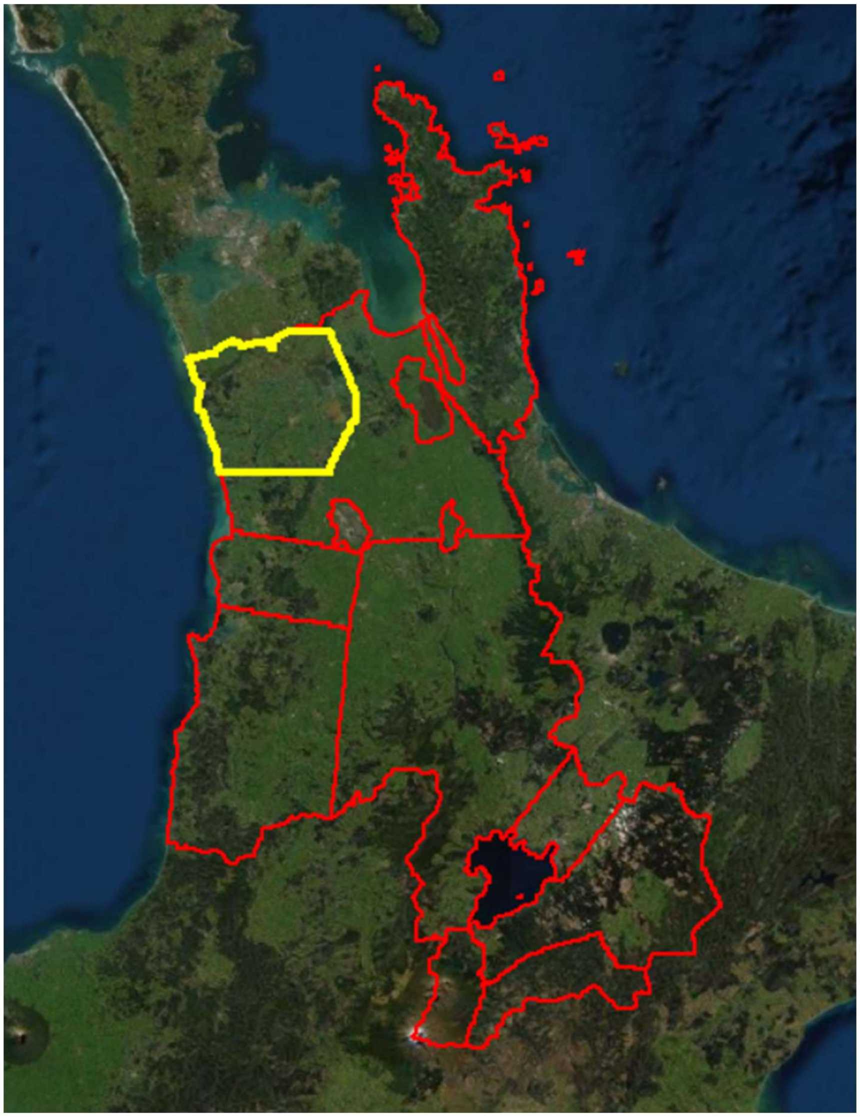

*Figure 1: Waikato Survey Area*

Block B Priority shown in Yellow on Northwest Section of Block B

# 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

AU411_WLASS-Collection_Report-10052021.pdf.

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 - Priority, as illustrated in yellow in Figure 1 - Waikato Survey.

It is noted that this Priority Block dataset has been subject to several supplies, rework and resupplies. New Appendices have been supplied along with screenshots showing how the previous datasets were affected and then corrected.

The previous rendition of this dataset was supplied on 26 April 2023. This underwent QA with WRC and LINZ. The dataset was ultimately rejected. This was discussed in a Technical Meeting with Ocean Infinity, Woolpert USA, Woolpert Australia (AAM), Waikato Regional Council (WRC) and Land Information New Zealand (LINZ). This meeting occurred on Tuesday 09 May.

One of the major points of discussion in the meeting was the negative influence of the macro introduced to minimise pitting and a corduroy type texture to ground surfaces. Ultimately the decision was made to revert to the previous supplied dataset “Waikato_Block_B_Priority_25012023_Resupply” and fix this as opposed to the most recent supply.

To this end, both Woolpert USA and Australia worked on the dataset and spent over 300 manual, manhours identifying, digitising and placing polygon’s around the worst affected areas for manual editing and correction. Both entities QA’d the data prior to resupply.

# 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).

https://www.linz.govt.nz/system/files_force/media/doc/pgf_version_new_zealand_national_aerial_lidar_base_specification.pdf?download=1

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*

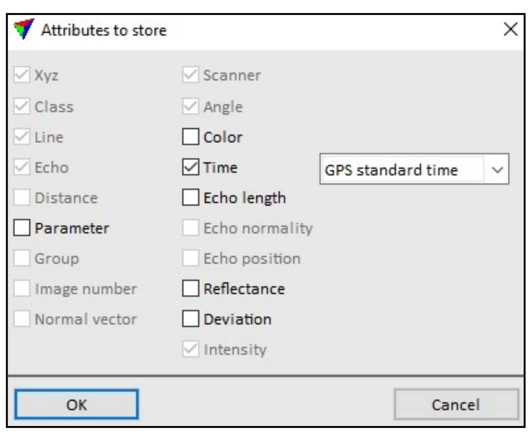


*Figure 3: Project settings used in TerraScan project when importing points into the project.*

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.

```
file source ID:              0
global_encoding:             17
project ID GUID data 1-4:    00000000-0000-0000-0000-000000000000
version major.minor:         1.4
```

*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)

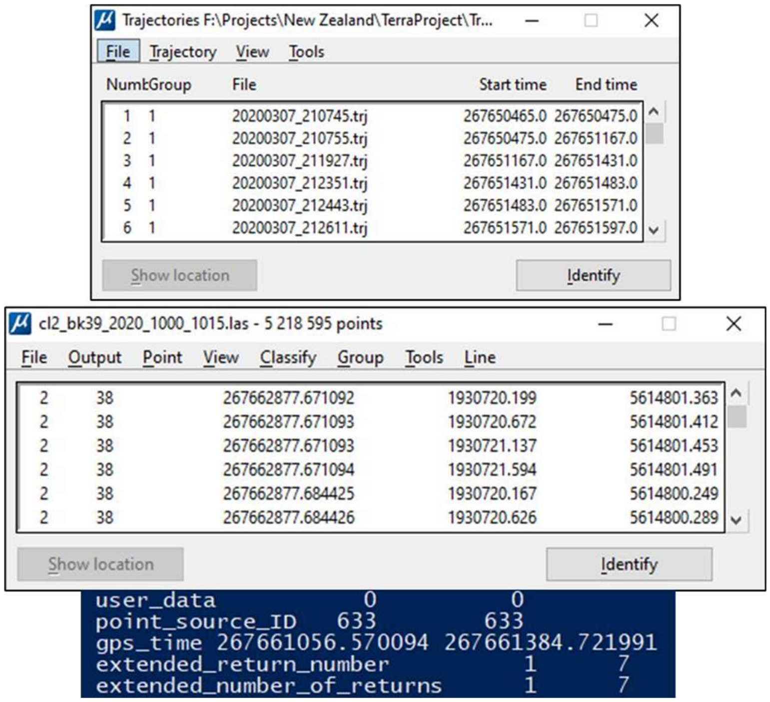


*Figure 5: Representative examples of LAS point attributes*

## 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.

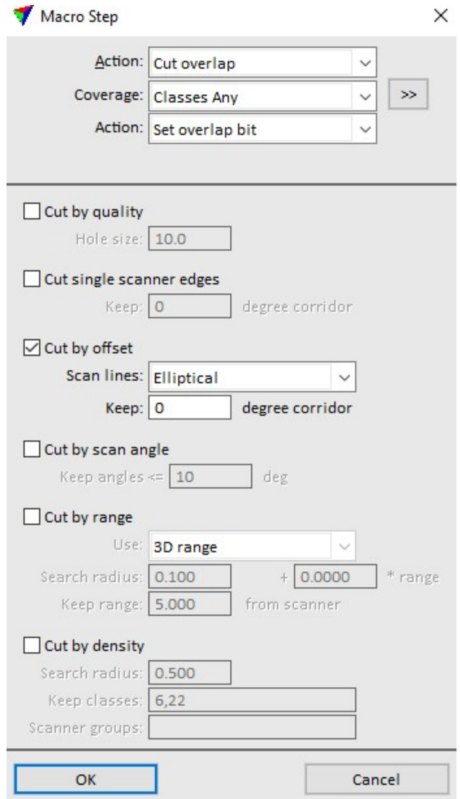


*Figure 6: Settings used when cutting overlap in Microstation.*

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:

| *Code* | *Description* |
|---|---|
| *1* | *Processed, but unclassified* |
| *2* | *Ground* |
| *3* | *Low vegetation <2m* |
| *4* | *Medium vegetation* |
| *5* | *High vegetation >8m* |
| *6* | *Building* |
| *7* | *Low noise* |
| *9* | *Water* |
| *17* | *Bridge deck* |
| *18* | *High noise* |

*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.

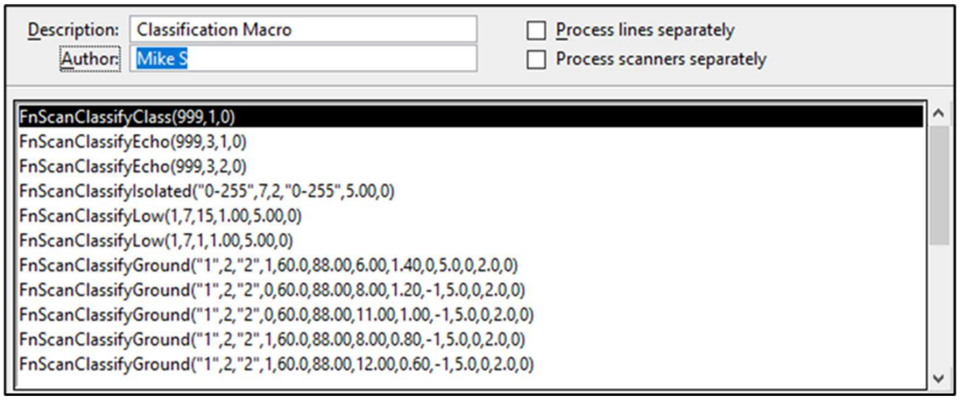


*Figure 7: Automatic classification macro developed for the project area.*

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.

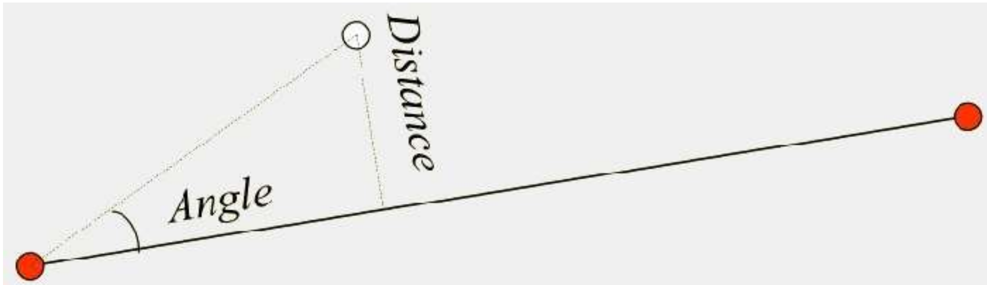


*Figure 8: Illustration of iteration angle and iteration distance parameters in the ground routine.*

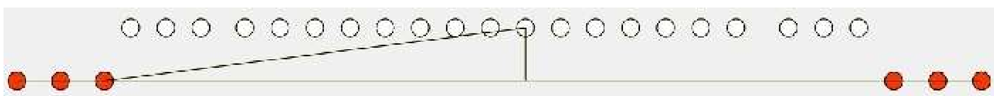

*Figure 9: A smaller iteration distance value avoids classification of ground points on low objects.*

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.

| Class # | Class | Priority B |
|---|---|---|
| 1 | Unclassified | 339884 |
| 2 | Ground | 10419570014 |
| 3 | Low Veg | 715805527 |
| 4 | Medium Veg | 1635087015 |
| 5 | High Veg | 2241538250 |
| 6 | Building | 38350952 |
| 7 | Noise | 624905886 |
| 9 | Water | 29825267 |
| 17 | Bridge Deck | 290803 |
| 18 | Reserved for ASPRS Definition | 32803327 |
| | Flagged as Withheld | 657709213 |
| | Flagged as extended overlap | 5526447681 |
| W7 | Withheld Low Noise | 624905886 |
| W18 | Withheld High Noise | 32803327 |
| O1 | Overlap Unclassified | 94019 |
| O2 | Overlap Ground | 3443700961 |
| O3 | Overlap Low Veg | 248030391 |
| O4 | Overlap Medium Veg | 582868279 |
| O5 | Overlap High Veg | 913339051 |
| O6 | Overlap Building | 12716062 |
| O7 | Overlap Noise | 312767697 |
| O9 | Overlap Water | 6127330 |
| O17 | Overlap Bridge | 87412 |
| OW18 | Overlap/Withheld High Noise | 6716479 |

*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.

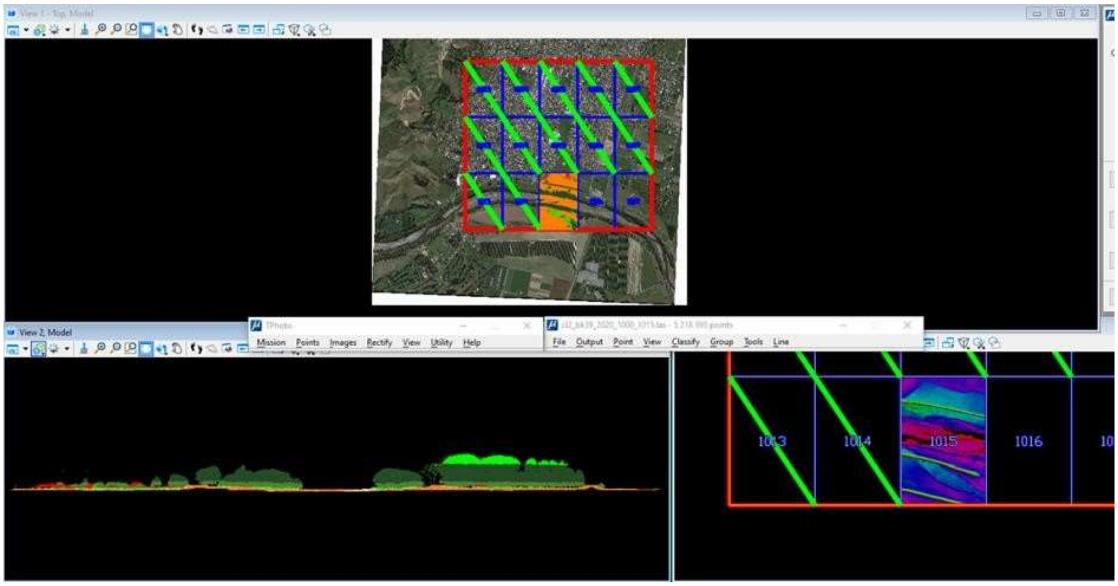


*Figure 11: The green diagonal hatching seen above shows blocks which have been fully checked.*

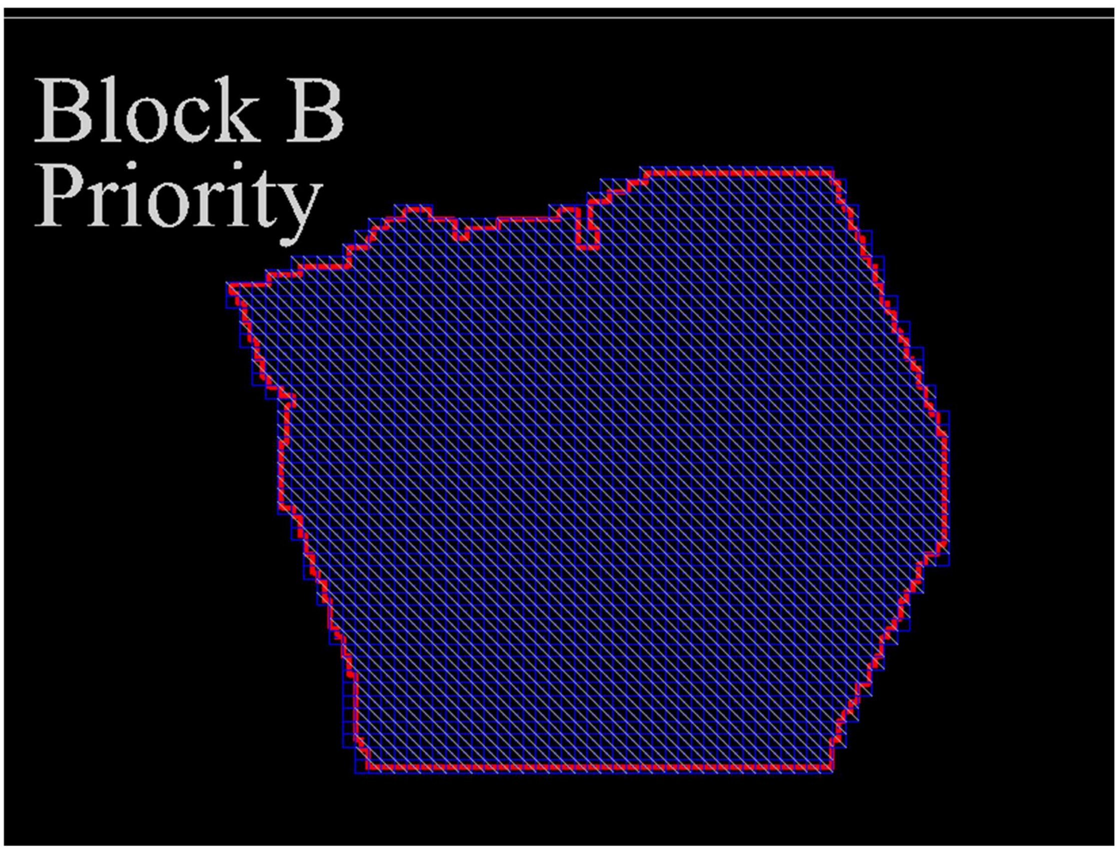


*Figure 12: The diagonal hatching seen above shows how the progress was tracked*

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 98%. 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.

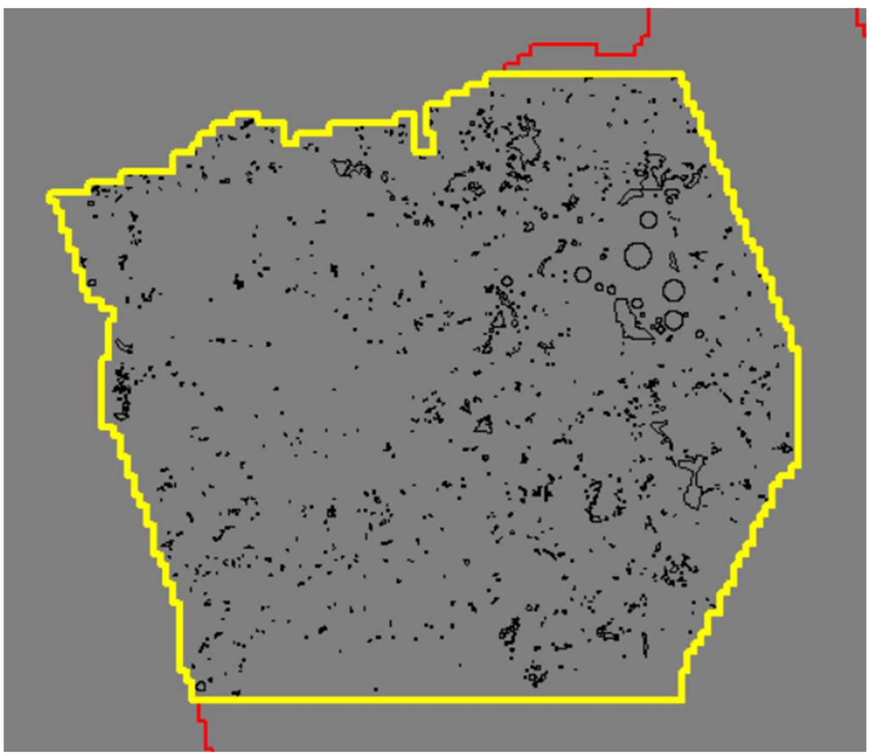

*Figure 13: The polygons are areas for further investigation*

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 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.

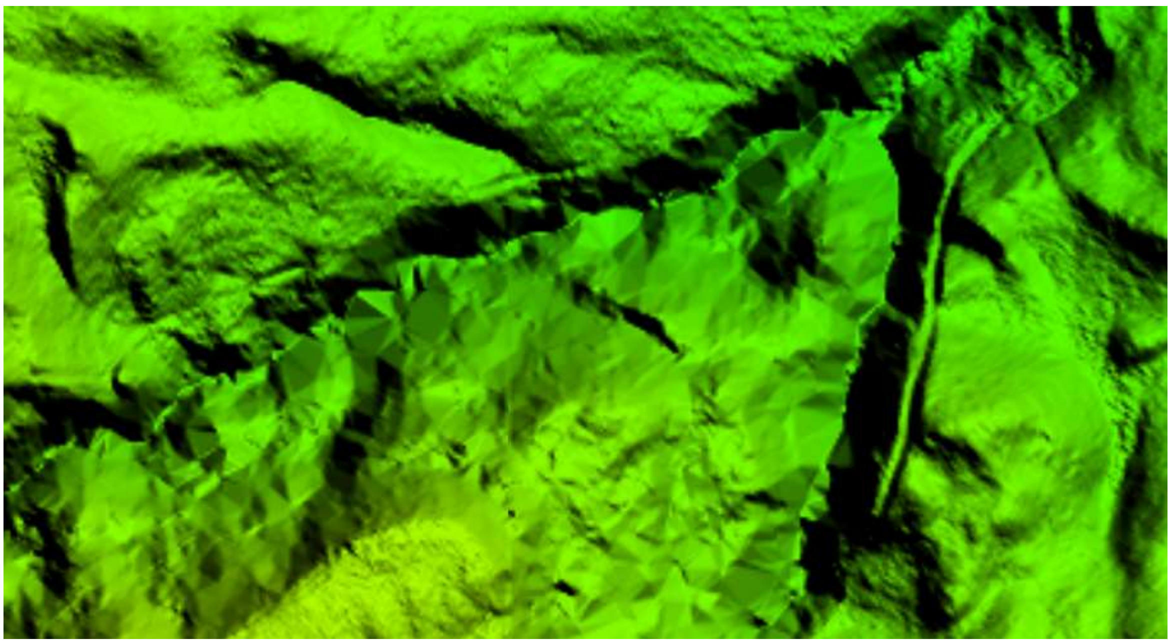

*Figure 14: Example overhead image of DEM interpolation*

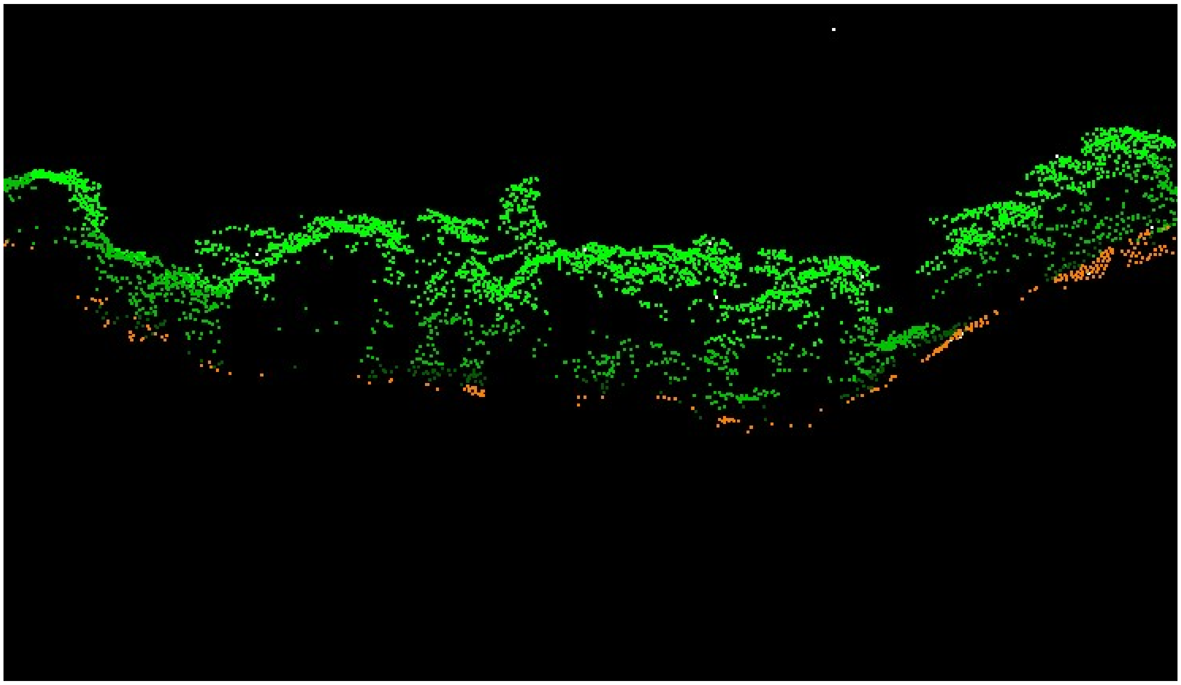

*Figure 15: LAS point cloud profile view from previous figure*

The figures below illustrate an occurrence of a rough DEM surface indicating possible misclassification. After investigating it was determined the areas in question are densely vegetated with rough and varied terrain characteristics and the DEM was determined to be an acceptable representation.

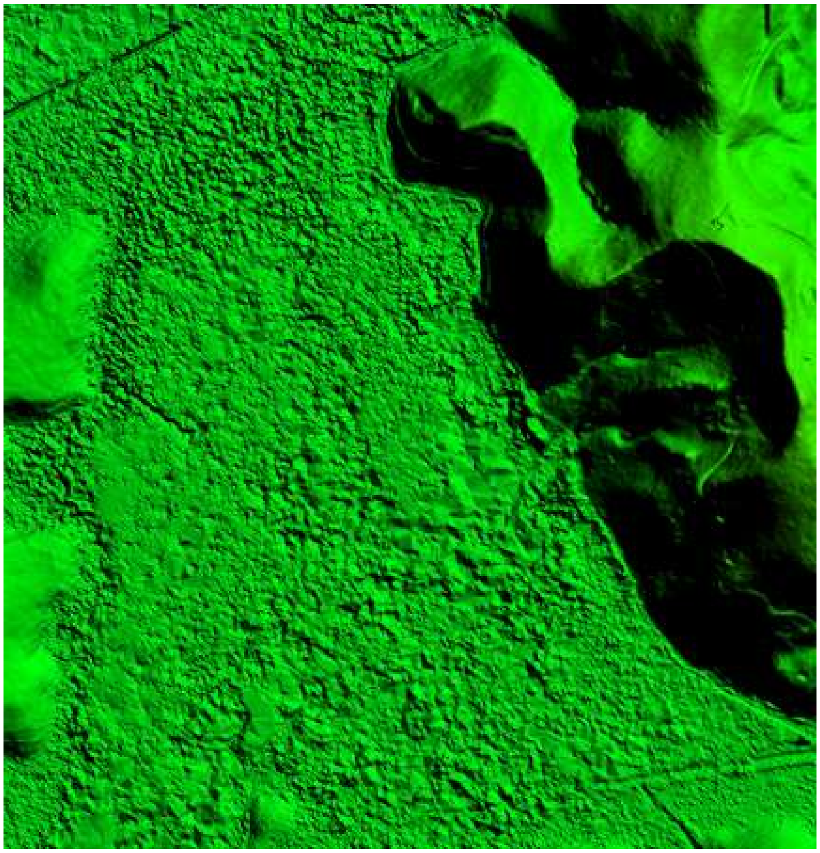

*Figure 16: Example overhead image of DEM surface roughness*

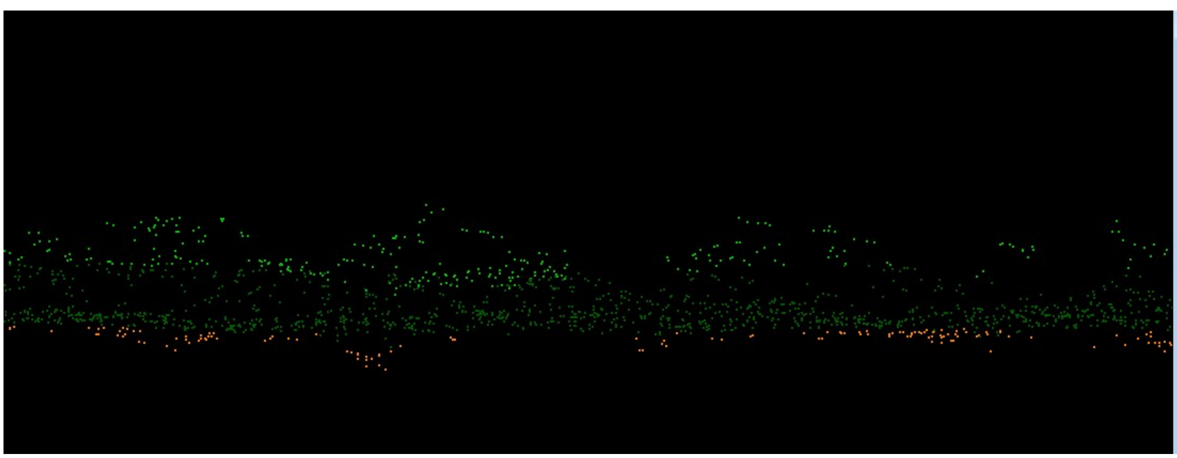

*Figure 17: LAS point cloud profile view from previous figure*

### 2.9.1 Changes to Classification Accuracy and Filters post LINZ and WRC QA

It was observed in the Waikato Priority B DEM/DSM the existence of a texturing/patterning appearance resembling "corduroy". This was also noted by LINZ and WRC as fail points in the QA document "AU411 WRC_Raised_Defect_Tracking_Block_B_Priority_v4_20230505".

Woolpert noted points approximately 20-30 cm above and below the trending ground surface were found to be in classes 1, 2, and 3 instead of class 7. These points manifested in the DEM/DSM as linear spikes/pits. See screenshot below showing the DSM surface screenshot and lidar profile view of texture/patterning/corduroy.

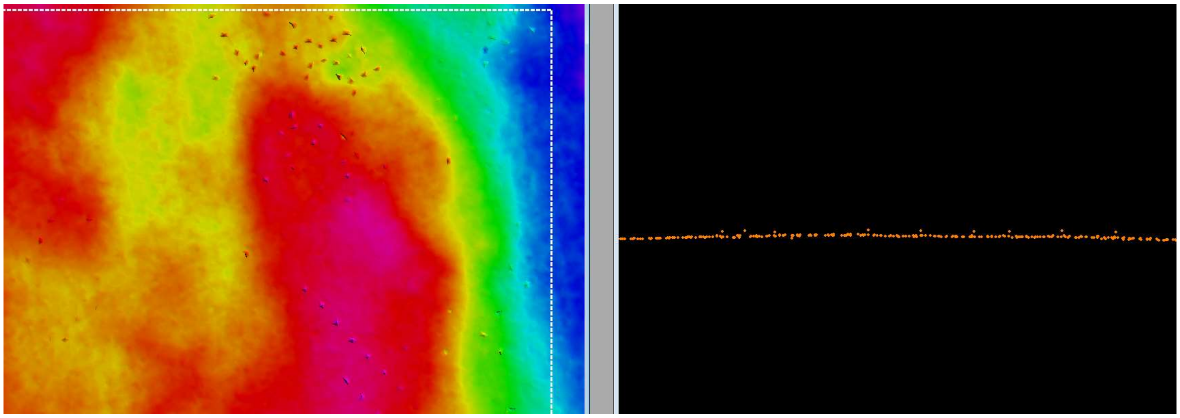

*Figure 18: Tile BC33_1000_3225*

Efforts were made to address this condition by the following-

-Manual review of DEM/DSM raster files to identify this condition and polygons around the affected areas. A filter was then applied to the points within these polygons to correct the texturing/patterning and new DEM/DSM products generated.

-The filter that runs within these polygons contains more aggressive ground filters and low points steps that will classify these points into class 7 noise. See screenshot below showing DSM surface screenshot and lidar profile view of lidar points after filter ran (yellow points are class 7, noise)

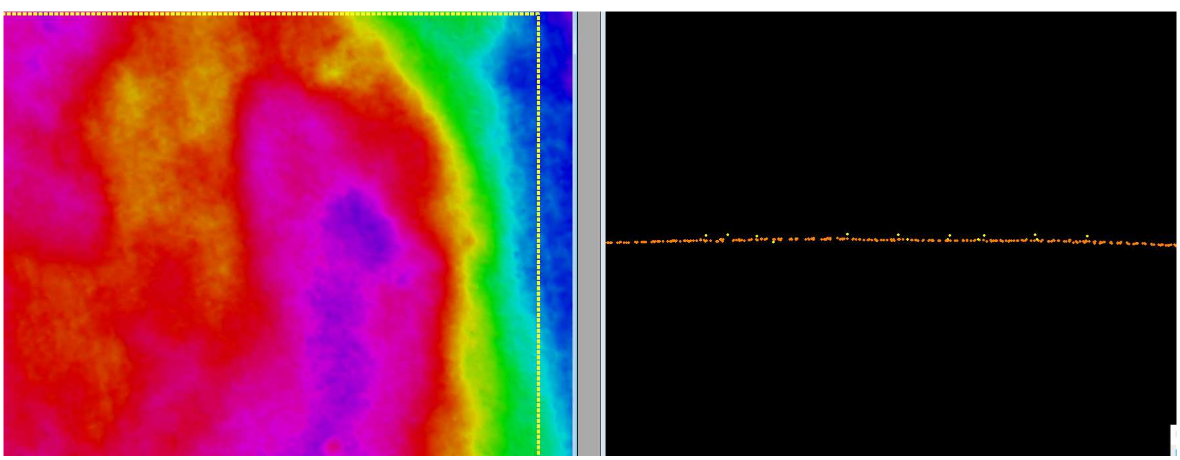

*Figure 19: Tile BC33_1000_3225 – Post filter*

## 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 5 000m² or larger in size.

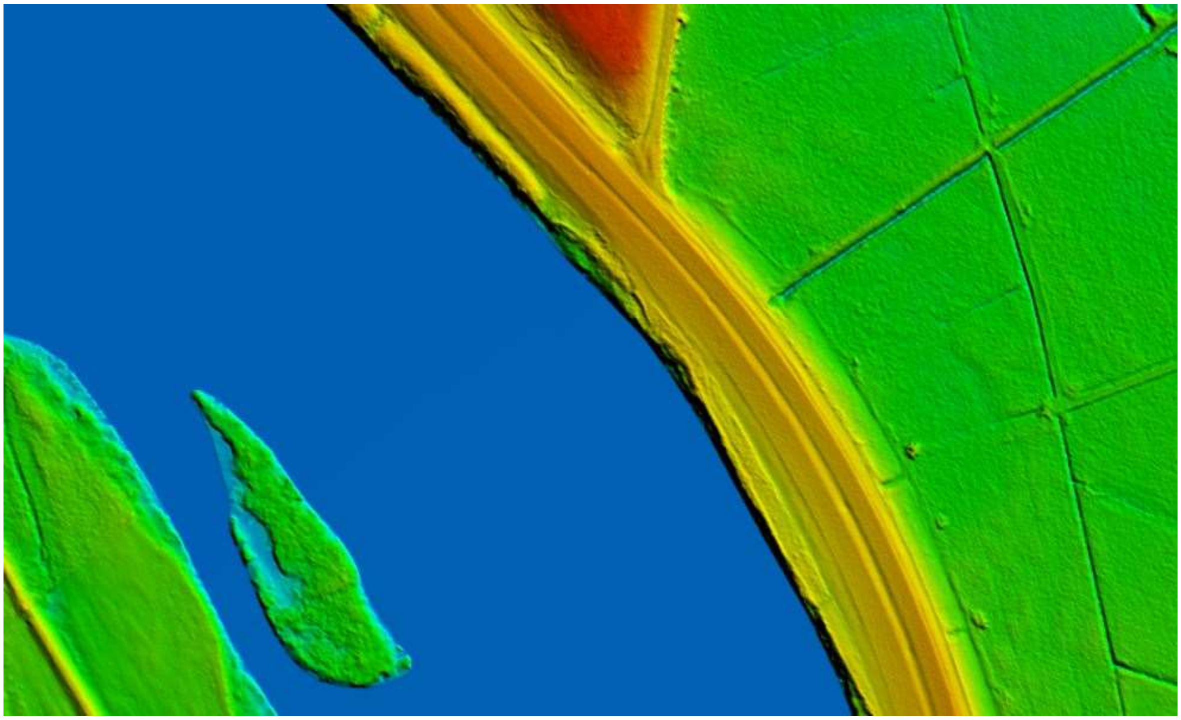

*Figure 20: Example of a hydro-flattened stream with a stream-island.*

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.

| | | | |
|---|---|---|---|
| 1 | 1929744.8358 | 5615128.2638 | 7.7096 |
| 2 | 1929746.0769 | 5615130.8498 | 7.6863 |
| 3 | 1929746.4280 | 5615131.5996 | 7.6796 |
| 4 | 1929746.5107 | 5615131.7727 | 7.678 |
| 5 | 1929746.7841 | 5615132.3591 | 7.6728 |
| 6 | 1929748.0794 | 5615135.0799 | 7.6483 |
| 7 | 1929748.5703 | 5615136.1455 | 7.6388 |
| 8 | 1929749.4246 | 5615138.0643 | 7.622 |
| 9 | 1929749.8587 | 5615139.0742 | 7.6132 |
| 10 | 1929750.6288 | 5615140.9327 | 7.5973 |
| 11 | 1929751.0393 | 5615141.7916 | 7.5896 |
| 12 | 1929751.5292 | 5615142.7809 | 7.5805 |
| 13 | 1929754.3861 | 5615148.3485 | 7.529 |
| 14 | 1929754.7868 | 5615149.1041 | 7.5219 |
| 15 | 1929754.7991 | 5615149.1267 | 7.5217 |
| 16 | 1929757.3347 | 5615152.1834 | 7.4808 |
| 17 | 1929757.8445 | 5615152.7752 | 7.4594 |

*Figure 21: Excerpt of river points used to create the centreline*

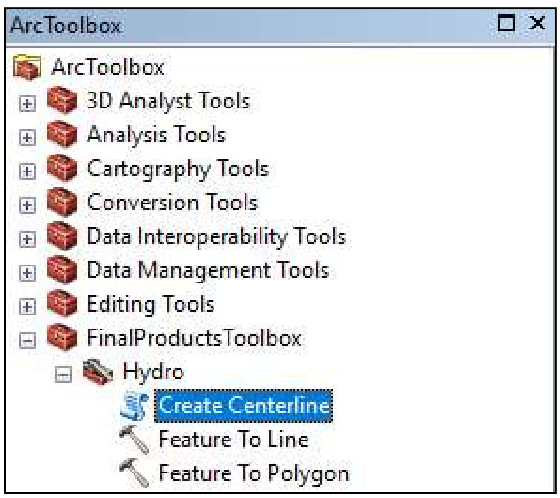


*Figure 22: Centreline for the stream within the project's survey*

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:

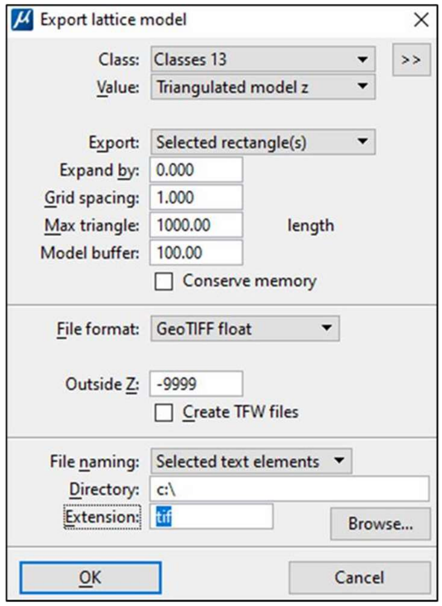


*Figure 23: Settings used to export lattice models.*

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.

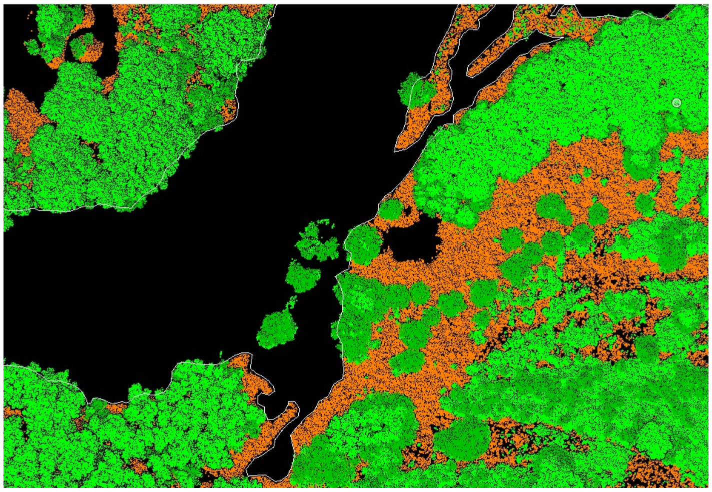

*Figure 24: Example of Pre-filter, overhead view of ground and veg points with hydro lines*

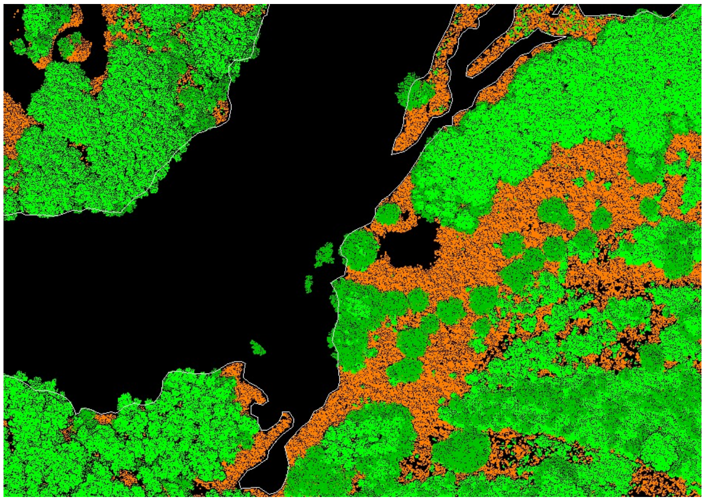

*Figure 25: Example of Post-filter, overhead view of ground and veg points with hydro lines*

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 26: Point cloud – boulder filled stream*


*Figure 27: 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 8.1.3 requires that a geo-referenced, digital spatial representation of the detailed extents of each delivered dataset.

The data for Block B – Priority was captured using Leica TerrainMapper sensors 513 and 559, flown on days 5th, 15th, 29th and 31st January 2021 and days 3rd, 16th, 17th of February 2021 and days 11th, 13th and 21st of March 2021. The extent of Block B Priority can be seen in Figure 27. 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.

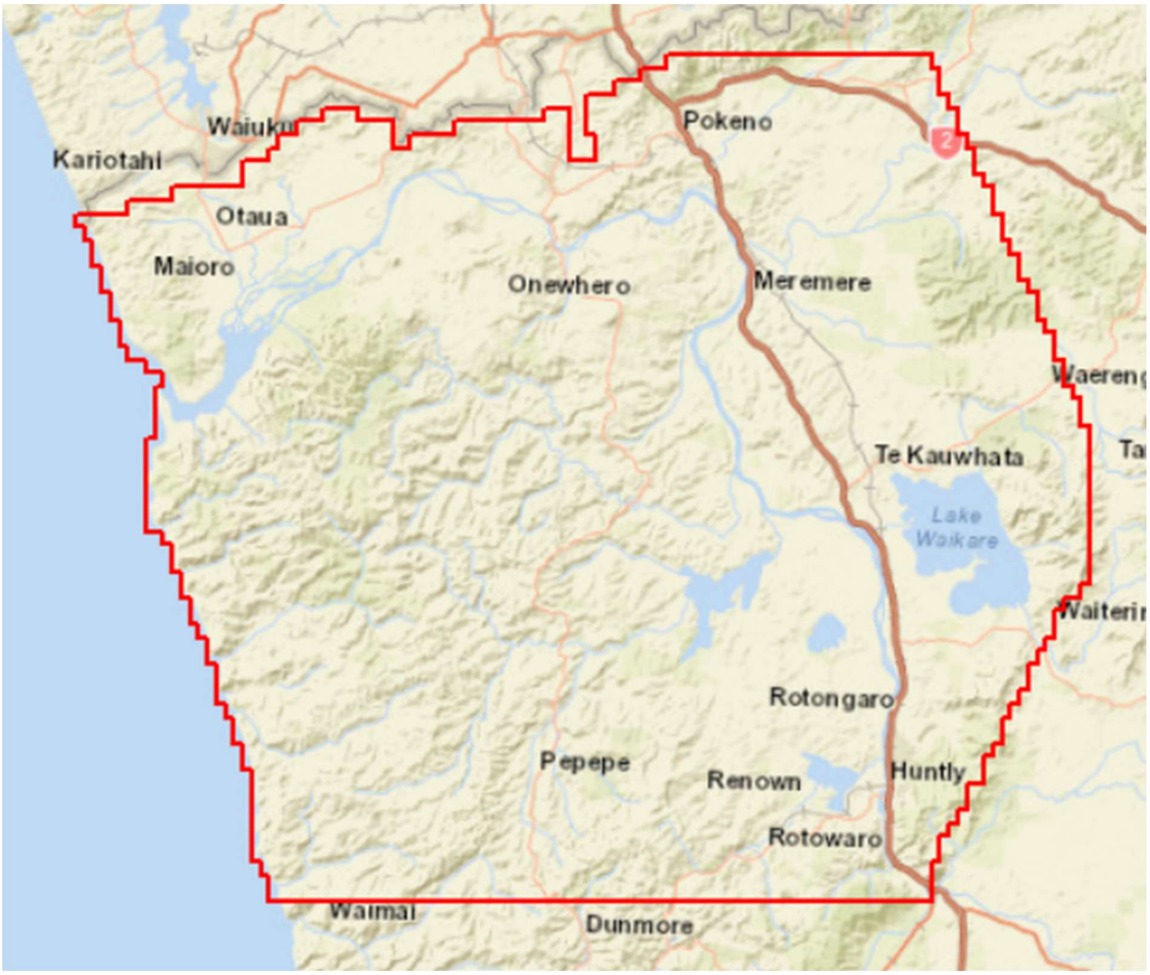


*Figure 28: Extent of deliverable data for Priority B (red outline)*

### 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.

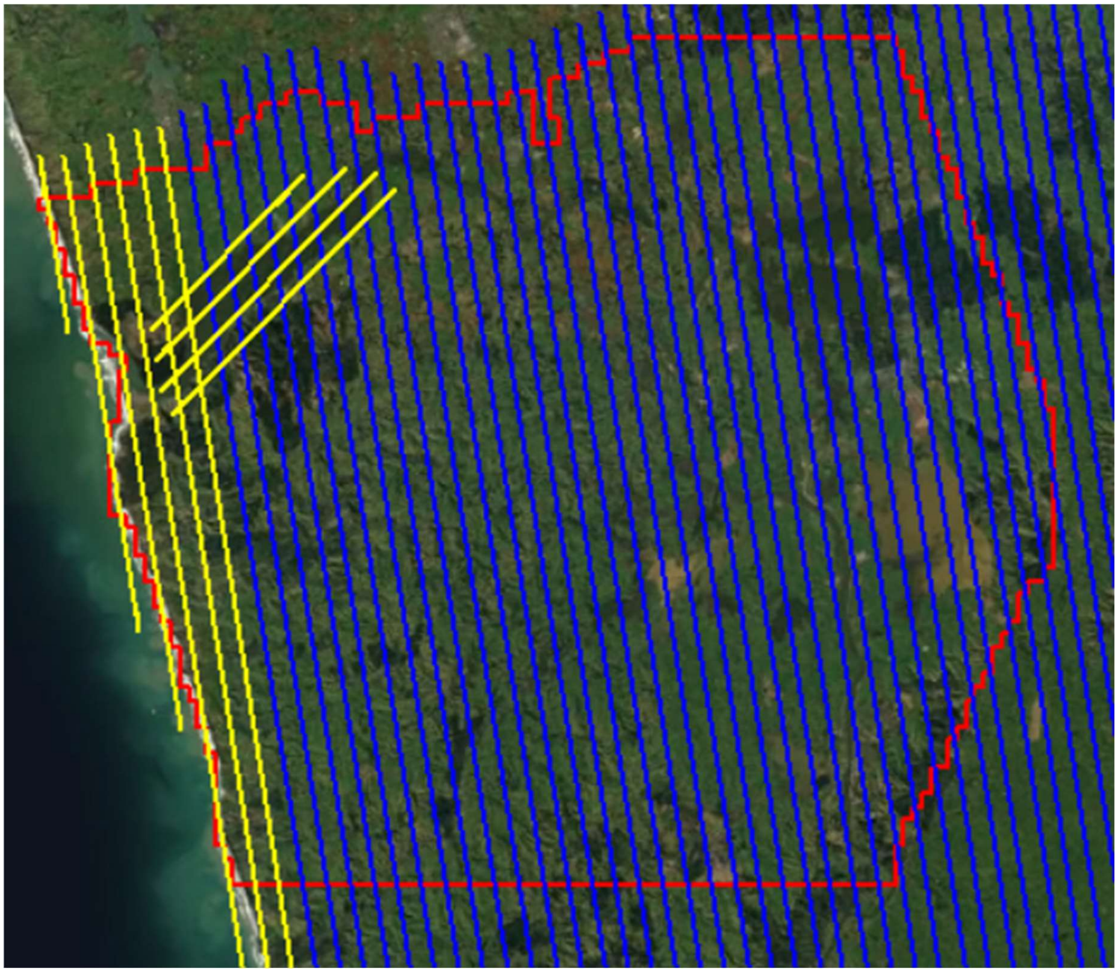

*Figure 29: Flight lines for 4ppm2 data coverage over Block B Priority – yellow lines are tidal*

## 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 30: WKT of a LAS file shown by LASTools.*

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.

| File | Points | Version | File Signature | File Source ID | SRS Source | System Identifier |
|---|---|---|---|---|---|---|
| CL2_BC31_2021_1000_4249.las | 1,248,386 | 1.4 | LASF | 0 | WKT | Leica Terrain Mapper |
| CL2_BC31_2021_1000_4250.las | 2,559,869 | 1.4 | LASF | 0 | WKT | Leica Terrain Mapper |
| CL2_BC31_2021_1000_4349.las | 676,633 | 1.4 | LASF | 0 | WKT | Leica Terrain Mapper |
| CL2_BC31_2021_1000_4350.las | 2,037,574 | 1.4 | LASF | 0 | WKT | Leica Terrain Mapper |
| CL2_BC31_2021_1000_4450.las | 1,347,018 | 1.4 | LASF | 0 | WKT | Leica Terrain Mapper |
| CL2_BC31_2021_1000_4550.las | 641,665 | 1.4 | LASF | 0 | WKT | Leica Terrain Mapper |
| CL2_BC32_2021_1000_0101.las | 2,597,542 | 1.4 | LASF | 0 | WKT | Leica Terrain Mapper |
| CL2_BC32_2021_1000_0102.las | 2,932,468 | 1.4 | LASF | 0 | WKT | Leica Terrain Mapper |
| CL2_BC32_2021_1000_0103.las | 1,778,666 | 1.4 | LASF | 0 | WKT | Leica Terrain Mapper |
| CL2_BC32_2021_1000_0104.las | 3,328,893 | 1.4 | LASF | 0 | WKT | Leica Terrain Mapper |
| CL2_BC32_2021_1000_0105.las | 2,440,255 | 1.4 | LASF | 0 | WKT | Leica Terrain Mapper |
| CL2_BC32_2021_1000_0106.las | 2,030,583 | 1.4 | LASF | 0 | WKT | Leica Terrain Mapper |
| CL2_BC32_2021_1000_0107.las | 3,282,435 | 1.4 | LASF | 0 | WKT | Leica Terrain Mapper |
| CL2_BC32_2021_1000_0108.las | 1,629,978 | 1.4 | LASF | 0 | WKT | Leica Terrain Mapper |
| CL2_BC32_2021_1000_0109.las | 2,857,975 | 1.4 | LASF | 0 | WKT | Leica Terrain Mapper |
| CL2_BC32_2021_1000_0110.las | 3,571,174 | 1.4 | LASF | 0 | WKT | Leica Terrain Mapper |
| CL2_BC32_2021_1000_0111.las | 2,487,738 | 1.4 | LASF | 0 | WKT | Leica Terrain Mapper |
| CL2_BC32_2021_1000_0112.las | 3,198,191 | 1.4 | LASF | 0 | WKT | Leica Terrain Mapper |
| CL2_BC32_2021_1000_0113.las | 2,840,889 | 1.4 | LASF | 0 | WKT | Leica Terrain Mapper |
| CL2_BC32_2021_1000_0114.las | 2,639,726 | 1.4 | LASF | 0 | WKT | Leica Terrain Mapper |
| CL2_BC32_2021_1000_0115.las | 4,412,648 | 1.4 | LASF | 0 | WKT | Leica Terrain Mapper |

*Table 2: Condensed output from LP360 illustrating LAS file specification compliance*

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 analysist 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.

| File | Format | NoData Value | BPB | Bands | Data Type | Pixel Size | Coordinate System |
|---|---|---|---|---|---|---|---|
| DEM_BC32_2021_1000_3406.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BC32_2021_1000_3407.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BC32_2021_1000_3408.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BC32_2021_1000_3409.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BC32_2021_1000_3410.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BC32_2021_1000_3411.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BC32_2021_1000_3412.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BC32_2021_1000_3413.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BC32_2021_1000_3414.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BC32_2021_1000_3415.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BC32_2021_1000_3416.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BC32_2021_1000_3417.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BC32_2021_1000_3418.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BC32_2021_1000_3419.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BC32_2021_1000_3420.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BC32_2021_1000_3421.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BC32_2021_1000_3422.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BC32_2021_1000_3423.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BC32_2021_1000_3424.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |

*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:

- o Grid Method = Binning (Maximum Value – DSM)
- o 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 29 is an excerpt of one of the DSM tiles created for the project area.

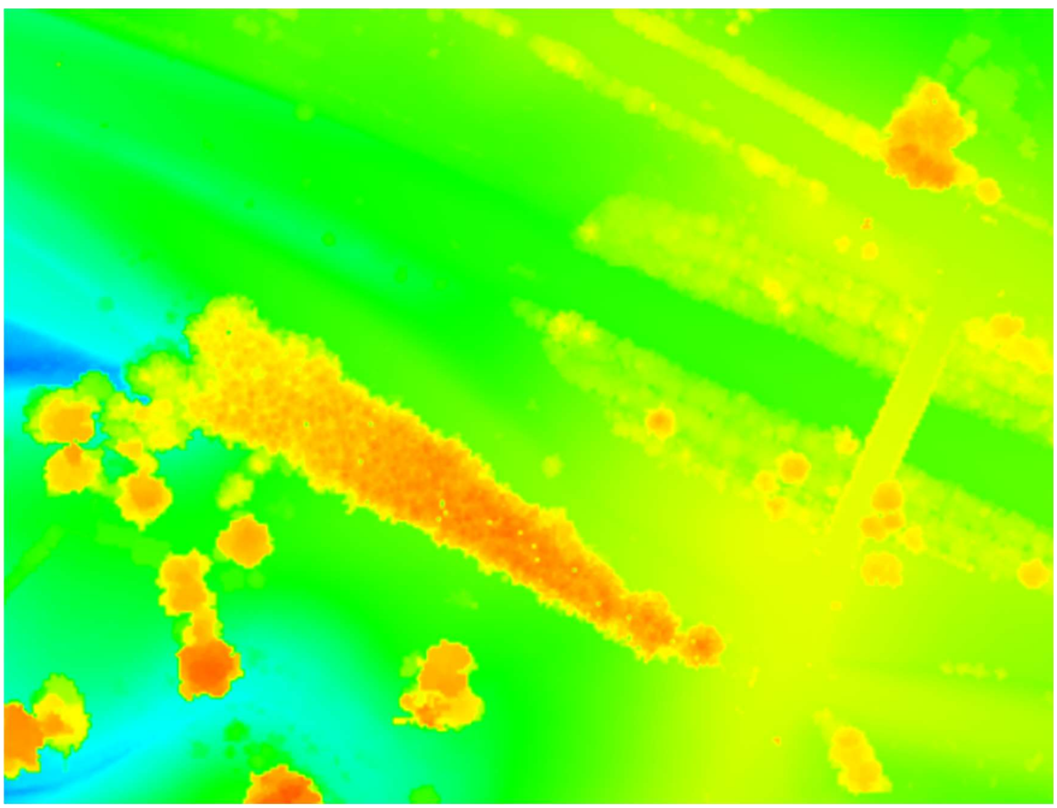

*Figure 31: Excerpt from DSM_BB33_2021_1000_4416*

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.

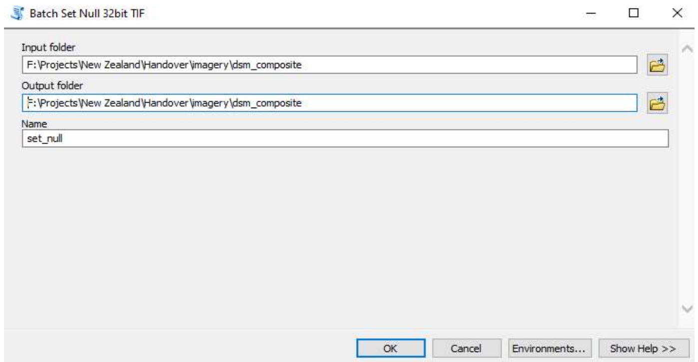


*Figure 32: Script used in ArcMap to achieve a NoData value of -9999.*

| | |
|---|---|
| Format | IMAGINE Image |
| Source Type | Generic |
| Pixel Type | floating point |
| Pixel Depth | 32 Bit |
| NoData Value | -9999 |

*Figure 33: 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.

| File | Format | NoData Value | BPB | Bands | Data Type | Pixel Size | Coordinate System |
|---|---|---|---|---|---|---|---|
| DSM_BC33_2021_1000_2905.tif | GTiff | 0 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BC33_2021_1000_2906.tif | GTiff | 0 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BC33_2021_1000_2907.tif | GTiff | 0 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BC33_2021_1000_2908.tif | GTiff | 0 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BC33_2021_1000_2909.tif | GTiff | 0 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BC33_2021_1000_2910.tif | GTiff | 0 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BC33_2021_1000_2911.tif | GTiff | 0 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BC33_2021_1000_2912.tif | GTiff | 0 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BC33_2021_1000_2913.tif | GTiff | 0 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BC33_2021_1000_2914.tif | GTiff | 0 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BC33_2021_1000_2915.tif | GTiff | 0 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BC33_2021_1000_2916.tif | GTiff | 0 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BC33_2021_1000_2917.tif | GTiff | 0 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BC33_2021_1000_2918.tif | GTiff | 0 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BC33_2021_1000_2919.tif | GTiff | 0 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BC33_2021_1000_2920.tif | GTiff | 0 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BC33_2021_1000_2921.tif | GTiff | 0 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BC33_2021_1000_2922.tif | GTiff | 0 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |

*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.

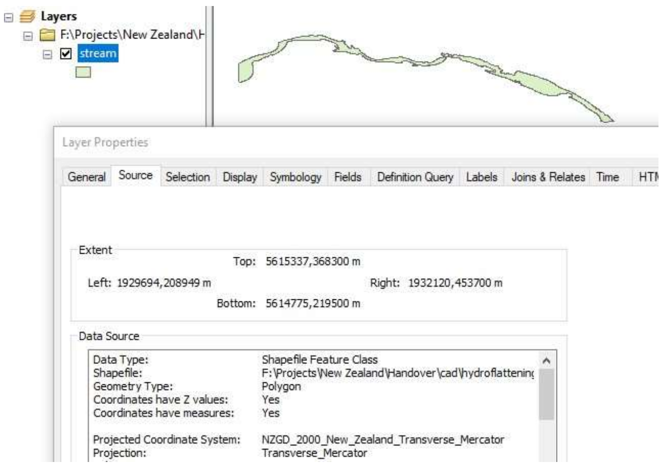


*Figure 34: Stream break line properties in ArcMap.*

## 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 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.

# 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_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.

| | | |
|---|---|---|
| Naming Convention for point clouds, DEMs, and other tiled products<br>*[product]_[sheet]_[year]_[scale]_[tile].[ext]* | | |
| **Product** | *DEM* | **CL2-Point Cloud Classification Level 2**<br>**DEM-Bare Earth Digital Elevation Model**<br>**DSM-Digital Surface Model**<br>DTM-Digital Terrain Model<br>UNC-Unclassified Point Cloud<br>INT-Intensity image<br>CHM – Canopy Height Model<br>IMG-Aerial photography<br>etc |
| **Sheet** | *BK34* | LINZ Topo50 identifier (4 characters) |
| **Year** | *2016* | Year of survey commencement |
| **Scale** | *1000* | Nominal scale of NZTopo50 subtiles |
| **Tile** | *4118* | Row number (41), Column number (18) of tile with respect to an upper left origin |
| **ext** | *tif* | File extension according to format conventions<br>las<br>tif<br>shp<br>etc |
| *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-flatting break line bank line strings
│       │ └───stream_islands – Hydro-flatting 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 Priority 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 and subsequent supplies of data did not meet specification. There were issues with classification, intensity and interblock consistency. This has been corrected in the latest supply. The following section and associated figures illustrate how the data did not meet specification as identified by both Waikato Regional Council and LINZ and the fixes employed to remedy.

Vegetation present in ground classes and subsequently removed.

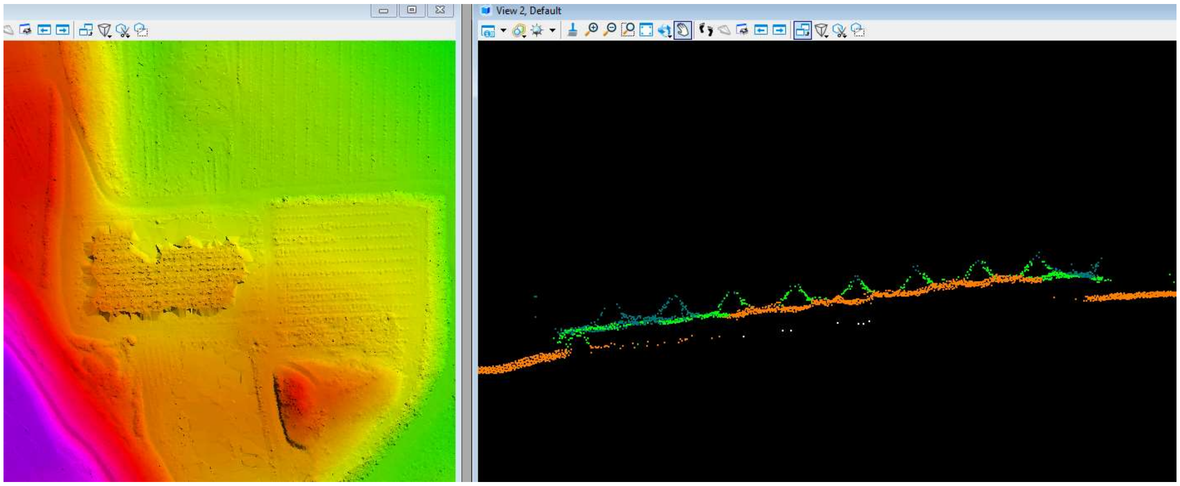

*Figure 35: Vegetation present in ground class (Tile example BC32_1648)*

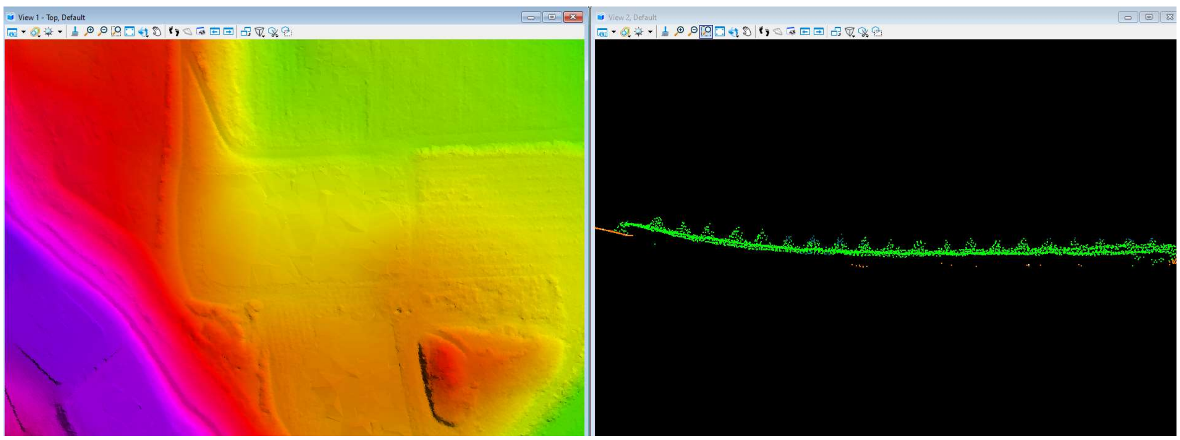

*Figure 36: Vegetation subsequently removed from ground class (Tile example BC32_1648)*

DEM Pitting. Reclassified points from ground class to noise

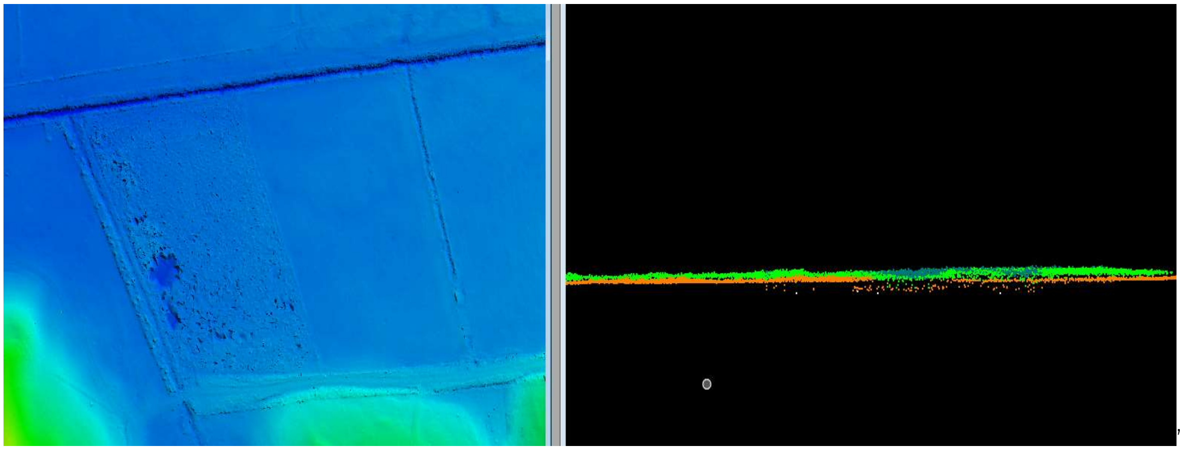

*Figure 37: DEM pitting evident in Tile BC32_4001*

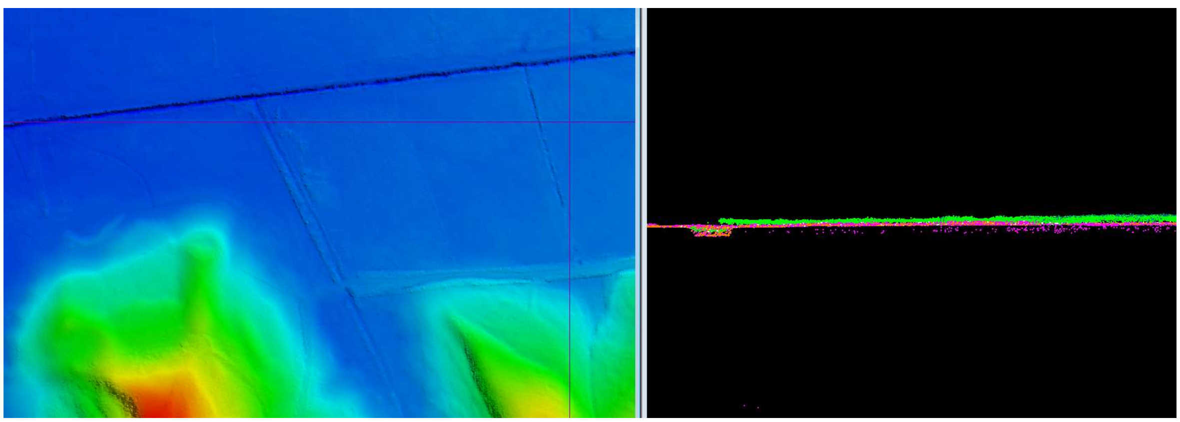

*Figure 38: DEM corrections in Tile BC32_4001*

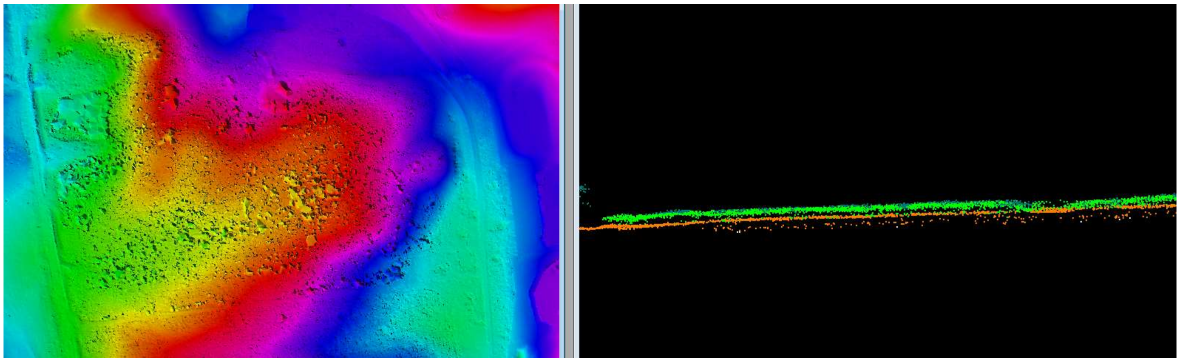

*Figure 39: DEM pitting evident in Tile BC33_1406*

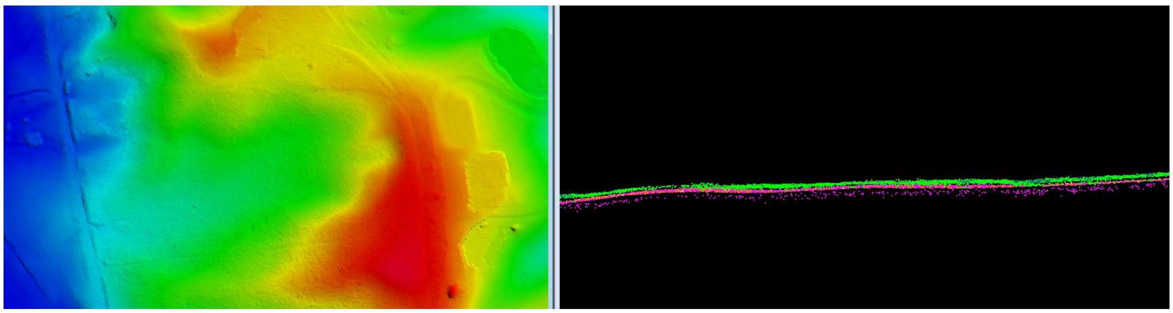

*Figure 40: DEM post correction in Tile BC33_1406*

DEM Spikes. Reclassify high points from ground class to noise points

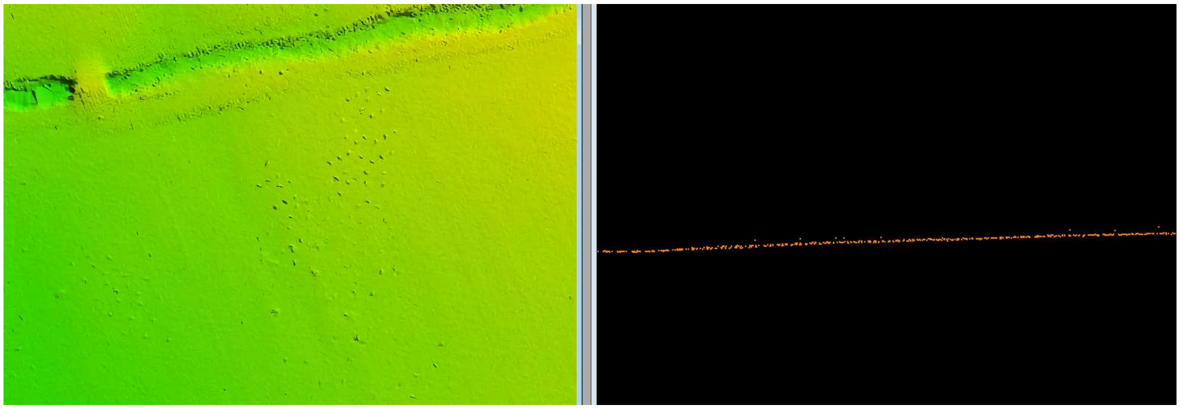

*Figure 41: DEM spikes evident in Tile BC33_4306*

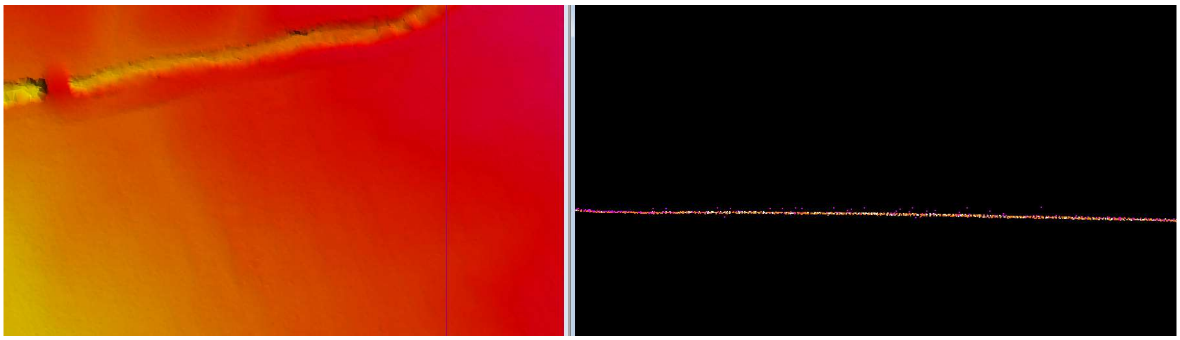

*Figure 42: DEM after spike removal in Tile BC33_4306*

Corduroy texture. Additional filter ran project wide to address texturing in DEM/DSM to derive more accurate surface.

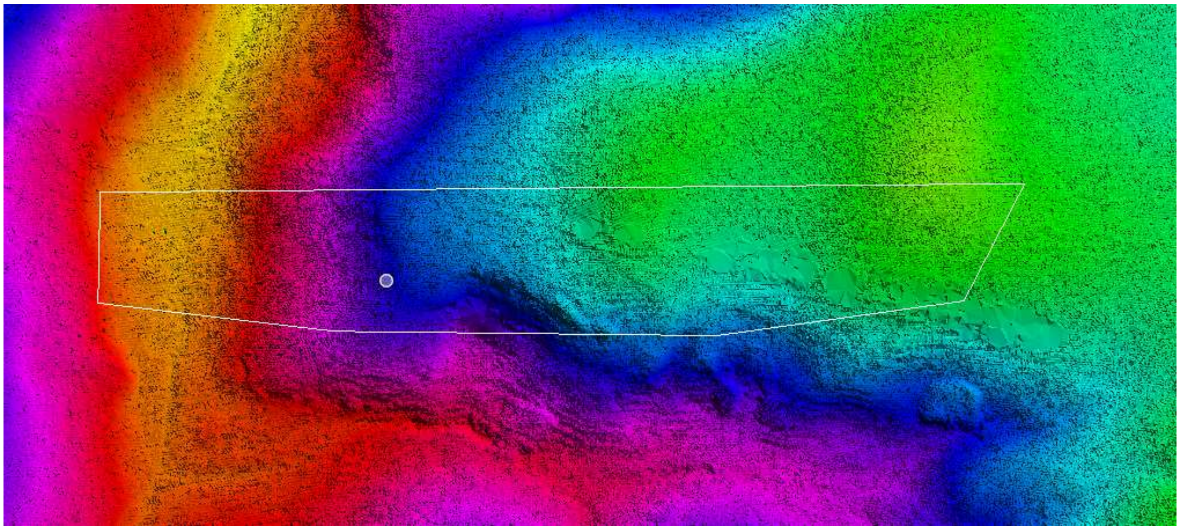

*Figure 43: Mottled surface evident in Tile BC32_4137*

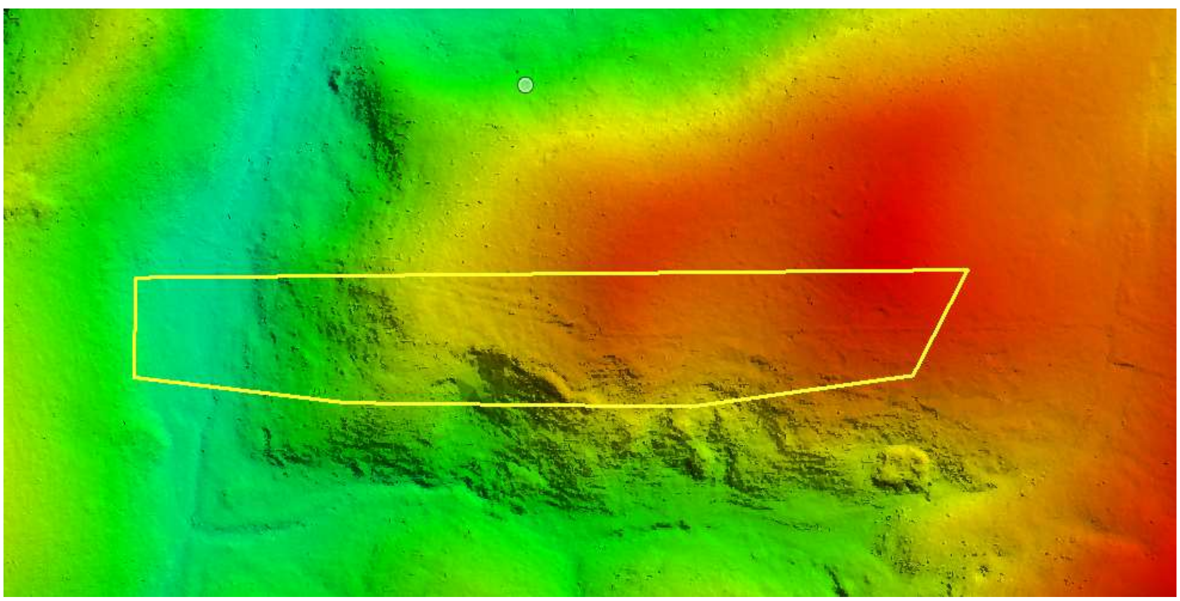

*Figure 44: Surface post filter in Tile BC32_4137*

Note further and more refined filters have been run on the latest supply of this dataset, further reducing the corduroy texture and remaining artefacts.

Reclassified ground points on bridge deck and regenerated DEM

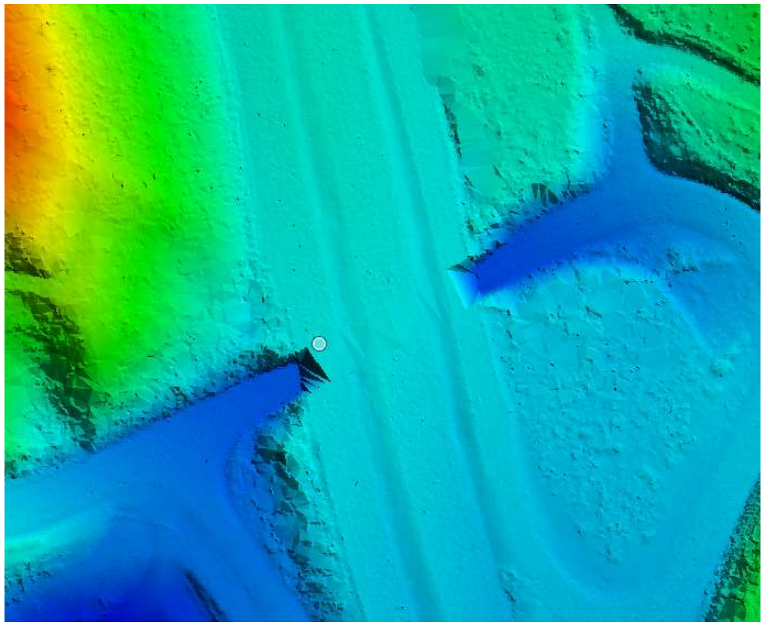

*Figure 45: Ground Points evident in Tile BB33_5002*

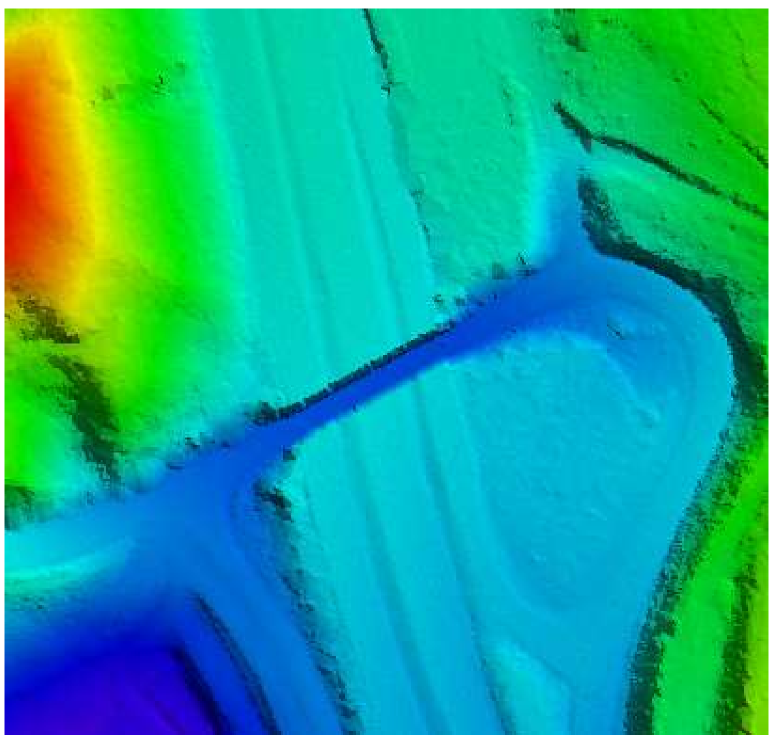

*Figure 46: Ground Points & Bridge removed in DEM Tile BB33_5002*

Shoreline placement. Horizontal placement was modified to include additional exposed ground.

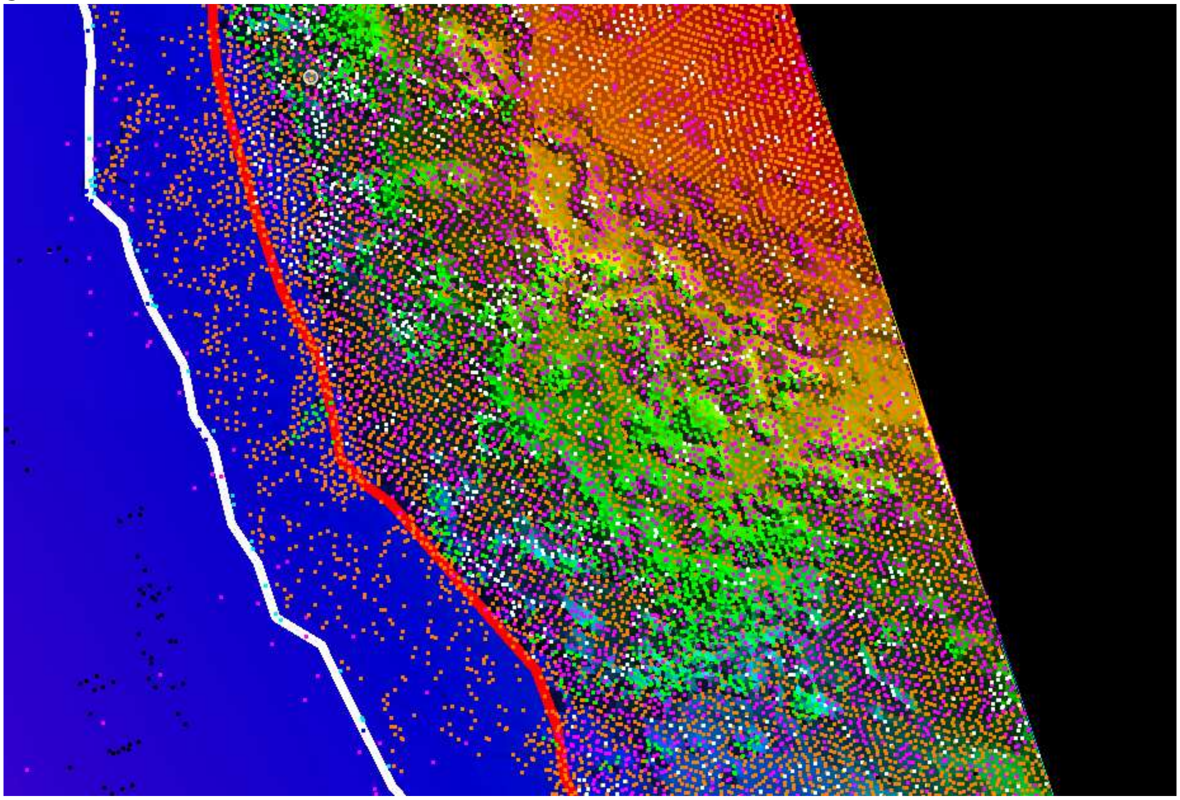

*Figure 47: Red is previous coastline. White is updated coastline Tile BC31_3445*

### 6.4.1 Delivery not Meeting Specification – Previous rendition

The last supply of Priority B prior to this supply was uploaded to Amazon S3 under the folder name Waikato_Block_B_Priority_26042023_Resupply. A Technical meeting was held between LINZ, WRC, Ocean Infinity and Woolpert to discuss the results of this dataset QA. It was widely agreed that this supply was of a poorer quality than the previous rendition. It seemed to introduce more errors than it fixed.

This latest supply of Priority B was a corrected version of the supply prior to above (Waikato_Block_B_Priority_25012023_Resupply). This approach was taken as it was deemed easier to fix this one as opposed to the latest resupply.

# 7 Results Acceptance & Signoff

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

| Result Acceptance | | | |
|---|---|---|---|
| Assessment Criteria | Status | Completed By | Date |
| Point cloud classification accuracy | Complete | Woolpert | 08/11/2022 |
| Point cloud classification consistency | Complete | Woolpert | 08/11/2022 |
| Point Cloud LAS tiled deliverables | Complete | Woolpert | 08/11/2022 |
| Hydro-flattened Digital Elevation Models | Complete | Woolpert | 08/11/2022 |
| Digital Survey Models | Complete | Woolpert | 08/11/2022 |
| Contours | Complete | Woolpert | 08/11/2022 |
| Extents, Flight Lines, Break lines, Tile Index | Complete | Woolpert | 08/11/2022 |
| | | | |
| Project Manager / Supervisor Signoff | Complete | Brian Foster | 08/11/2022 |
| Ocean Infinity Review | Complete | Luke Leydon | 10/11/2022 |

*Table 6: Processing Results Acceptable Signoff*

| Result Acceptance | | | |
|---|---|---|---|
| Assessment Criteria | Status | Completed By | Date |
| Point cloud classification accuracy | Complete | Woolpert | 08/11/2022 |
| Point cloud classification consistency | Complete | Woolpert | 08/11/2022 |
| Point Cloud LAS tiled deliverables | Complete | Woolpert | 08/11/2022 |
| Hydro-flattened Digital Elevation Models | Complete | Woolpert | 08/11/2022 |
| Digital Survey Models | Complete | Woolpert | 08/11/2022 |
| Contours | Complete | Woolpert | 08/11/2022 |
| Extents, Flight Lines, Break lines, Tile Index | Complete | Woolpert | 08/11/2022 |
| | | | |
| Project Manager / Supervisor Signoff | Complete | Mike Meiser | 18/11/2022 |
| Ocean Infinity Review | Complete | Luke Leydon | 18/11/2022 |

*Table 7: Processing Results Acceptable signoff (Rev1)*

| Result Acceptance | | | |
|---|---|---|---|
| Assessment Criteria | Status | Completed By | Date |
| Point cloud classification accuracy | Complete | Woolpert | 25/04/2023 |
| Point cloud classification consistency | Complete | Woolpert | 25/04/2023 |
| Point Cloud LAS tiled deliverables | Complete | Woolpert | 25/04/2023 |
| Hydro-flattened Digital Elevation Models | Complete | Woolpert | 25/04/2023 |
| Digital Survey Models | Complete | Woolpert | 25/04/2023 |
| Contours | Complete | Woolpert | 25/04/2023 |
| Extents, Flight Lines, Break lines, Tile Index | Complete | Woolpert | 25/04/2023 |
| | | | |
| Project Manager / Supervisor Signoff | Complete | Brian Foster | 25/04/2023 |
| Ocean Infinity Review | Complete | Luke Leydon | 26/04/2023 |

*Table 8: Processing Results Acceptable signoff (Rev2)*

| Result Acceptance | | | |
|---|---|---|---|
| Assessment Criteria | Status | Completed By | Date |
| Point cloud classification accuracy | Complete | Woolpert | 08/06/2023 |
| Point cloud classification consistency | Complete | Woolpert | 08/06/2023 |
| Point Cloud LAS tiled deliverables | Complete | Woolpert | 08/06/2023 |
| Hydro-flattened Digital Elevation Models | Complete | Woolpert | 08/06/2023 |
| Digital Survey Models | Complete | Woolpert | 08/06/2023 |
| Contours | Complete | Woolpert | 08/06/2023 |
| Extents, Flight Lines, Break lines, Tile Index | Complete | Woolpert | 08/06/2023 |
| | | | |
| Project Manager / Supervisor Signoff | Complete | Brian Foster | 08/06/2023 |
| Ocean Infinity Review | Complete | Luke Leydon | 22/06/2023 |

*Table 9: Processing Results Acceptable signoff (Rev3)*

# Appendix A: Lidar Quality Assurance Results

Provided as separate Documents:

| | | | |
|---|---|---|---|
| Priority_B_deliver_LASQC_Waikato_June2023 | 14/06/2023 9:56 AM | Microsoft Excel M... | 17,729 KB |
| Priority_B_LP360_results_for_DEMs_June2023 | 14/06/2023 9:56 AM | Microsoft Excel W... | 563 KB |
| Priority_B_LP360_results_for_DSMs_June2023 | 14/06/2023 9:56 AM | Microsoft Excel W... | 561 KB |
| Priority_B_LP360_results_point_LAS_June2023 | 14/06/2023 9:56 AM | Microsoft Excel W... | 4,317 KB |
| Priority_B_TSCAN_classes_June2023 | 14/06/2023 9:56 AM | Microsoft Excel W... | 10 KB |

# Waikato Local Authority Shared Services (WLASS) / CoLAB LiDAR Data Capture Services

# LiDAR Processing Report Block B Remainder

Contract Number: AU411

Surveyed By: iXblue Pty Ltd / Ocean Infinity

Processing Completed By: WOOLPERT

Prepared For: Waikato Local Authority Shared Services / CoLAB Better Together

Document Date: 12 December 2022

Ocean Infinity (Australia) Pty Ltd
ABN 61 128 811 978
oceaninfinity.com

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## Document Revision

| Revision No | Issue Purpose | Prepared | Checked | Approved |
|---|---|---|---|---|
| 0 | Issue Block B LiDAR Processing Report | L Leydon | BF/MM | D Field |
| 1 | Revised Report at resupply | L Leydon | BF/MM | D Field |
| 2 | Revised DEM section 4.3.1 | L Leydon | MM | D Field |
| 3 | Updated at data Resupply | L Leydon | BF | D Feild |

## Approval for Issue

| Name | Signature | Date |
|---|---|---|
| Luke Leydon | | 12-12-2022 |

# Revision History

| Item | Description of change | Section | Revision |
|---|---|---|---|
| 1 | Amendment to Introduction, Additional text added to classification consistency section, Additional text added to DSM section, Section 6.5 added | 1,2.11,4.3.2,6.5 | 1 |
| 2 | Revised DEM Methodology | 4.3.1 | 2 |
| 3 | New Appendices supplied to reflect data resupply. Amendment to Introduction. Section 6.5 updated. Update figure 10 – point classification statistics. | 1, 6.5, Appendices | 3 |
| | | | |
| | | | |
| | | | |
| | | | |

# Contents

# Tables

# Figures

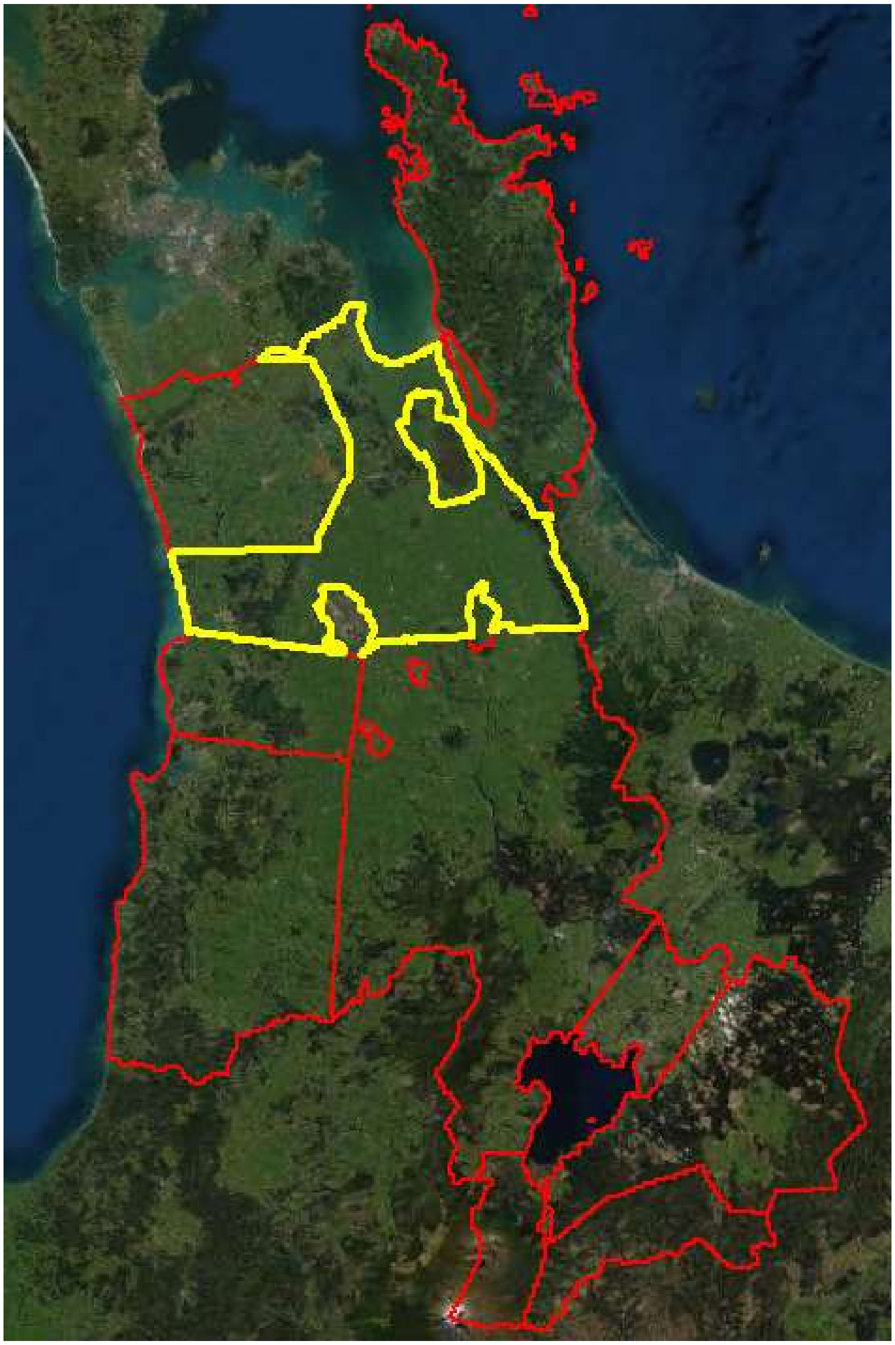

*Figure 1: Waikato Survey Area*

# 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

- AU411_WLASS-Collection_Report-10052021.pdf.

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).

https://www.linz.govt.nz/system/files_force/media/doc/pgf_version_new_zealand_national_aerial_lidar_base_specification.pdf?download=1

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:

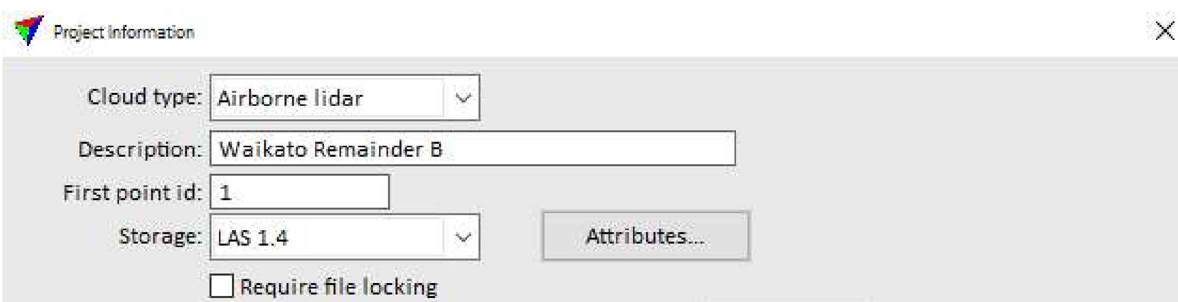


*Figure 2: LAS 1.4 being specified during project*

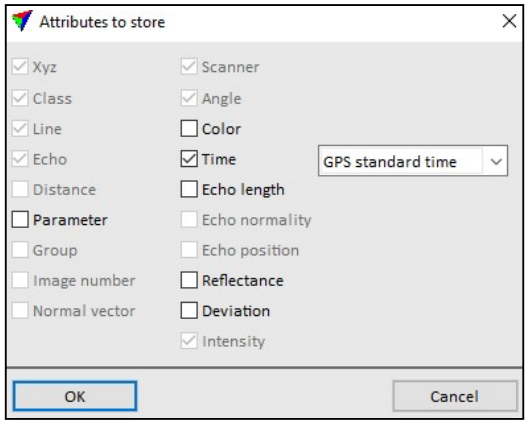


*Figure 3: Project settings used in TerraScan project when importing points into the project.*

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.

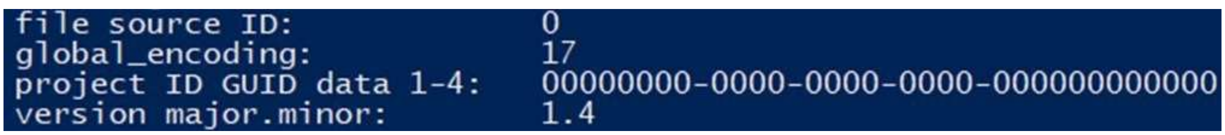


*Figure 4: Confirmation of LAS 1.4 being the file format of handover laser point files using LASTools*

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)

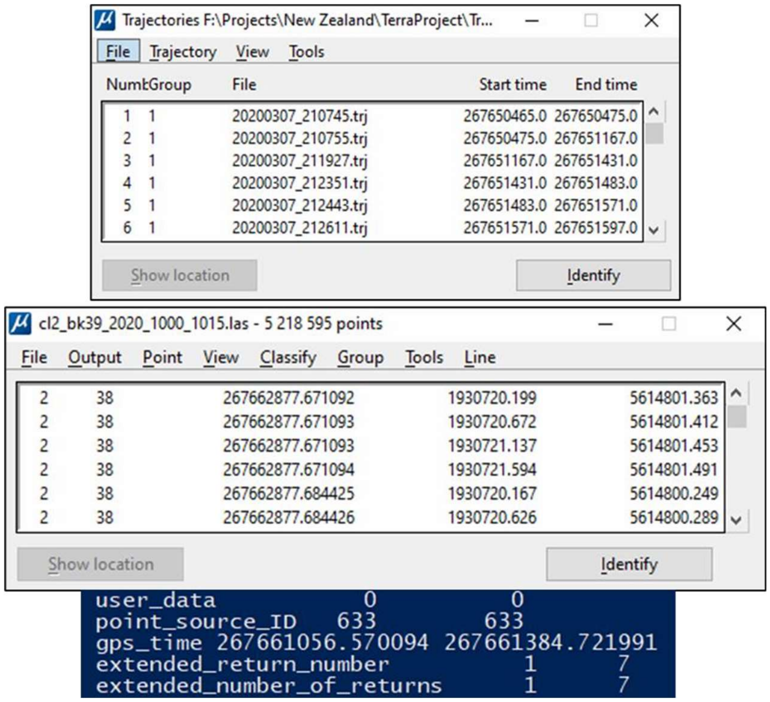


*Figure 5: Representative examples of LAS point attributes*

## 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.

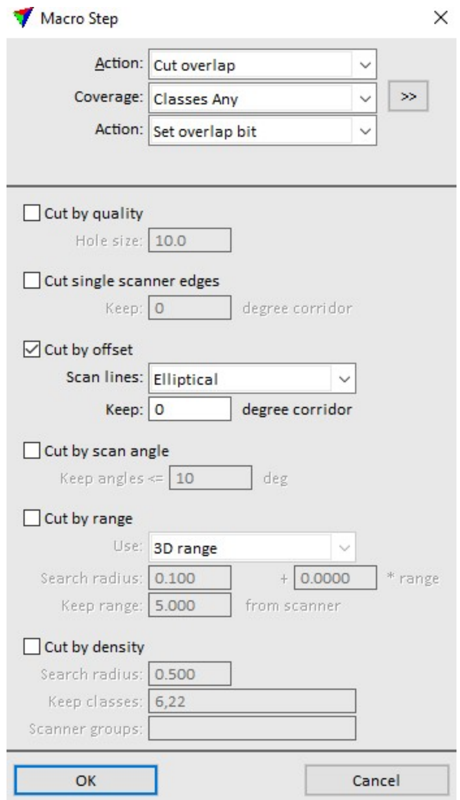


*Figure 6: Settings used when cutting overlap in Microstation.*

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:

| Code | Description |
|---|---|
| 1 | Processed, but unclassified |
| 2 | Ground |
| 3 | Low vegetation <2m |
| 4 | Medium vegetation |
| 5 | High vegetation >8m |
| 6 | Building |
| 7 | Low noise |
| 9 | Water |
| 17 | Bridge deck |
| 18 | High noise |

*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.

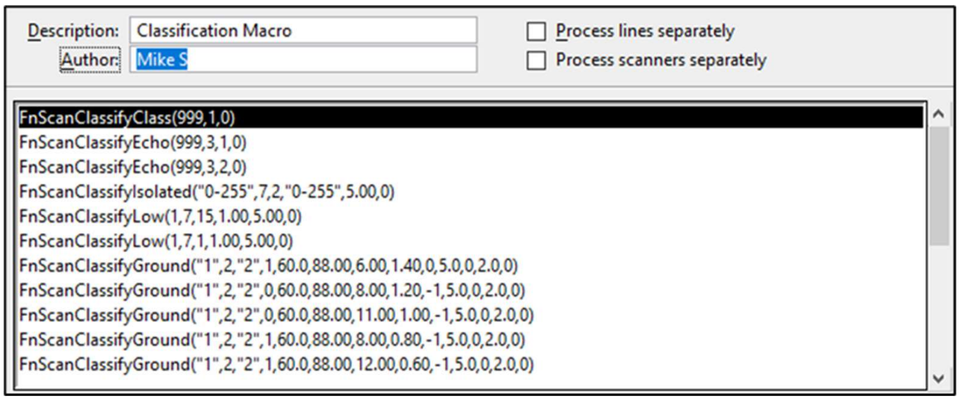


*Figure 7: Automatic classification macro developed for the project area.*

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.

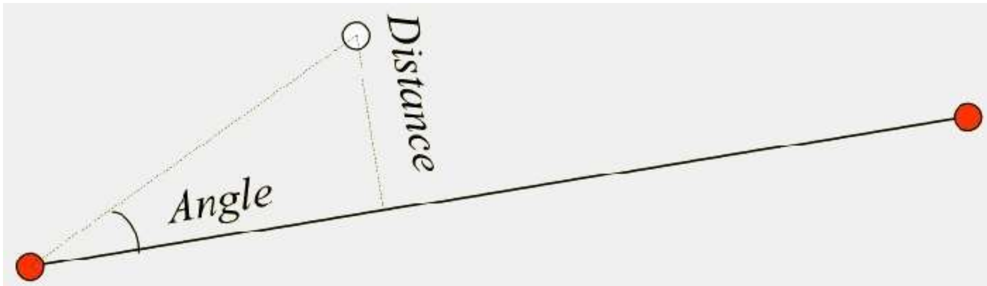


*Figure 8: Illustration of iteration angle and iteration distance parameters in the ground routine.*

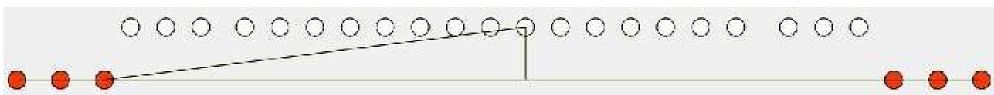

*Figure 9: A smaller iteration distance value avoids classification of ground points on low objects.*

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.

| Class # | Class | Count |
|---|---|---|
| 1 | Unclassified | 30686649 |
| 2 | Ground | 19756365059 |
| 3 | Low Veg | 1066086938 |
| 4 | Medium Veg | 2894068914 |
| 5 | High Veg | 4954331584 |
| 6 | Building | 79988352 |
| 9 | Water | 15286408 |
| 17 | Bridge Deck | 556184 |
| W7 | Witheld Low Noise | 1673690020 |
| W18 | Witheld High Noise | 50629487 |
| O1 | Overlap Unclassified | 9850325 |
| O2 | Overlap Ground | 7622487971 |
| O3 | Overlap Low Veg | 403539841 |
| O4 | Overlap Medium Veg | 1025451110 |
| O5 | Overlap High Veg | 1751872720 |
| O6 | Overlap Building | 28537166 |
| O17 | Overlap Bridge | 177654 |
| OW7 | Overlap/Witheld Low Noise | 894838077 |
| OW18 | Overlap/Witheld High Noise | 10621542 |

*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.

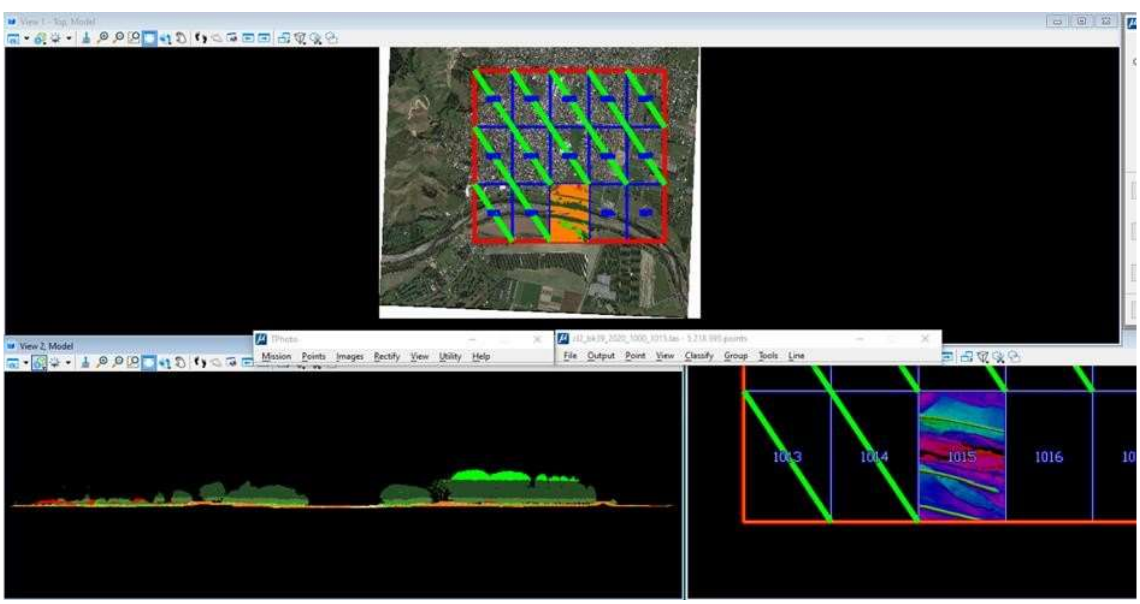

*Figure 11: The green diagonal hatching seen above shows blocks which have been fully checked.*

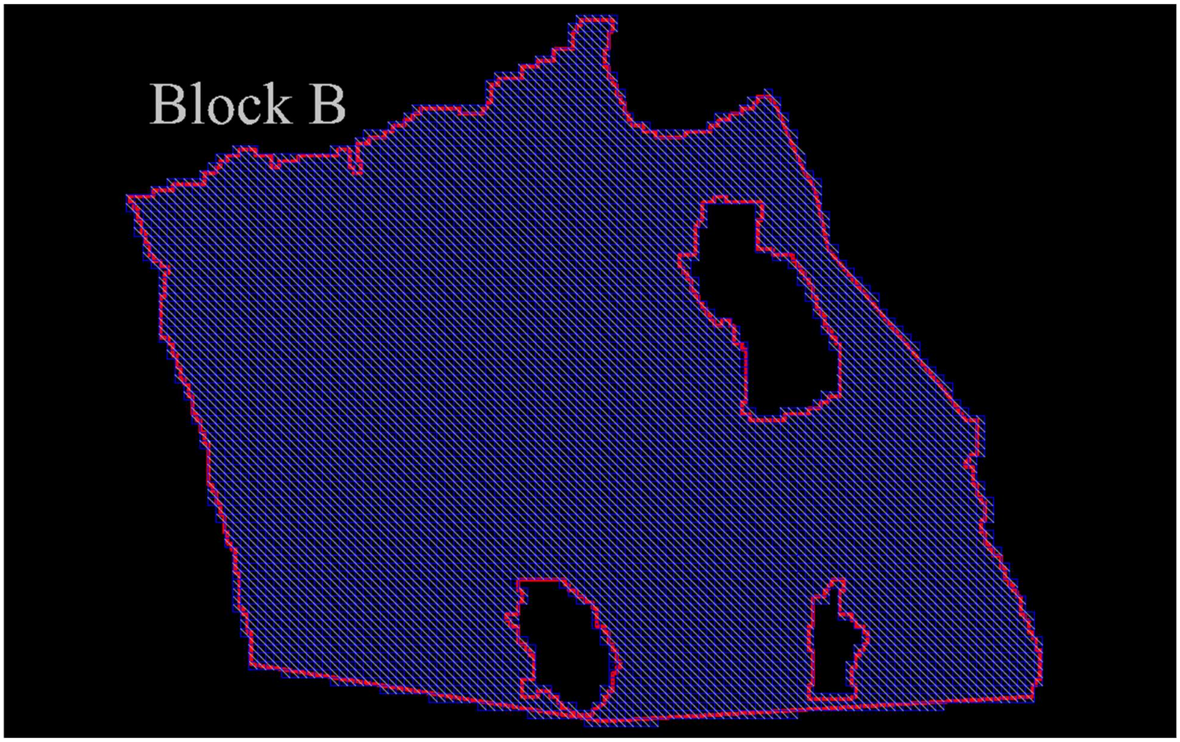


*Figure 12: The diagonal hatching seen above shows how the progress was tracked*

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.

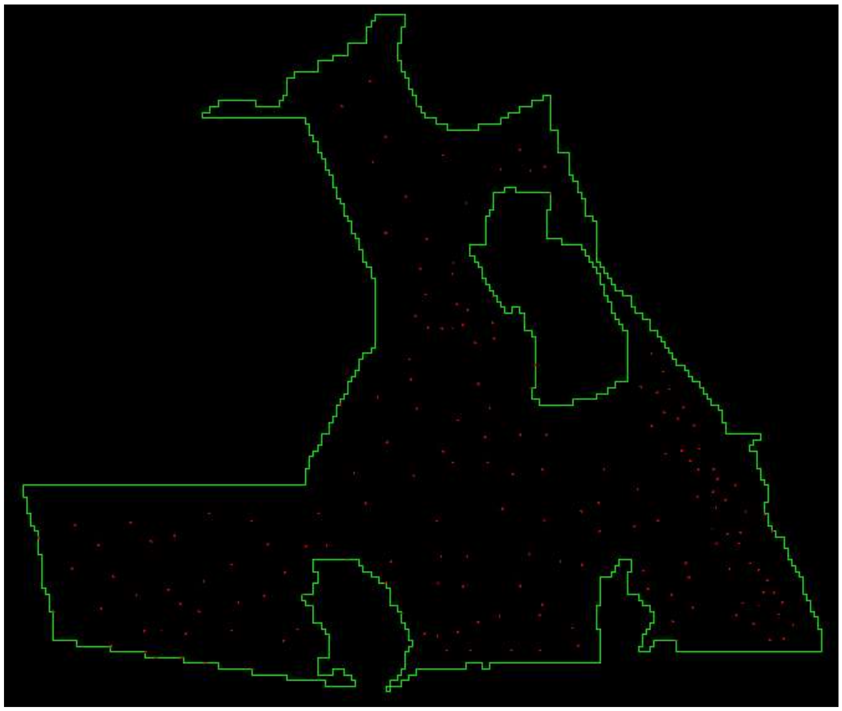

*Figure 13: The polygons are areas for further investigation*

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 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.

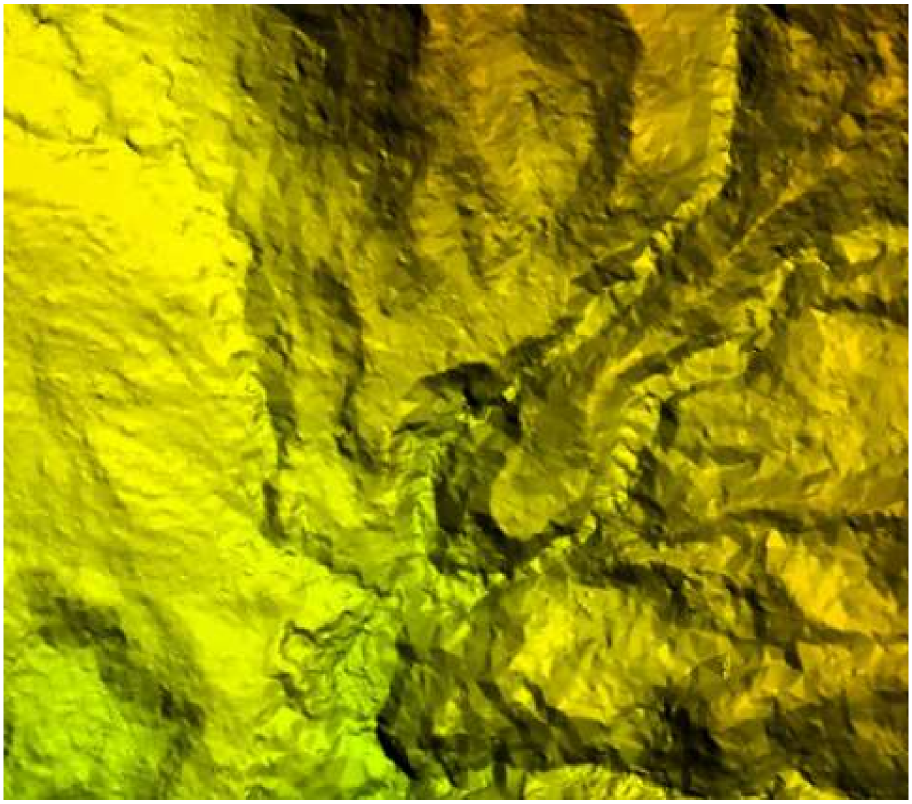

*Figure 14: Example overhead image of DEM Interpolation*

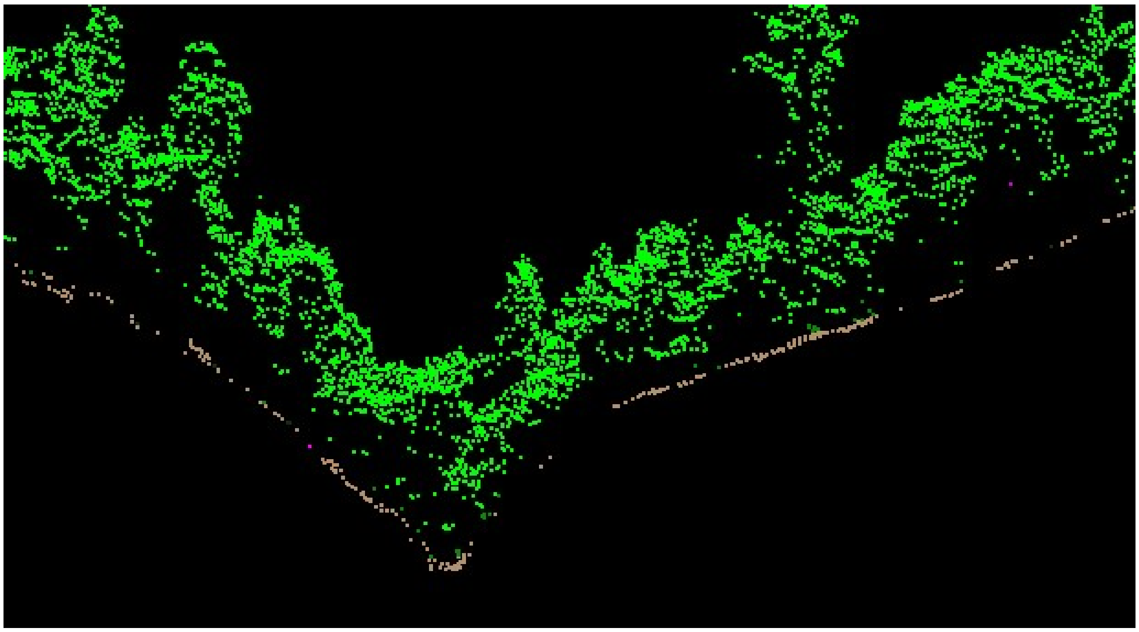

*Figure 15: LAS point cloud view from previous figure*

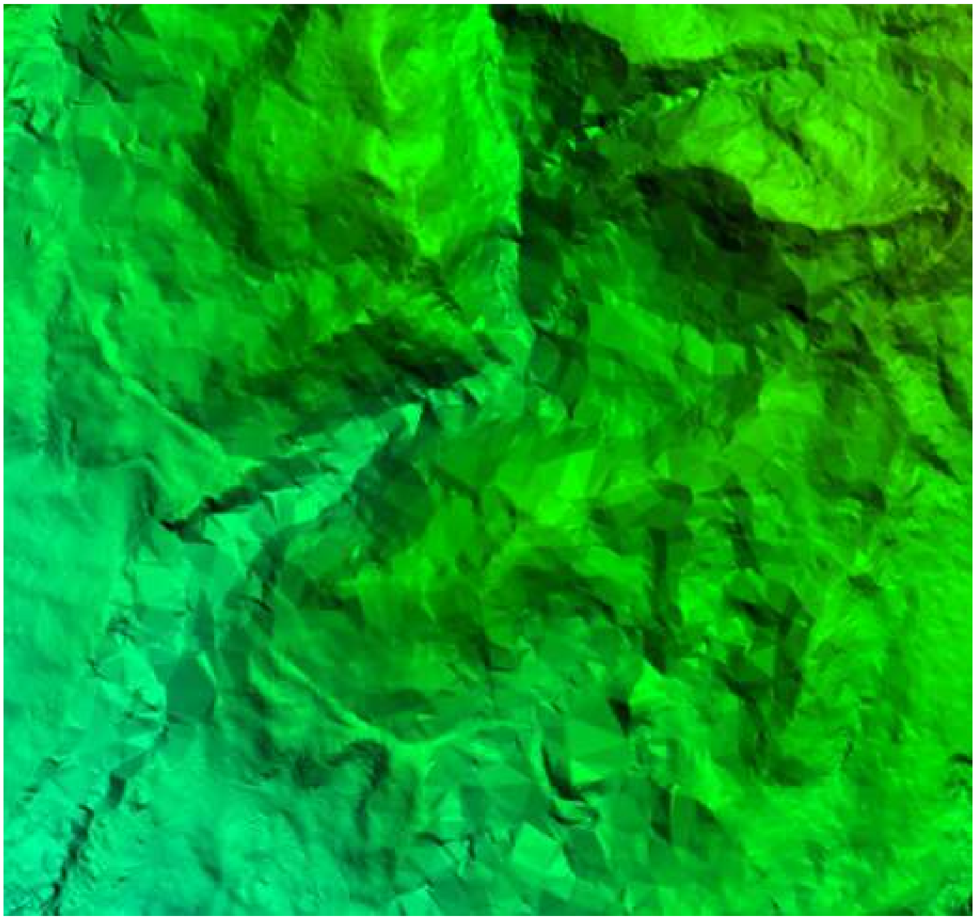

*Figure 16: Example overhead image of DEM interpolation*

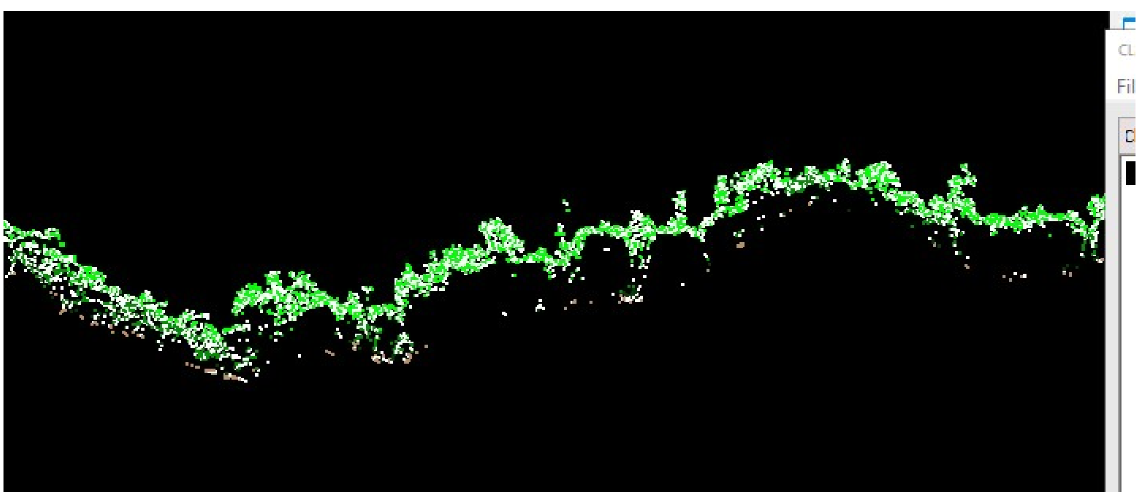

*Figure 17: LAS Point cloud view from previous figure*

## 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 5 000m$^2$ or larger in size.

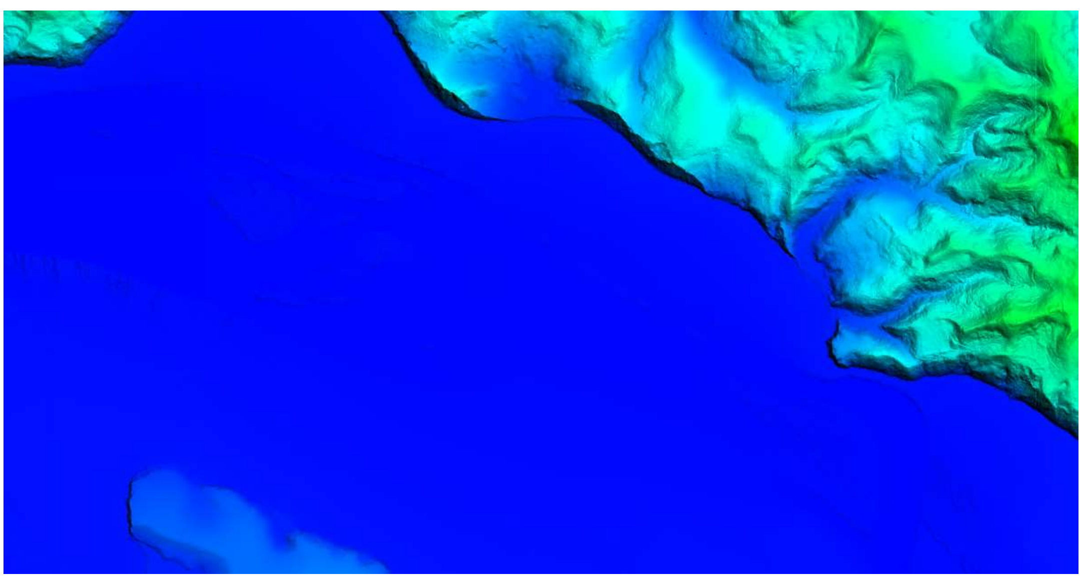

*Figure 18: Example of a hydro-flattened stream with a stream-island.*

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.

| | | | |
|---|---|---|---|
| 1 | 1929744.8358 | 5615128.2638 | 7.7096 |
| 2 | 1929746.0769 | 5615130.8498 | 7.6863 |
| 3 | 1929746.4280 | 5615131.5996 | 7.6796 |
| 4 | 1929746.5107 | 5615131.7727 | 7.678 |
| 5 | 1929746.7841 | 5615132.3591 | 7.6728 |
| 6 | 1929748.0794 | 5615135.0799 | 7.6483 |
| 7 | 1929748.5703 | 5615136.1455 | 7.6388 |
| 8 | 1929749.4246 | 5615138.0643 | 7.622 |
| 9 | 1929749.8587 | 5615139.0742 | 7.6132 |
| 10 | 1929750.6288 | 5615140.9327 | 7.5973 |
| 11 | 1929751.0393 | 5615141.7916 | 7.5896 |
| 12 | 1929751.5292 | 5615142.7809 | 7.5805 |
| 13 | 1929754.3861 | 5615148.3485 | 7.529 |
| 14 | 1929754.7868 | 5615149.1041 | 7.5219 |
| 15 | 1929754.7991 | 5615149.1267 | 7.5217 |
| 16 | 1929757.3347 | 5615152.1834 | 7.4808 |
| 17 | 1929757.8445 | 5615152.7752 | 7.4594 |

*Figure 19: Excerpt of river points used to create the centreline*

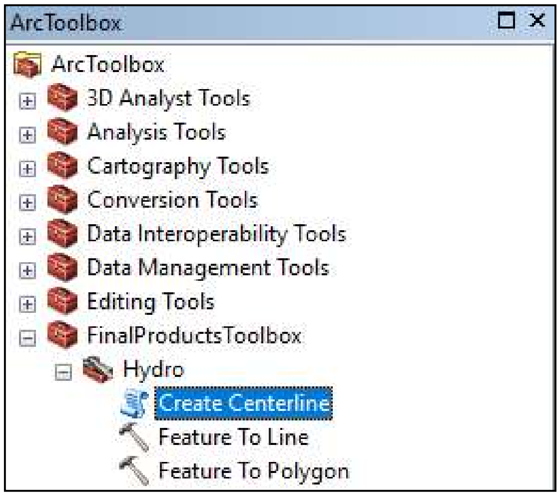


*Figure 20: Centreline for the stream within the project's survey*

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:

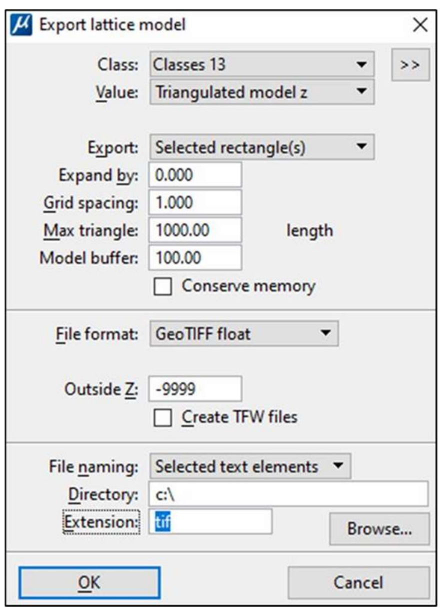


*Figure 21: Settings used to export lattice models.*

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.

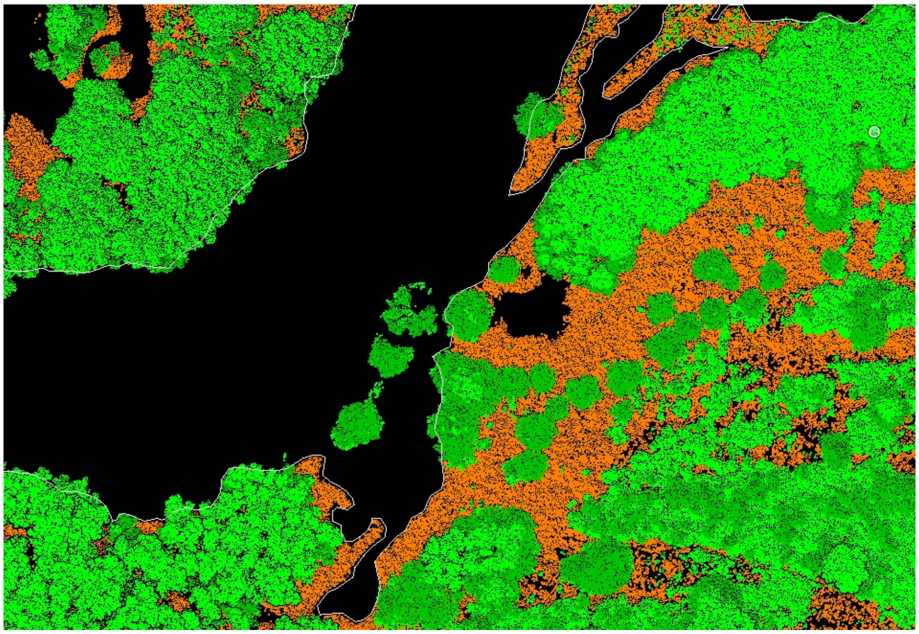

*Figure 22: Pre-filter, overhead view of ground and veg points with hydro lines*

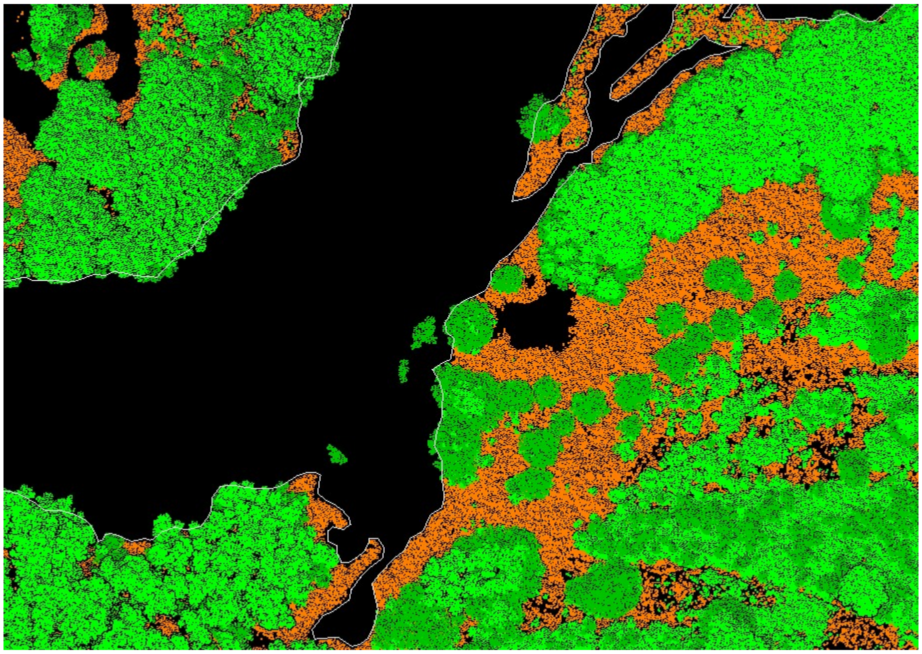

*Figure 23: Post-filter, overhead view of ground and veg points with hydro lines*

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 8.1.3 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, 15$^{th}$,27$^{th}$, 28$^{th}$, 29$^{th}$ 30$^{th}$ and 31$^{st}$ January 2021 and days 3$^{rd}$, 12$^{th}$, 16$^{th}$, 17$^{th}$, 18$^{th}$ , of February 2021 and days 11$^{th}$,13$^{th}$, 21$^{st}$, 22$^{nd}$, 23$^{rd}$, 24$^{th}$, 25$^{th}$ 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.

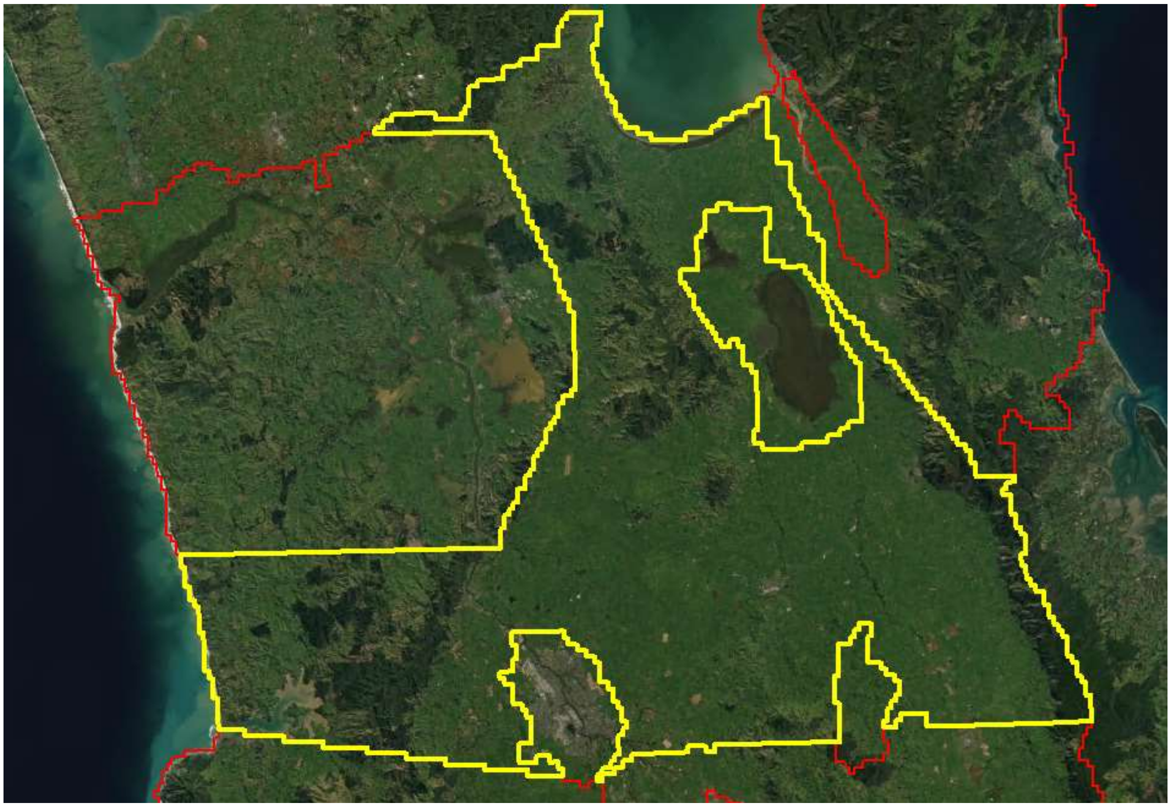

*Figure 26: Extent of deliverable data for Remainder B (yellow outline)*

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.

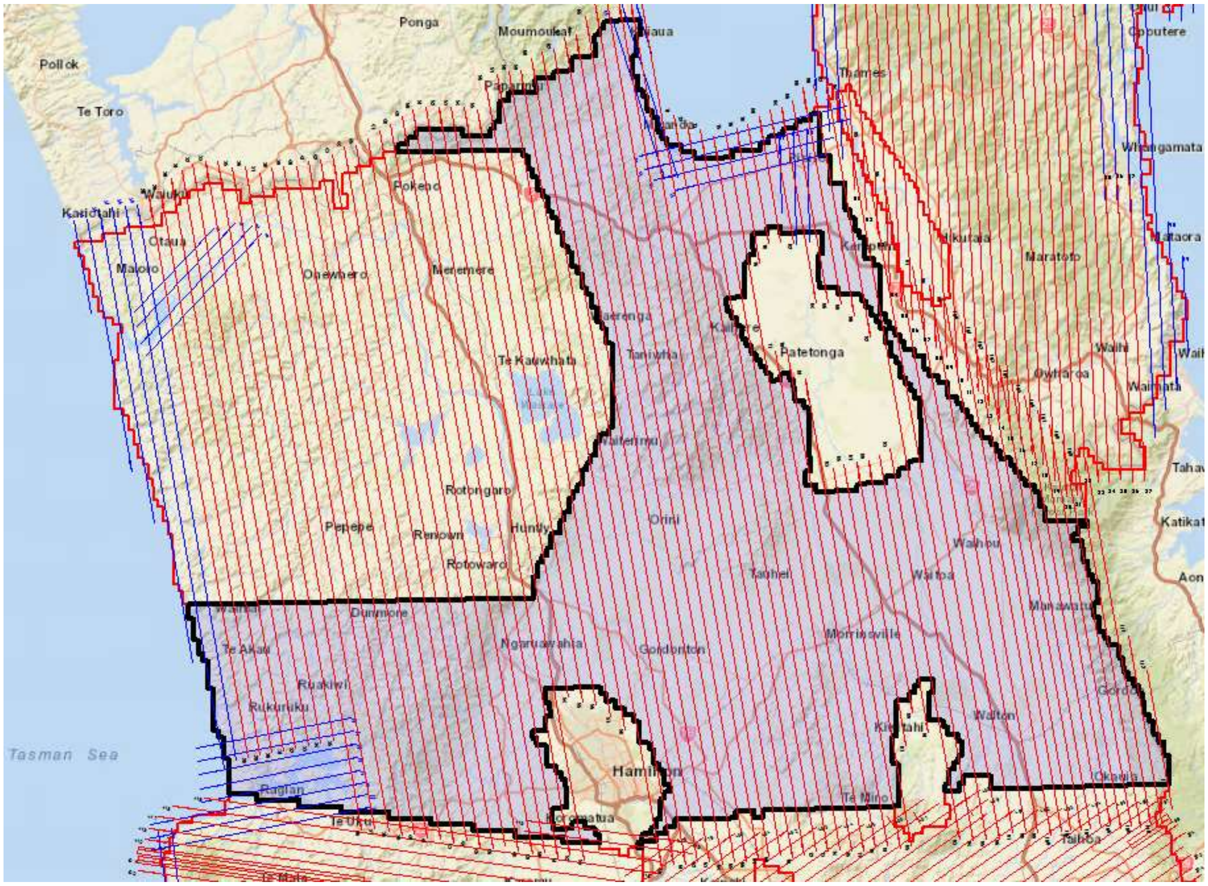


*Figure 27: Flight lines for 4ppm2 data coverage over Block B Remainder*

## 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.

```
variable length header record 1 of 1:
  reserved             0
  user ID              'LASF_Projection'
  record ID            2112
  length after header  951
  description          'by LAStools of rapidlasso GmbH'
    WKT OGC COORDINATE SYSTEM:
    COMPD_CS["NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016",PROJCS["NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000",GEOGCS["NZGD2000",DATUM["New_Zealan
d_Geodetic_Datum_2000",SPHEROID["GRS 1980",6378137,298.257222101,AUTHORITY["EPSG","7019"]],AUTHORITY["EPSG","6167"]],PRIMEM["Greenwich",0,AUTHORITY["EPSG","8901"]],UNIT["degree",0.0174532
251994328,AUTHORITY["EPSG","9122"]],AUTHORITY["EPSG","4167"]],PROJECTION["Transverse_Mercator"],PARAMETER["latitude_of_origin",0],PARAMETER["central_meridian",173],PARAMETER["scale_factor"
,0.9996],PARAMETER["false_easting",1600000],PARAMETER["false_northing",10000000],UNIT["metre",1,AUTHORITY["EPSG","9001"]],AXIS["Easting",EAST],AXIS["Northing",NORTH],AUTHORITY["EPSG","219
"]],VERT_CS["NZVD2016",VERT_DATUM["New Zealand Vertical Datum 2016",2005,AUTHORITY["EPSG","7839"]],UNIT["metre",1.0,AUTHORITY["EPSG","9001"]],AXIS["Gravity-related height",UP],AUTHORITY["E
PSG","7839"]]]
```

*Figure 28: WKT of a LAS file shown by LASTools.*

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.

| File | Points | Version | File Signature | File Source ID | CRS is WKT | System Identifier |
|---|---|---|---|---|---|---|
| CL2_BB33_2021_1000_2446.las | 4,447,397 | 1.4 | LASF | 0 | TRUE | Leica Terrain Mapper |
| CL2_BB33_2021_1000_2447.las | 2,563,807 | 1.4 | LASF | 0 | TRUE | Leica Terrain Mapper |
| CL2_BB33_2021_1000_2448.las | 3,530,507 | 1.4 | LASF | 0 | TRUE | Leica Terrain Mapper |
| CL2_BB33_2021_1000_2449.las | 5,076,742 | 1.4 | LASF | 0 | TRUE | Leica Terrain Mapper |
| CL2_BB33_2021_1000_2450.las | 3,519,328 | 1.4 | LASF | 0 | TRUE | Leica Terrain Mapper |
| CL2_BB33_2021_1000_2545.las | 2,562,712 | 1.4 | LASF | 0 | TRUE | Leica Terrain Mapper |
| CL2_BB33_2021_1000_2546.las | 4,397,136 | 1.4 | LASF | 0 | TRUE | Leica Terrain Mapper |
| CL2_BB33_2021_1000_2547.las | 3,039,872 | 1.4 | LASF | 0 | TRUE | Leica Terrain Mapper |
| CL2_BB33_2021_1000_2548.las | 3,981,573 | 1.4 | LASF | 0 | TRUE | Leica Terrain Mapper |
| CL2_BB33_2021_1000_2549.las | 4,100,164 | 1.4 | LASF | 0 | TRUE | Leica Terrain Mapper |
| CL2_BB33_2021_1000_2550.las | 4,228,343 | 1.4 | LASF | 0 | TRUE | Leica Terrain Mapper |
| CL2_BB33_2021_1000_2446.las | 3,493,064 | 1.4 | LASF | 0 | TRUE | Leica Terrain Mapper |
| CL2_BB33_2021_1000_2644.las | 4,447,397 | 1.4 | LASF | 0 | TRUE | Leica Terrain Mapper |

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

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 analysist 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.

| File | Format | NoData Value | BPB | Bands | Data Type | Pixel Size | Coordinate System |
|---|---|---|---|---|---|---|---|
| DEM_BB33_2021_1000_2450.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BB33_2021_1000_4043.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BC33_2021_1000_0343.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BC34_2021_1000_2326.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BC34_2021_1000_4237.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BD32_2021_1000_0729.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BD32_2021_1000_3043.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BD33_2021_1000_1509.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BD33_2021_1000_3618.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BD34_2021_1000_1025.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BD34_2021_1000_2025.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BD35_2021_1000_0104.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |

*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.

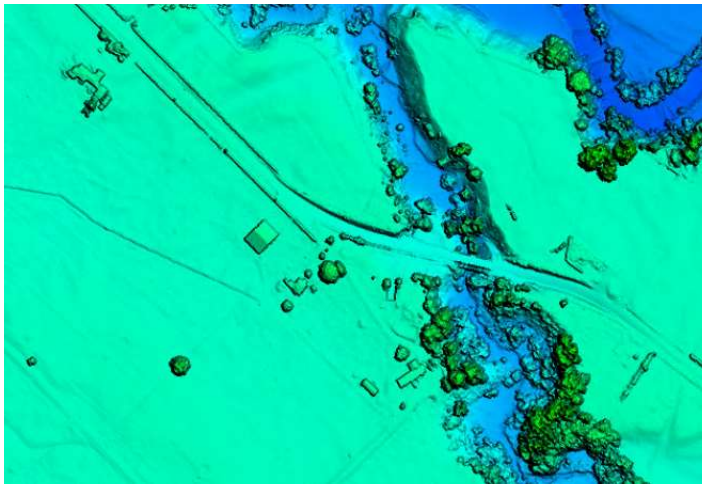

*Figure 29: Excerpt from DSM_BD35_2021_1000_2144.*

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.

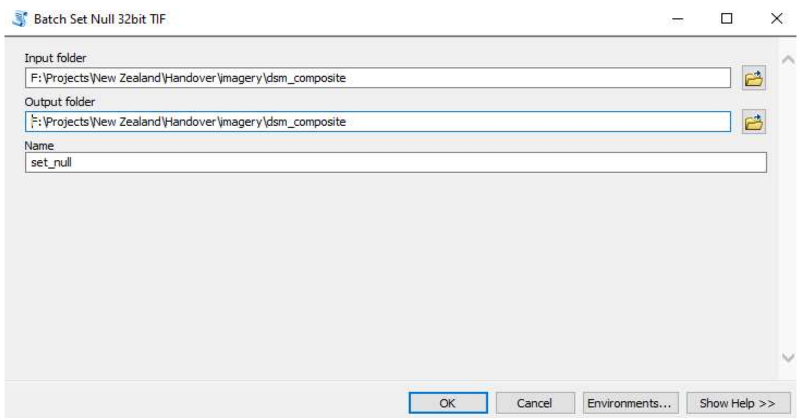


*Figure 30: Script used in ArcMap to achieve a NoData value of -9999.*

| | |
|---|---|
| Format | IMAGINE Image |
| Source Type | Generic |
| Pixel Type | floating point |
| Pixel Depth | 32 Bit |
| NoData Value | -9999 |

*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.

| File | Format | NoData Value | BPB | Bands | Data Type | Pixel Size | Coordinate System |
|---|---|---|---|---|---|---|---|
| DSM_BB33_2021_1000_2450.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BB33_2021_1000_4043.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BC33_2021_1000_0343.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BC34_2021_1000_2326.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BC34_2021_1000_4237.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BD32_2021_1000_0729.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BD32_2021_1000_3043.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BD33_2021_1000_1509.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BD33_2021_1000_3618.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BD34_2021_1000_1025.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BD34_2021_1000_2025.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BD35_2021_1000_0104.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |

*Table 4: LP360 Results example table*

## 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.

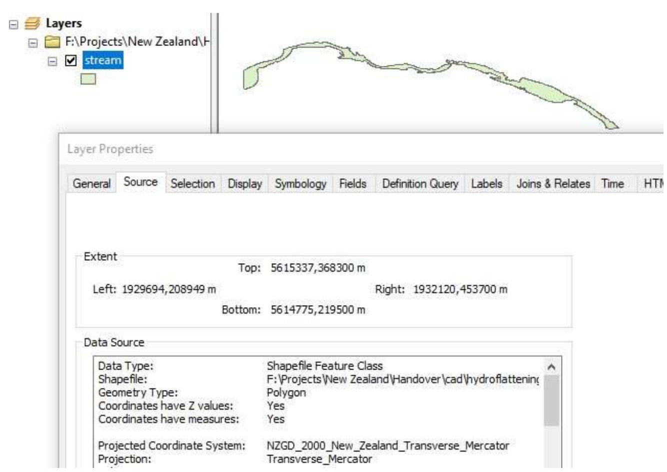


*Figure 32: Stream break line properties in ArcMap.*

## 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.

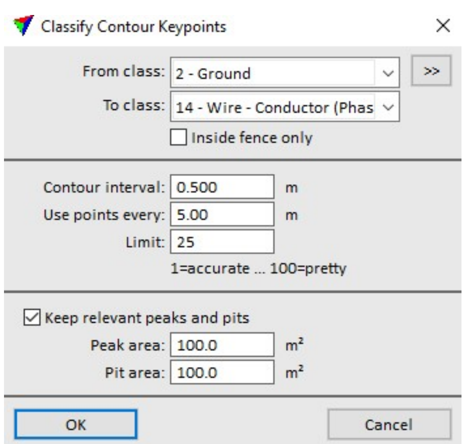


*Figure 33: Contour key points settings used in Terrascan.*

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_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.

o Check for presence of correct ESPG Codes for geodetic & vertical datums, and map projection

o 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.

| Naming Convention for point clouds, DEMs, and other tiled products<br>*[product]_[sheet]_[year]_[scale]_[tile].[ext]* | | |
|---|---|---|
| **Product** | *DEM* | **CL2-Point Cloud Classification Level 2**<br>**DEM-Bare Earth Digital Elevation Model**<br>**DSM-Digital Surface Model**<br>DTM-Digital Terrain Model<br>UNC-Unclassified Point Cloud<br>INT-Intensity image<br>CHM – Canopy Height Model<br>IMG-Aerial photography<br>etc |
| **Sheet** | *BK34* | LINZ Topo50 identifier (4 characters) |
| **Year** | *2016* | Year of survey commencement |
| **Scale** | *1000* | Nominal scale of NZTopo50 subtiles |
| **Tile** | *4118* | Row number (41), Column number (18) of tile with respect to an upper left origin |
| **ext** | *tif* | File extension according to format conventions<br>las<br>tif<br>shp<br>etc |
| *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-flatting break line bank line strings
│     │ └───stream_islands – Hydro-flatting 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.

| Result Acceptance | | | |
|---|---|---|---|
| Assessment Criteria | Status | Completed By | Date |
| Point cloud classification accuracy | Complete | Woolpert | 10 August 2022 |
| Point cloud classification consistency | Complete | Woolpert | 20 August 2022 |
| Point Cloud LAS tiled deliverables | Complete | Woolpert | 20 August 2022 |
| Hydro-flattened Digital Elevation Models | Complete | Woolpert | 20 August 2022 |
| Digital Survey Models | Complete | Woolpert | 20 August 2022 |
| Contours | Complete | Woolpert | 20 August 2022 |
| Extents, Flight Lines, Break lines, Tile Index | Complete | Woolpert | 20 August 2022 |
| | | | |
| Project Manager / Supervisor Signoff | Complete | Brian Foster | 20 August 2022 |
| Ocean Infinity Review | Complete | Luke Leydon | 09 September 2022 |

*Table 6: Processing Results Acceptable Signoff*

| Result Acceptance | | | |
|---|---|---|---|
| Assessment Criteria | Status | Completed By | Date |
| Point cloud classification accuracy | Complete | Woolpert | 29 October 2022 |
| Point cloud classification consistency | Complete | Woolpert | 29 October 2022 |
| Point Cloud LAS tiled deliverables | Complete | Woolpert | 29 October 2022 |
| Hydro-flattened Digital Elevation Models | Complete | Woolpert | 29 October 2022 |
| Digital Survey Models | Complete | Woolpert | 29 October 2022 |
| Contours | Complete | Woolpert | 29 October 2022 |
| Extents, Flight Lines, Break lines, Tile Index | Complete | Woolpert | 29 October 2022 |
| | | | |
| Project Manager / Supervisor Signoff | Complete | Luke Graham | 29 October 2022 |
| Ocean Infinity Review | Complete | Luke Leydon | 10 November 2022 |

*Table 7: Processing Results Acceptable Signoff (Revision 1)*

| Result Acceptance | | | |
|---|---|---|---|
| Assessment Criteria | Status | Completed By | Date |
| Point cloud classification accuracy | Complete | Woolpert | 29 October 2022 |
| Point cloud classification consistency | Complete | Woolpert | 29 October 2022 |
| Point Cloud LAS tiled deliverables | Complete | Woolpert | 29 October 2022 |
| Hydro-flattened Digital Elevation Models | Complete | Woolpert | 29 October 2022 |
| Digital Survey Models | Complete | Woolpert | 29 October 2022 |
| Contours | Complete | Woolpert | 29 October 2022 |
| Extents, Flight Lines, Break lines, Tile Index | Complete | Woolpert | 29 October 2022 |
| | | | |
| Project Manager / Supervisor Signoff | Complete | Mike Meiser | 18 November 2022 |
| Ocean Infinity Review | Complete | Luke Leydon | 18 November 2022 |

*Table 8: Processing Results Acceptable Signoff (Revision 2)*

| Result Acceptance | | | |
|---|---|---|---|
| Assessment Criteria | Status | Completed By | Date |
| Point cloud classification accuracy | Complete | Woolpert | 12 December 2022 |
| Point cloud classification consistency | Complete | Woolpert | 12 December 2022 |
| Point Cloud LAS tiled deliverables | Complete | Woolpert | 12 December 2022 |
| Hydro-flattened Digital Elevation Models | Complete | Woolpert | 12 December 2022 |
| Digital Survey Models | Complete | Woolpert | 12 December 2022 |
| Contours | Complete | Woolpert | 12 December 2022 |
| Extents, Flight Lines, Break lines, Tile Index | Complete | Woolpert | 12 December 2022 |
| | | | |
| Project Manager / Supervisor Signoff | Complete | Luke Graham | 12 December 2022 |
| Ocean Infinity Review | Complete | Luke Leydon | 12 December 2022 |

*Table 9: Processing Results Acceptable Signoff (Revision 3)*

# Appendix A: Lidar Quality Assurance Results

Provided as separate Documents

- Waikato_QAQC_Block_B_LASQC_results.csv
- Waikato_QAQC_Block_B_LP360_Results_for_DEMs.xlsx
- Waikato_QAQC_Block_B_LP360_Results_for_DSMs.xlsx
- Waikato_QAQC_Block_B_LP360_Results_for_LAS.xlsx
- Waikato_QAQC_Block_B_WKT_LASQC.xlsx
- Waikato_QAQC_Remainder_B_05122022.xlsm
- WRC_Raised_Defect_Tracking_Block_B_Remainder_v2_20221205.xlsx

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# Waikato Local Authority Shared Services (WLASS) / CoLAB LiDAR Data Capture Services

# LiDAR Processing Report Blocks C&D (Rev1)

Contract Number: AU411

Surveyed By: iXblue Pty Ltd / Ocean Infinity

Processing Completed By: Woolpert and Woolpert Australia

Prepared For: Colab (formerly WLASS)

Document Date: 1 October 2023

Ocean Infinity (Australia) Pty Ltd
ABN 61 128 811 978
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## Document Revision

| Revision No | Issue Purpose | Prepared | Checked | Approved |
|---|---|---|---|---|
| 0 | Issue Blocks C&D LiDAR Processing Report | L Leydon | L Graham | D Field |
| | | | | |
| | | | | |
| | | | | |

## Approval for Issue

| Name | Signature | Date |
|---|---|---|
| Luke Leydon |  | 01 October 2023 |

# Revision History

| Item | Description of change | Section | Revision |
|---|---|---|---|
| 1 | Added Section to introduction – Rev1 | 1.1 | 1 |
| 2 | Added new Points classification figure | Figure 11 | 1 |
| 3 | New LP360 example tables added | Tables 3,5,7 | 1 |
| 4 | Notes added to contours | 4.7 | 1 |
| 5 | Section added explaining feedback and rework - WRC feedback and rework | 6.3 | 1 |
| 6 | | | |
| 7 | | | |

# Contents

# Tables

# Figures

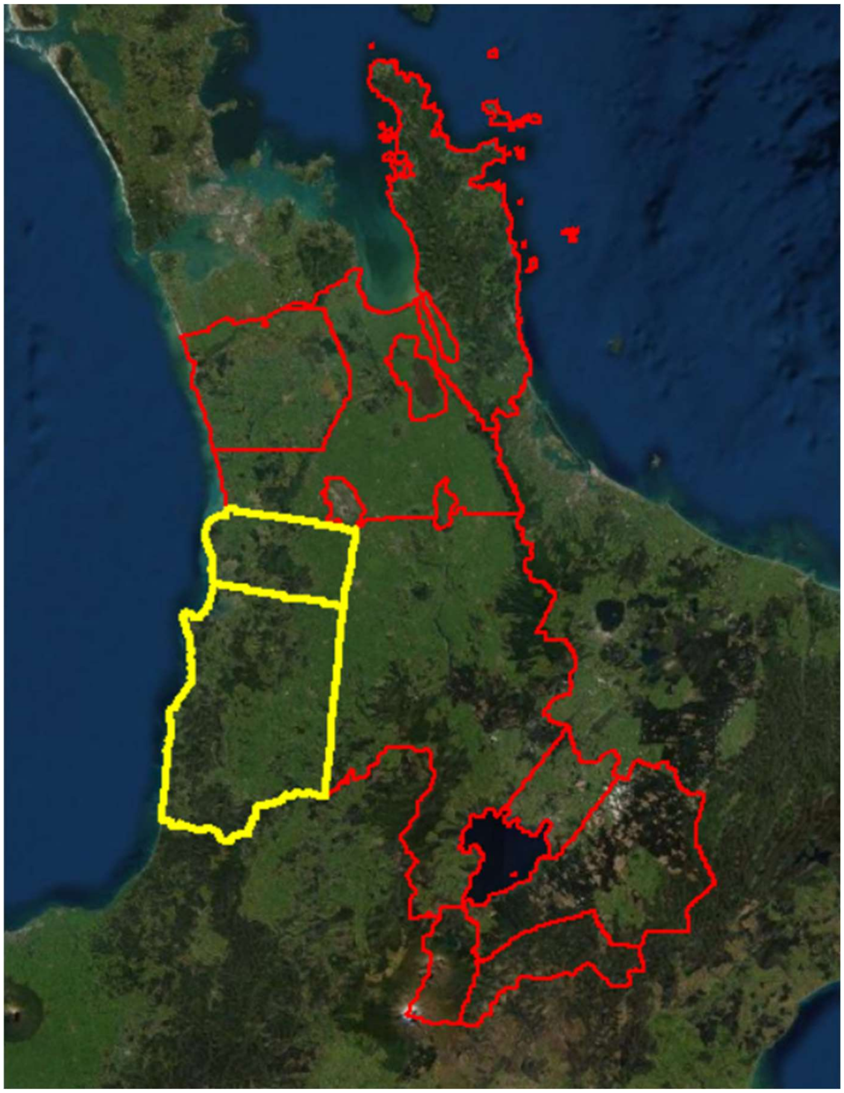


*Figure 1: Waikato Survey Area*

C & D illustrated in Yellow. C is the Northern most block

# 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

- AU411_WLASS-Collection_Report-10052021.pdf.

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 Blocks C&D, as illustrated in yellow in Figure 1 - Waikato Survey.

This dataset was uploaded by Woolpert Australia on 03 July 2023. This was transferred to WRC the same day. The Appendix files and Hydroflattening shapefiles were delivered the following day 04 July 2023.

## 1.1 Revision 1

The dataset was formally rejected by WRC and LINZ on 03 August 2023. There were some quality issues and also requests for implications associated with changes that may or may not be necessary.

Woolpert worked on repair of the dataset and resupplied this on 22 September 2023. The resupply and actions contained were tracked using AU411 WRC_Raised_Defect_Tracking_Block_CD_v1.xlsx, this was supported by LINZ_issues_block_CD_with_aam_comments_20230920.shp and WRC_Issues_with_aam_comments_20230920.shp.

# 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).

https://www.linz.govt.nz/system/files_force/media/doc/pgf_version_new_zealand_national_aerial_lidar_base_specification.pdf?download=1

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:

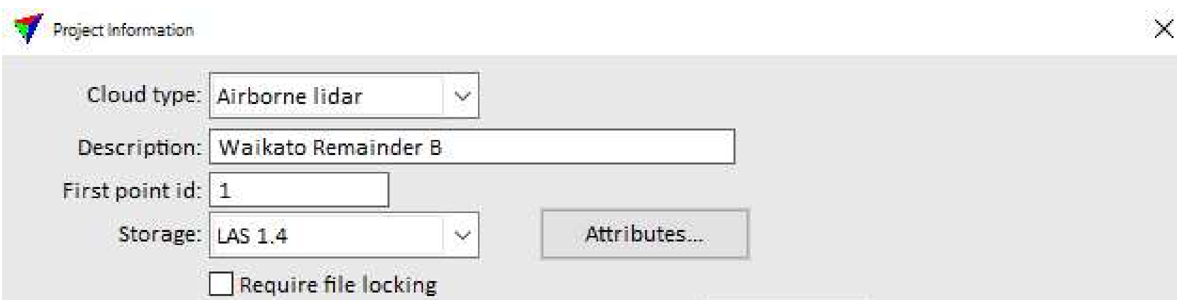



*Figure 2: LAS 1.4 being specified during project – example*

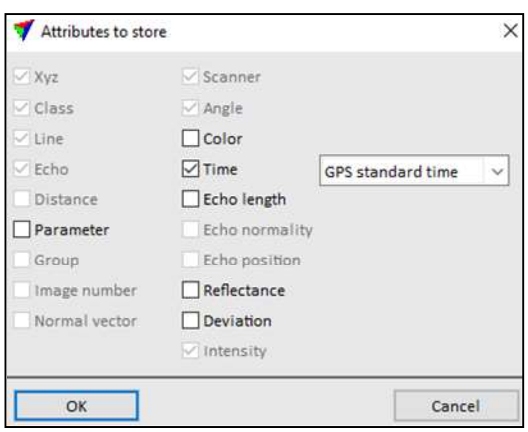



*Figure 3: Project settings used in TerraScan project when importing points into the project.*

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.

```
file source ID:              0
global_encoding:             17
project ID GUID data 1-4:    00000000-0000-0000-0000-000000000000
version major.minor:         1.4
```

*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)

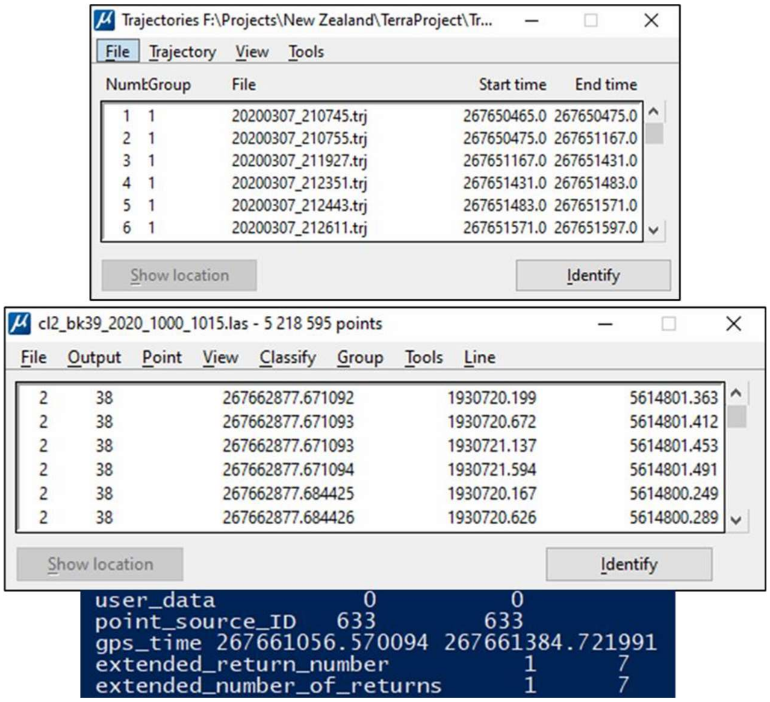



*Figure 5: Representative examples of LAS point attributes*

## 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.

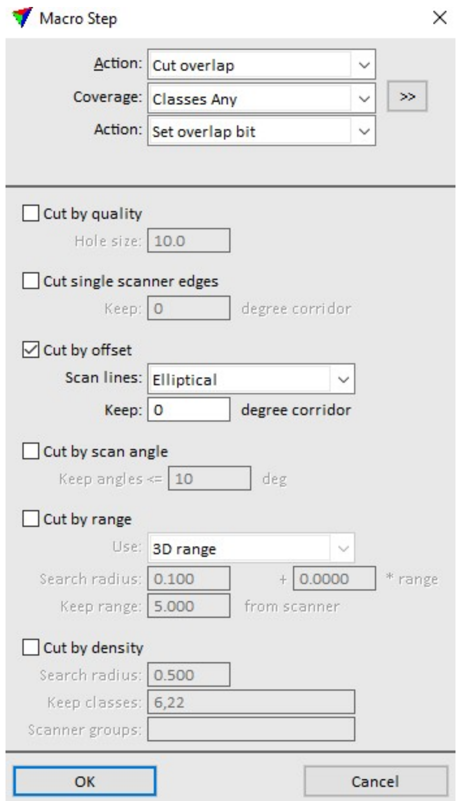



*Figure 6: Settings used when cutting overlap in Microstation.*

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:

| Code | Description |
|---|---|
| 1 | Processed, but unclassified |
| 2 | Ground |
| 3 | Low vegetation <2m |
| 4 | Medium vegetation |
| 5 | High vegetation >8m |
| 6 | Building |
| 7 | Low noise |
| 9 | Water |
| 17 | Bridge deck |
| 18 | High noise |

*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.

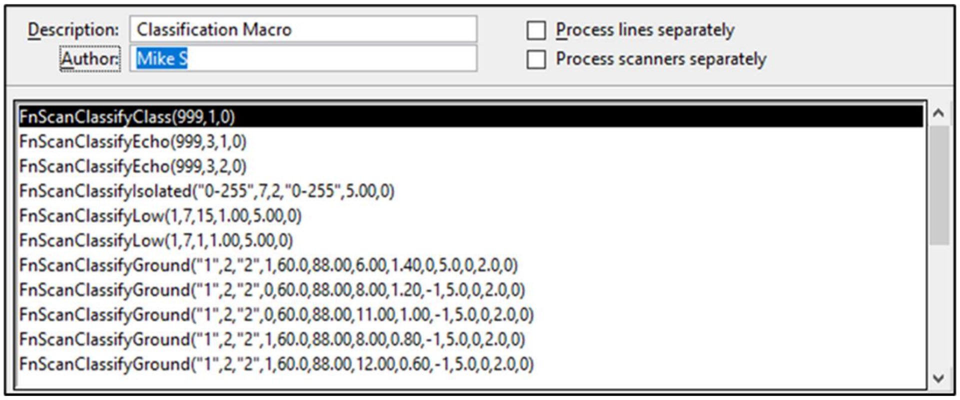



*Figure 7: Automatic classification macro developed for the project area.*

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.

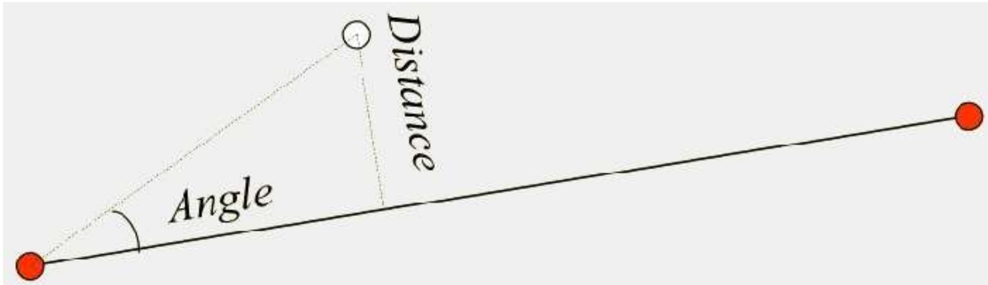



*Figure 8: Illustration of iteration angle and iteration distance parameters in the ground routine.*

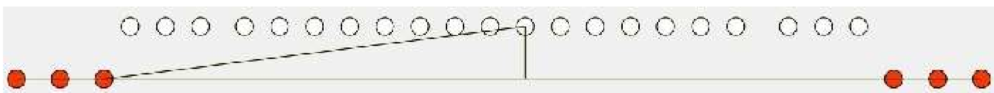


*Figure 9: A smaller iteration distance value avoids classification of ground points on low objects.*

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.

```
histogram of classification of points:
          294397  unclassified (1)
     20732991974  ground (2)
      2042342026  low vegetation (3)
      8740865354  medium vegetation (4)
     17401995113  high vegetation (5)
        39843945  building (6)
      5968284827  noise (7)
        40928904  water (9)
          529544  bridge deck (17)
        83836949  Reserved for ASPRS Definition (18)
 +-> flagged as extended overlap: 24934341424
  +--->          134460 of those are unclassified (1)
  +--->      9321907217 of those are ground (2)
  +--->       943287418 of those are low vegetation (3)
  +--->      3787219096 of those are medium vegetation (4)
  +--->      7455578739 of those are high vegetation (5)
  +--->        19504001 of those are building (6)
  +--->      3371373805 of those are noise (7)
  +--->        12462947 of those are water (9)
  +--->          254229 of those are bridge deck (17)
  +--->        22619512 of those are Reserved for ASPRS Definition (18)
```

*Figure 10: Statistics showing the classes - LAS points within the project area (Block C & D)*

```
histogram of classification of points:
        21353196  unclassified (1)
     20730533894  ground (2)
      2033329433  low vegetation (3)
      8732425924  medium vegetation (4)
     17397914801  high vegetation (5)
        39843905  building (6)
      5968307779  noise (7)
        42110789  water (9)
          529728  bridge deck (17)
        85563977  Reserved for ASPRS Definition (18)
 +-> flagged as keypoints: 7
  +--->               1 of those are ground (2)
  +--->               1 of those are building (6)
  +--->               2 of those are noise (7)
  +--->               2 of those are bridge deck (17)
  +--->               1 of those are Reserved for ASPRS Definition (18)
 +-> flagged as withheld:  6053871756
  +--->      5968307779 of those are noise (7)
  +--->        85563977 of those are Reserved for ASPRS Definition (18)
 +-> flagged as extended overlap: 24918510991
  +--->        14565640 of those are unclassified (1)
  +--->      9315627270 of those are ground (2)
  +--->       936365383 of those are low vegetation (3)
  +--->      3778651556 of those are medium vegetation (4)
  +--->      7447792565 of those are high vegetation (5)
  +--->        19481808 of those are building (6)
  +--->      3369750993 of those are noise (7)
  +--->        12689369 of those are water (9)
  +--->          254395 of those are bridge deck (17)
  +--->        23332012 of those are Reserved for ASPRS Definition (18)
```

*Figure 11: Statistics showing the classes - LAS points within the project area (Block C & D)(Rev1)*

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. Examples of this process have been provided for previous blocks.

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.

### 2.8.1 Building Classification

The classification of building points has been undertaken by utilizing the TerraScan *buildings* routine. This routine classifies points on buildings which form a planar surface, several rules can be set to fine tune these results including the minimum building size/footprint, z tolerance of the point alignment along the roof line and use of echo information.

The use of echo information can further support the classification as points on roofs mostly belong to the echo type 'only echo' whereas vegetation usually contains a lot of 'first of many' and 'intermediate' echoes.

Additionally, the LINZ building footprint was also integrated into the building classification workflow to further constrain the classification and improve the overall output.

### 2.8.2 Vegetation & Low-Level Noise Classification:

In agreeance with all parties, Woolpert have classified the lower 0 – 0.3m of the low vegetation class to class 7 (low noise).

This was done to effectively remove the lower noise stratification points and unused ground points from class 3 over areas which do not represent vegetation e.g. man-made surfaces and structures (sealed roads).

The remaining vegetation points were classified using TerraScan's classify *By height from ground* which uses the ground surface to calculate the distance of each point above and below ground. All identified vegetation points were classified to the nominated classes using the height ranges specified in the *New Zealand Nation Aerial LiDAR Base Specification* (See below).

**Table 4 Minimum LAS point cloud classification scheme**

| Code | Description |
|---|---|
| 1 | Processed, but unclassified |
| 2 | Ground |
| 3 | Low vegetation <2m |
| 4 | Medium vegetation |
| 5 | High vegetation >8m |
| 6 | Building |
| 7 | Low noise |
| 9 | Water |
| 18 | High noise |

## 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.

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 that appear to have a rough surface.

Editing example. Rocky promontory required editing.

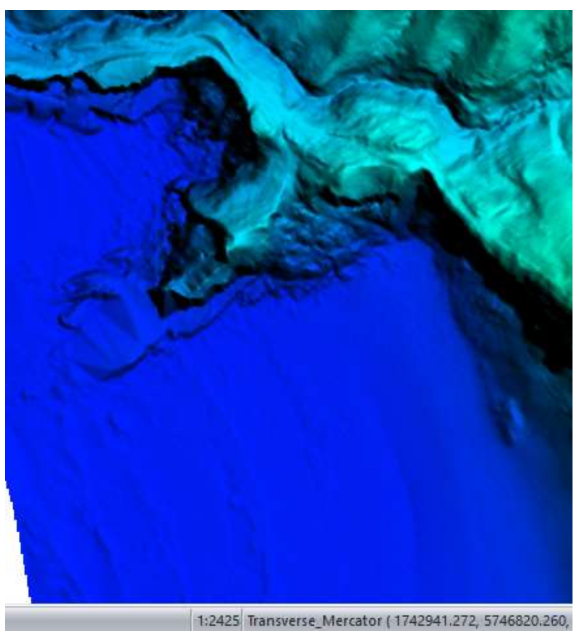



*Figure 12: Unedited, autoclassified Tile BF31_2723*

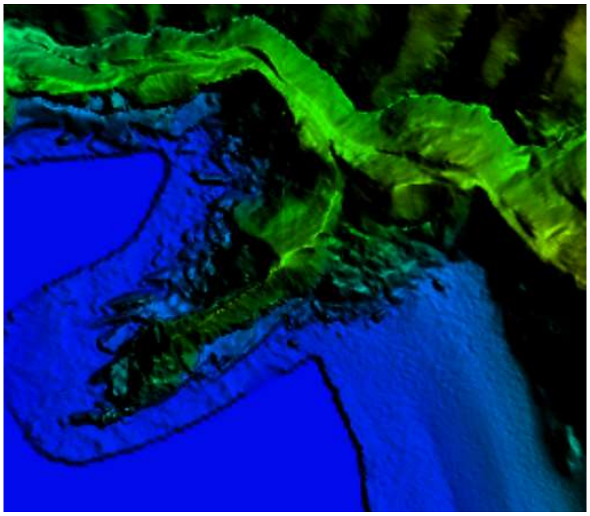


*Figure 13: Post-edit Tile BF31_2723*

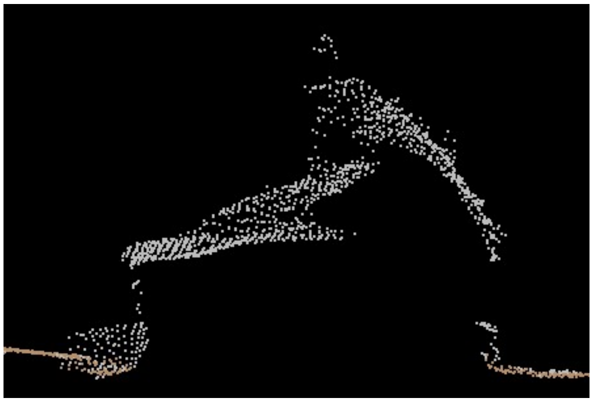


Figure 14: LAS pointcloud profile view from previous – required editing

Figure 15: LAS point cloud profile view from previous – post editing - introduced ground points

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.

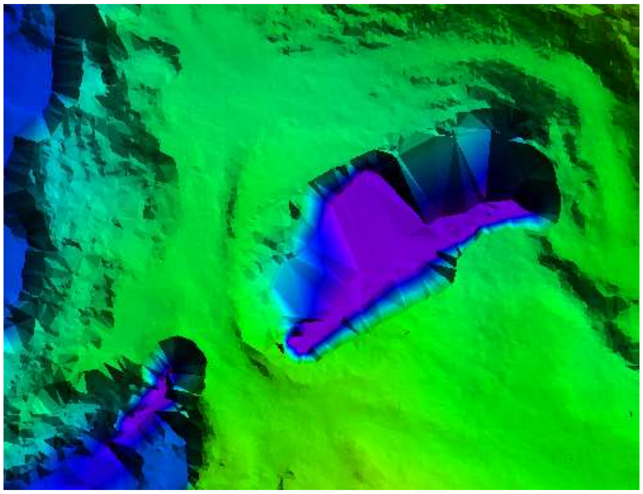


*Figure 16: Example overhead image of DEM over cliffs. Tile BF31_2623*

*Figure 17: Example overhead image of Pointcloud over cliffs. Tile BF31_2623*

*Figure 18: LAS point cloud profile view from previous figure*

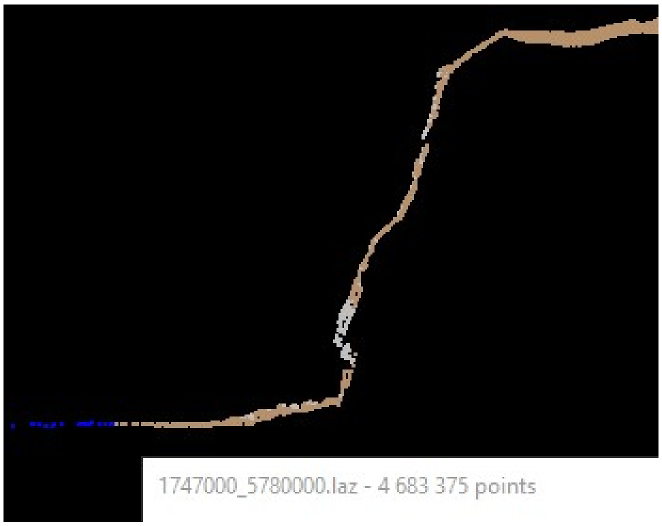



*Figure 19: Example (A) of terrain where DEM DSM differences to be expected*

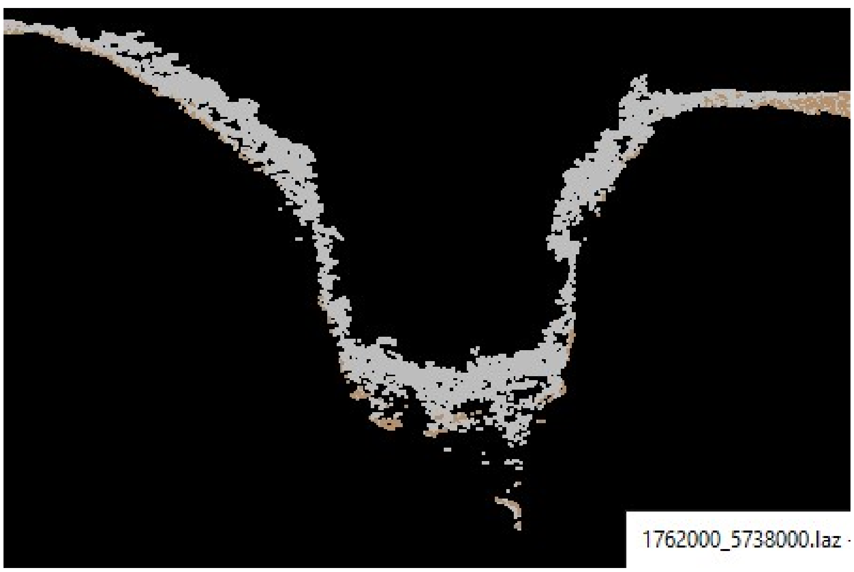



*Figure 20: Example (B) of terrain where DEM DSM differences to be expected*

## 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.

The following shows examples that were misaligned with the LINZ bridge Shapefile

Culvert – listed as bridge in LINZ shapefile

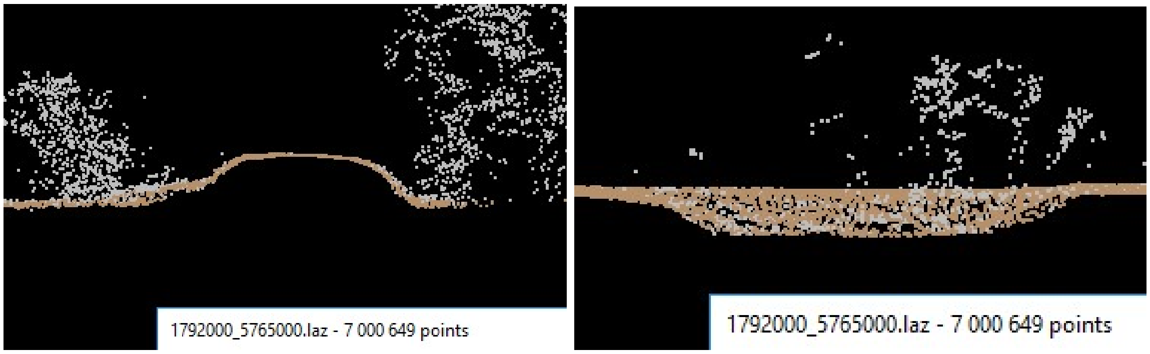



*Figure 21: Perpendicular (L) & Parallel (R)*

Bridge – not listed in LINZ shapefile

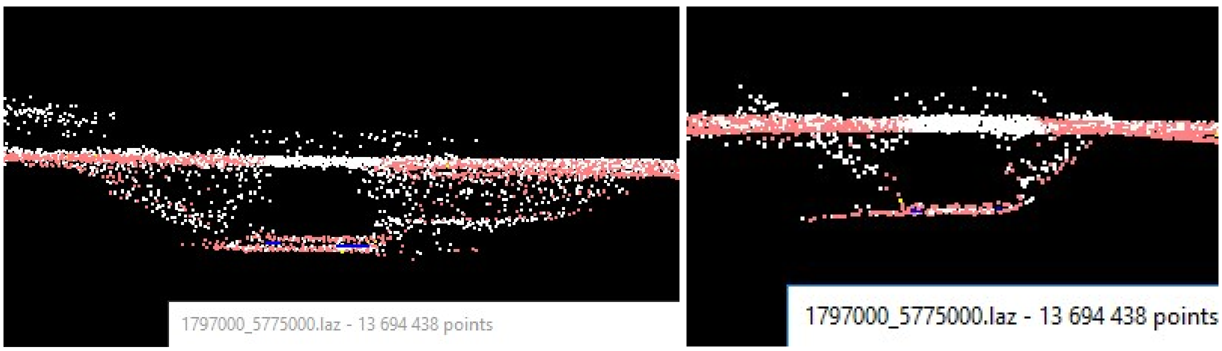



*Figure 22: Bridge but not shown in LINZ Shapefile*

Bridge – listed in LINZ shapefile but does NOT exist

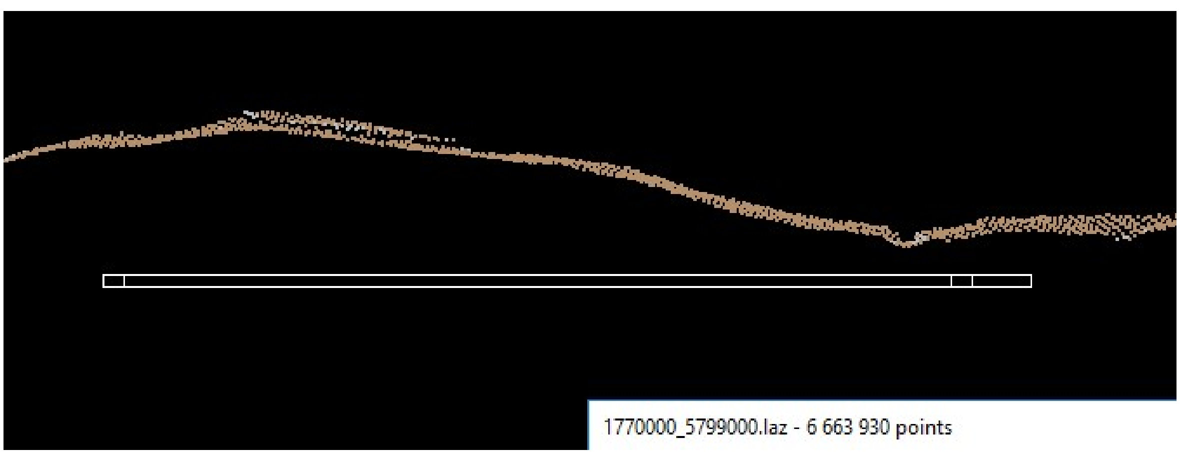



*Figure 23: Non-existent Bridge*

# 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.

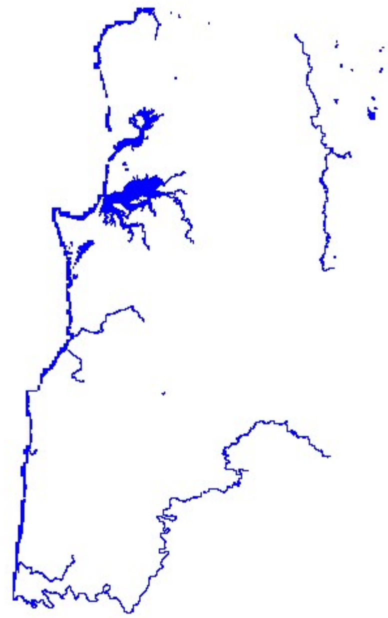


*Figure 24: Hydroflattening Polygons for Blocks C&D*

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.

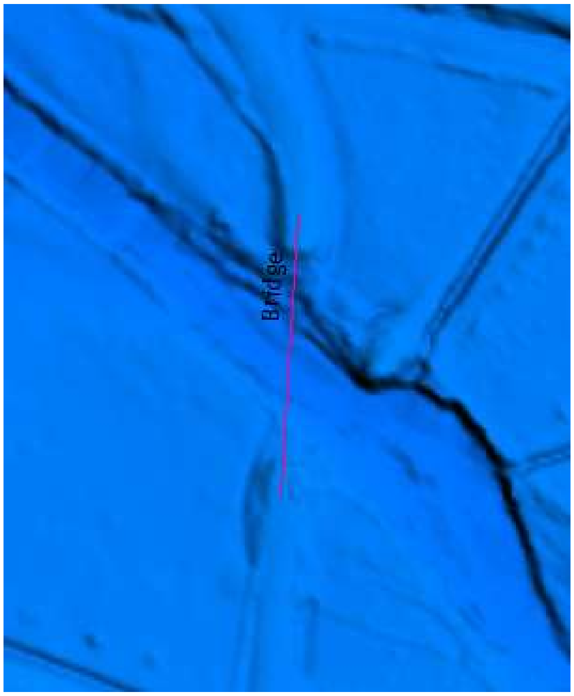



Figure 25: Tile DEM_BF31_2021_1000_3732 with LINZ bridge centreline

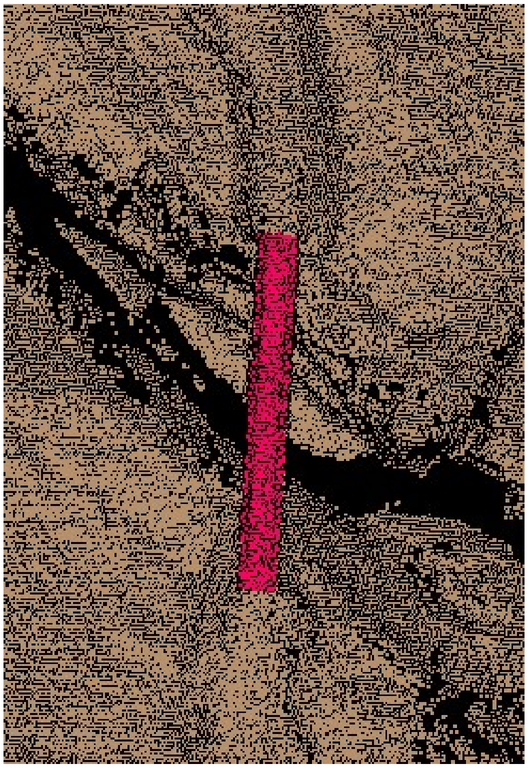


*Figure 26: Tile DEM_BF31_2021_1000_3732 classified*

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.

| | | | |
|---|---|---|---|
| 1 | 1929744.8358 | 5615128.2638 | 7.7096 |
| 2 | 1929746.0769 | 5615130.8498 | 7.6863 |
| 3 | 1929746.4280 | 5615131.5996 | 7.6796 |
| 4 | 1929746.5107 | 5615131.7727 | 7.678 |
| 5 | 1929746.7841 | 5615132.3591 | 7.6728 |
| 6 | 1929748.0794 | 5615135.0799 | 7.6483 |
| 7 | 1929748.5703 | 5615136.1455 | 7.6388 |
| 8 | 1929749.4246 | 5615138.0643 | 7.622 |
| 9 | 1929749.8587 | 5615139.0742 | 7.6132 |
| 10 | 1929750.6288 | 5615140.9327 | 7.5973 |
| 11 | 1929751.0393 | 5615141.7916 | 7.5896 |
| 12 | 1929751.5292 | 5615142.7809 | 7.5805 |
| 13 | 1929754.3861 | 5615148.3485 | 7.529 |
| 14 | 1929754.7868 | 5615149.1041 | 7.5219 |
| 15 | 1929754.7991 | 5615149.1267 | 7.5217 |
| 16 | 1929757.3347 | 5615152.1834 | 7.4808 |
| 17 | 1929757.8445 | 5615152.7752 | 7.4594 |

*Figure 27: Excerpt of river points used to create the centreline*

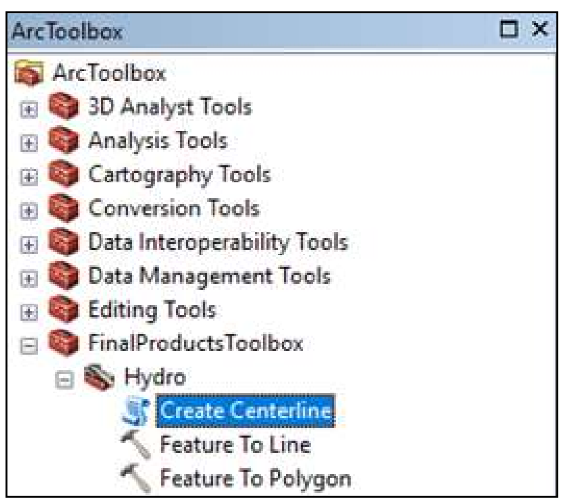
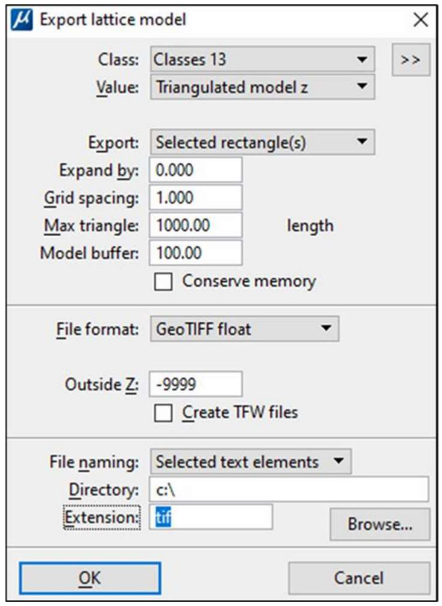



*Figure 28: Centreline for the stream within the project's survey*

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:

*Figure 29: 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.

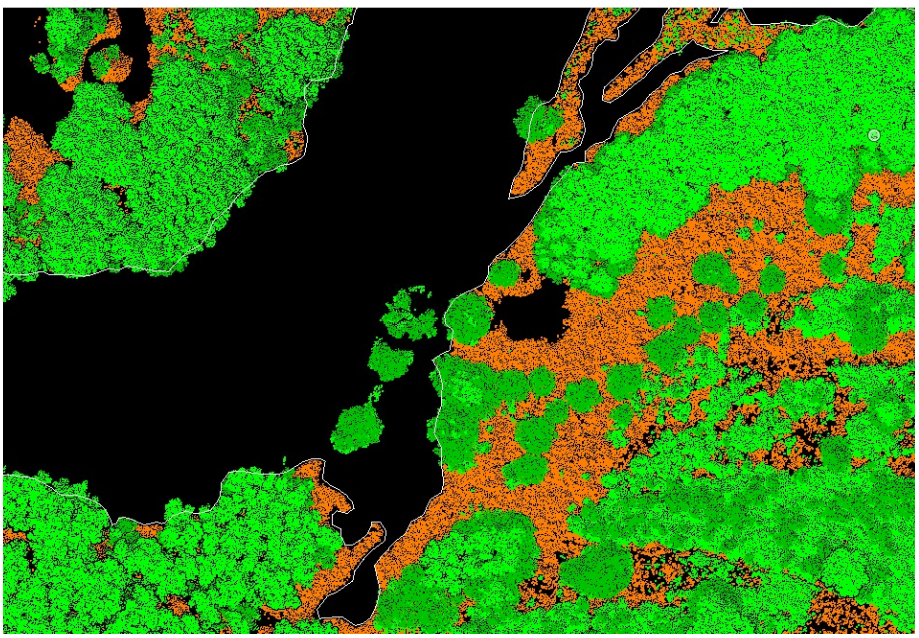


*Figure 30: Pre-filter, overhead view of ground and veg points with hydro lines*

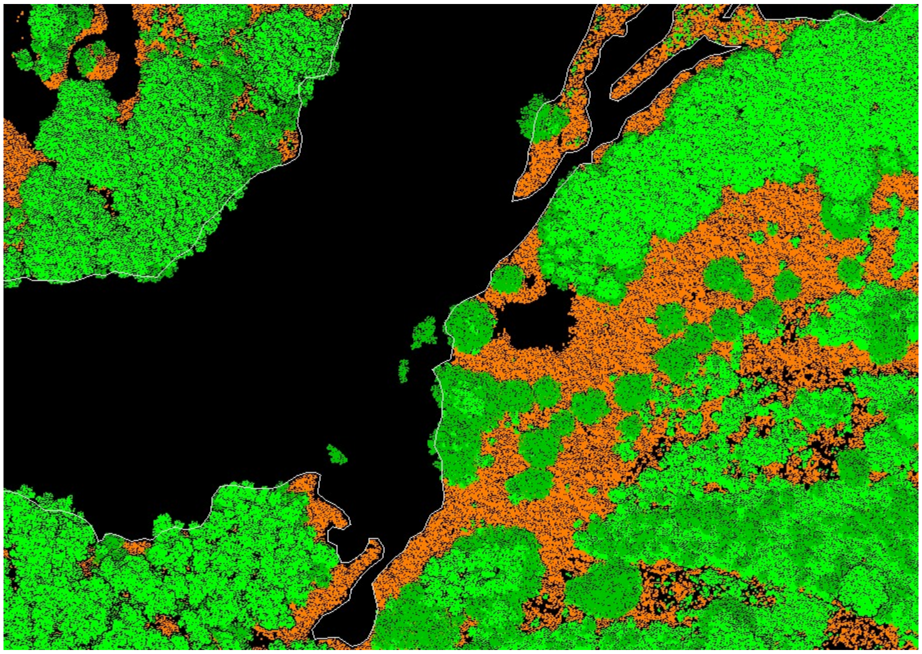


*Figure 31: Post-filter, overhead view of ground and veg points with hydro lines*

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 32: Point cloud – boulder filled stream*


*Figure 33: Imagery – boulder filled stream*

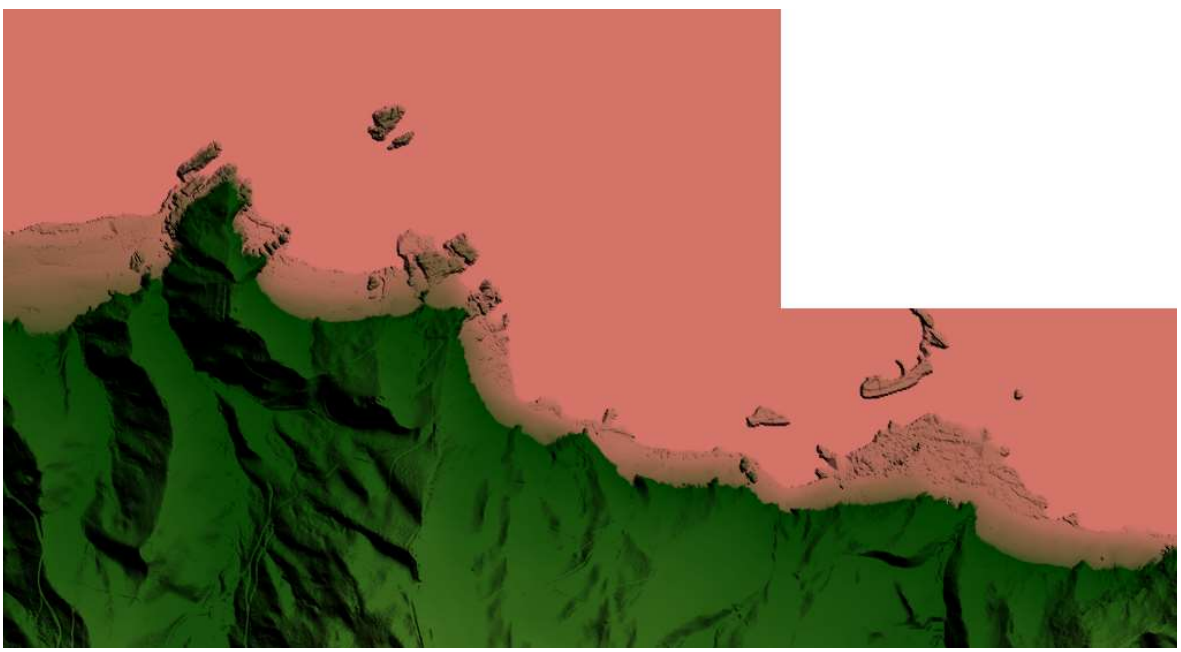


*Figure 34: Example of hydroflattened Coastal DEMs: DEM_BE32_2021_1000_3137*

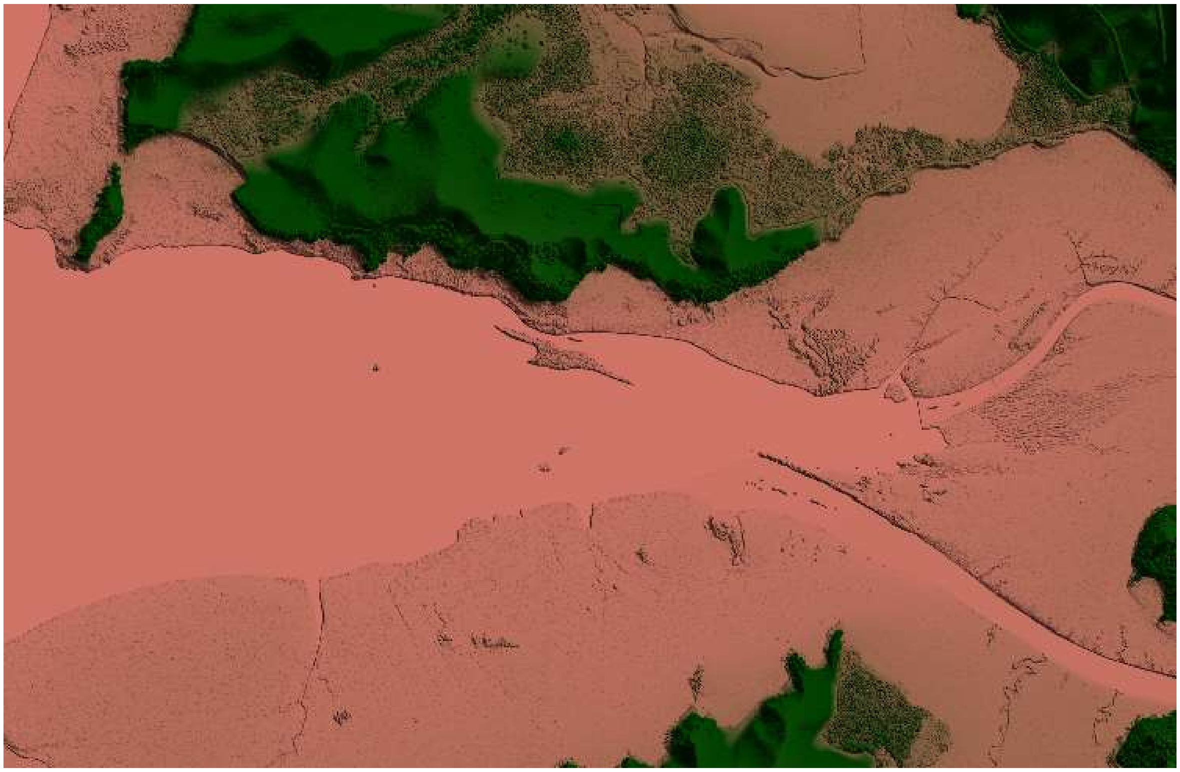


*Figure 35: Inlet, with hydro-flattening Tile BE32_2620 and neighbours (DSM)*

# 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 C was captured using Leica TerrainMapper sensor 513 and 559, flown on days 05th, 06th, 29th, 31st of January, 03rd, 13th, 17th, 20th, February and 13th 17th, 21st, 23rd of March 2021.

The data for Block D was captured using Leica TerrainMapper sensor 513 and 559, flown on days 05th, 27th, 31st of January, 03rd, 13th, 17th February and 13th 16th, 21st, 23rd and 24th of March 2021.

The extent of Block C & D can be seen in Figure 34. The flight lines relating to the area can be seen in Figure 37.

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 figure 41.


*Figure 36: Extent of deliverable data for Block C & D*

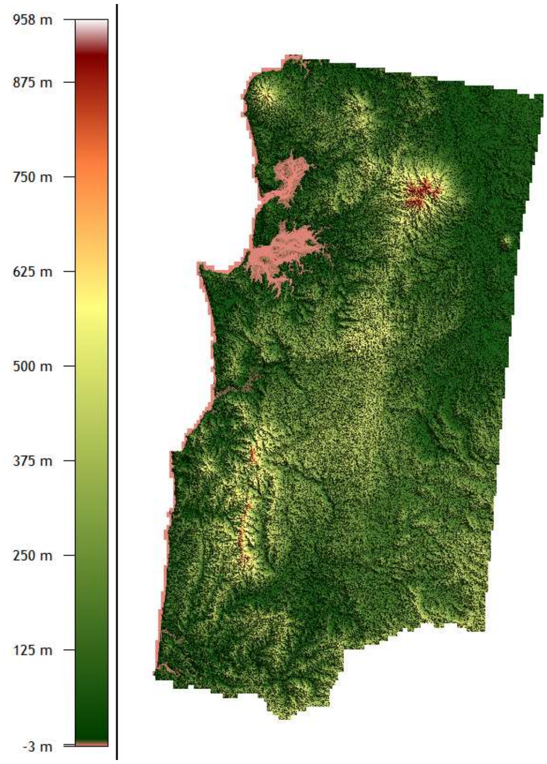



*Figure 37: Extent of deliverable data for Block C& D - DEM*

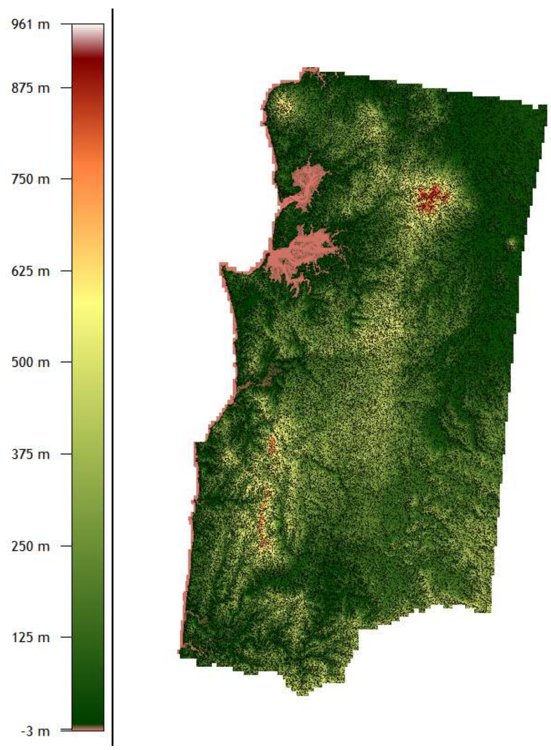



*Figure 38: Extent of deliverable data for Block C & D - DSM*

### 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.

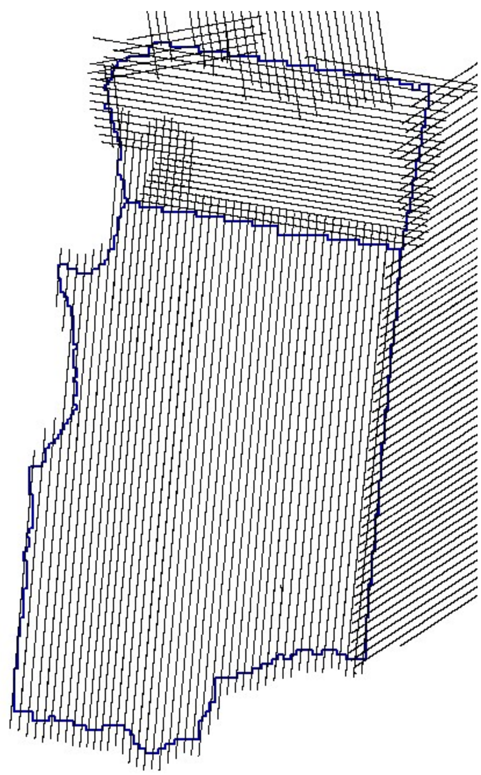


*Figure 39: Flight lines for 4ppm2 data coverage over Block C & D*

## 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.


```
variable length header record 1 of 1:
  reserved             0
  user ID              'LASF_Projection'
  record ID            2112
  length after header  951
  description          'by LAStools of rapidlasso GmbH'
    WKT OGC COORDINATE SYSTEM:
    COMPD_CS["NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016",PROJCS["NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000",GEOGCS["NZGD2000",DATUM["New_Zealan
d_Geodetic_Datum_2000",SPHEROID["GRS 1980",6378137,298.257222101,AUTHORITY["EPSG","7019"]],AUTHORITY["EPSG","6167"]],PRIMEM["Greenwich",0,AUTHORITY["EPSG","8901"]],UNIT["degree",0.0174532
251994328,AUTHORITY["EPSG","9122"]],AUTHORITY["EPSG","4167"]],PROJECTION["Transverse_Mercator"],PARAMETER["latitude_of_origin",0],PARAMETER["central_meridian",173],PARAMETER["scale_factor
,0.9996],PARAMETER["false_easting",1600000],PARAMETER["false_northing",10000000],UNIT["metre",1,AUTHORITY["EPSG","9001"]],AXIS["Easting",EAST],AXIS["Northing",NORTH],AUTHORITY["EPSG","219
"]],VERT_CS["NZVD2016",VERT_DATUM["New Zealand Vertical Datum 2016",2005,AUTHORITY["EPSG","7839"]],UNIT["metre",1.0,AUTHORITY["EPSG","9001"]],AXIS["Gravity-related height",UP],AUTHORITY["
PSG","7839"]]]
```

*Figure 40: WKT of a LAS file shown by LASTools.*

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.

| File | Version | PDRF | QVR File | File Signature | File Source ID |
|---|---|---|---|---|---|
| CL2_BD31_2021_1000_3850.las | 1.4 | 6 | No | LASF | 0 |
| CL2_BD31_2021_1000_3949.las | 1.4 | 6 | No | LASF | 0 |
| CL2_BD31_2021_1000_3950.las | 1.4 | 6 | No | LASF | 0 |
| CL2_BD31_2021_1000_4049.las | 1.4 | 6 | No | LASF | 0 |
| CL2_BD31_2021_1000_4050.las | 1.4 | 6 | No | LASF | 0 |
| CL2_BD31_2021_1000_4148.las | 1.4 | 6 | No | LASF | 0 |
| CL2_BD31_2021_1000_4149.las | 1.4 | 6 | No | LASF | 0 |
| CL2_BD31_2021_1000_4150.las | 1.4 | 6 | No | LASF | 0 |
| CL2_BD31_2021_1000_4247.las | 1.4 | 6 | No | LASF | 0 |

*Table 2: Representative output from LP360 illustrating LAS file specification compliance- Block C&D*

| File | Version | PDRF | QVR File | File Signature | File Source ID | CRS is WKT | Total Points by Return |
|---|---|---|---|---|---|---|---|
| CL2_BE31_2021_1000_4449.las | 1.4 | 6 | No | LASF | 0 | TRUE | 3,238,856 |
| CL2_BE31_2021_1000_4450.las | 1.4 | 6 | No | LASF | 0 | TRUE | 1,822,693 |
| CL2_BE31_2021_1000_4537.las | 1.4 | 6 | No | LASF | 0 | TRUE | 106,166 |
| CL2_BE31_2021_1000_4538.las | 1.4 | 6 | No | LASF | 0 | TRUE | 1,700,250 |
| CL2_BE31_2021_1000_4539.las | 1.4 | 6 | No | LASF | 0 | TRUE | 2,825,850 |
| CL2_BE31_2021_1000_4540.las | 1.4 | 6 | No | LASF | 0 | TRUE | 2,184,389 |
| CL2_BE31_2021_1000_4541.las | 1.4 | 6 | No | LASF | 0 | TRUE | 3,522,348 |
| CL2_BE31_2021_1000_4542.las | 1.4 | 6 | No | LASF | 0 | TRUE | 3,617,463 |
| CL2_BE31_2021_1000_4543.las | 1.4 | 6 | No | LASF | 0 | TRUE | 2,505,719 |
| CL2_BE31_2021_1000_4544.las | 1.4 | 6 | No | LASF | 0 | TRUE | 4,065,516 |
| CL2_BE31_2021_1000_4545.las | 1.4 | 6 | No | LASF | 0 | TRUE | 1,955,369 |

*Table 3: LP360 illustrating LAS file specification compliance- Block C&D (Rev1)*

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 analysist 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.

| File | Format | Big TIFF | NoData Value | Rows | Columns | BPB | Bands | Data Type | .. | Band Types | ). | Pixel Size |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEM_BE31_2021_1000_0150.tif | GTiff | False | -9999 | 720 | 480 | 32 | 1 | FLOAT | | GrayIndex | 0 | 1.000 |
| DEM_BE31_2021_1000_2450.tif | GTiff | False | -9999 | 720 | 480 | 32 | 1 | FLOAT | | GrayIndex | 0 | 1.000 |
| DEM_BE31_2021_1000_2550.tif | GTiff | False | -9999 | 720 | 480 | 32 | 1 | FLOAT | | GrayIndex | 0 | 1.000 |
| DEM_BE31_2021_1000_2650.tif | GTiff | False | -9999 | 720 | 480 | 32 | 1 | FLOAT | | GrayIndex | 0 | 1.000 |
| DEM_BE31_2021_1000_2748.tif | GTiff | False | -9999 | 720 | 480 | 32 | 1 | FLOAT | | GrayIndex | 0 | 1.000 |
| DEM_BE31_2021_1000_2749.tif | GTiff | False | -9999 | 720 | 480 | 32 | 1 | FLOAT | | GrayIndex | 0 | 1.000 |
| DEM_BE31_2021_1000_2750.tif | GTiff | False | -9999 | 720 | 480 | 32 | 1 | FLOAT | | GrayIndex | 0 | 1.000 |
| DEM_BE31_2021_1000_2848.tif | GTiff | False | -9999 | 720 | 480 | 32 | 1 | FLOAT | | GrayIndex | 0 | 1.000 |
| DEM_BE31_2021_1000_2849.tif | GTiff | False | -9999 | 720 | 480 | 32 | 1 | FLOAT | | GrayIndex | 0 | 1.000 |
| DEM_BE31_2021_1000_2850.tif | GTiff | False | -9999 | 720 | 480 | 32 | 1 | FLOAT | | GrayIndex | 0 | 1.000 |
| DEM_BE31_2021_1000_2947.tif | GTiff | False | -9999 | 720 | 480 | 32 | 1 | FLOAT | | GrayIndex | 0 | 1.000 |

*Table 4: Condensed output from LP360 illustrating DEM file specification compliance – Block C & D*

| File | Format | Big TIFF | NoData Value | Rows | Columns | BPB | Bands | Data Type | Band Types | Pixel Size |
|---|---|---|---|---|---|---|---|---|---|---|
| BD32_1000_3617.tif | GTiff | FALSE | -9999 | 720 | 480 | 32 | 1 | FLOAT | GrayIndex | 1 |
| BD32_1000_3618.tif | GTiff | FALSE | -9999 | 720 | 480 | 32 | 1 | FLOAT | GrayIndex | 1 |
| BD32_1000_3619.tif | GTiff | FALSE | -9999 | 720 | 480 | 32 | 1 | FLOAT | GrayIndex | 1 |
| BD32_1000_3620.tif | GTiff | FALSE | -9999 | 720 | 480 | 32 | 1 | FLOAT | GrayIndex | 1 |
| BD32_1000_3621.tif | GTiff | FALSE | -9999 | 720 | 480 | 32 | 1 | FLOAT | GrayIndex | 1 |
| BD32_1000_3622.tif | GTiff | FALSE | -9999 | 720 | 480 | 32 | 1 | FLOAT | GrayIndex | 1 |
| BD32_1000_3623.tif | GTiff | FALSE | -9999 | 720 | 480 | 32 | 1 | FLOAT | GrayIndex | 1 |
| BD32_1000_3624.tif | GTiff | FALSE | -9999 | 720 | 480 | 32 | 1 | FLOAT | GrayIndex | 1 |
| BD32_1000_3625.tif | GTiff | FALSE | -9999 | 720 | 480 | 32 | 1 | FLOAT | GrayIndex | 1 |
| BD32_1000_3626.tif | GTiff | FALSE | -9999 | 720 | 480 | 32 | 1 | FLOAT | GrayIndex | 1 |
| BD32_1000_3627.tif | GTiff | FALSE | -9999 | 720 | 480 | 32 | 1 | FLOAT | GrayIndex | 1 |
| BD32_1000_3628.tif | GTiff | FALSE | -9999 | 720 | 480 | 32 | 1 | FLOAT | GrayIndex | 1 |
| BD32_1000_3629.tif | GTiff | FALSE | -9999 | 720 | 480 | 32 | 1 | FLOAT | GrayIndex | 1 |

*Table 5: LP360 illustrating DEM file specification compliance – Block C & D (Rev1)*

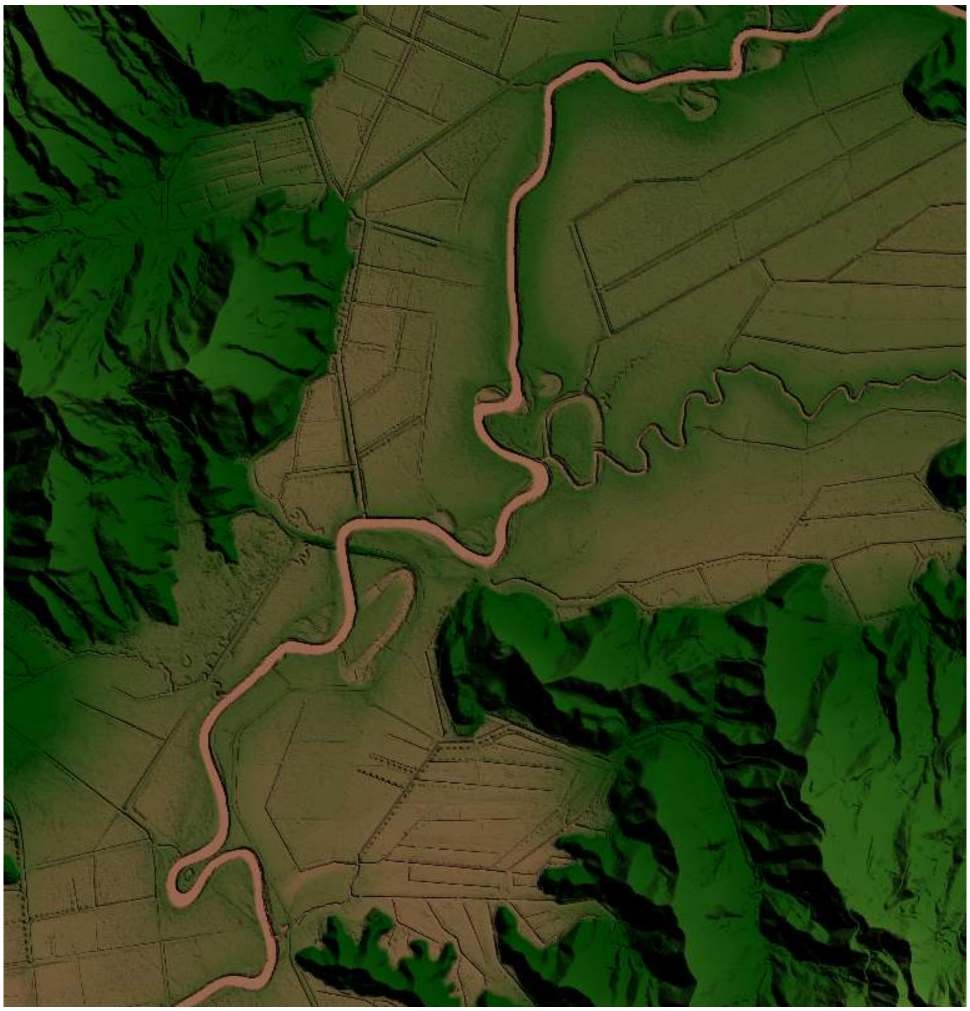


*Figure 41: DEM Example Tile River Valley - DEM_BF31_2021_1000_0650*

### 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.

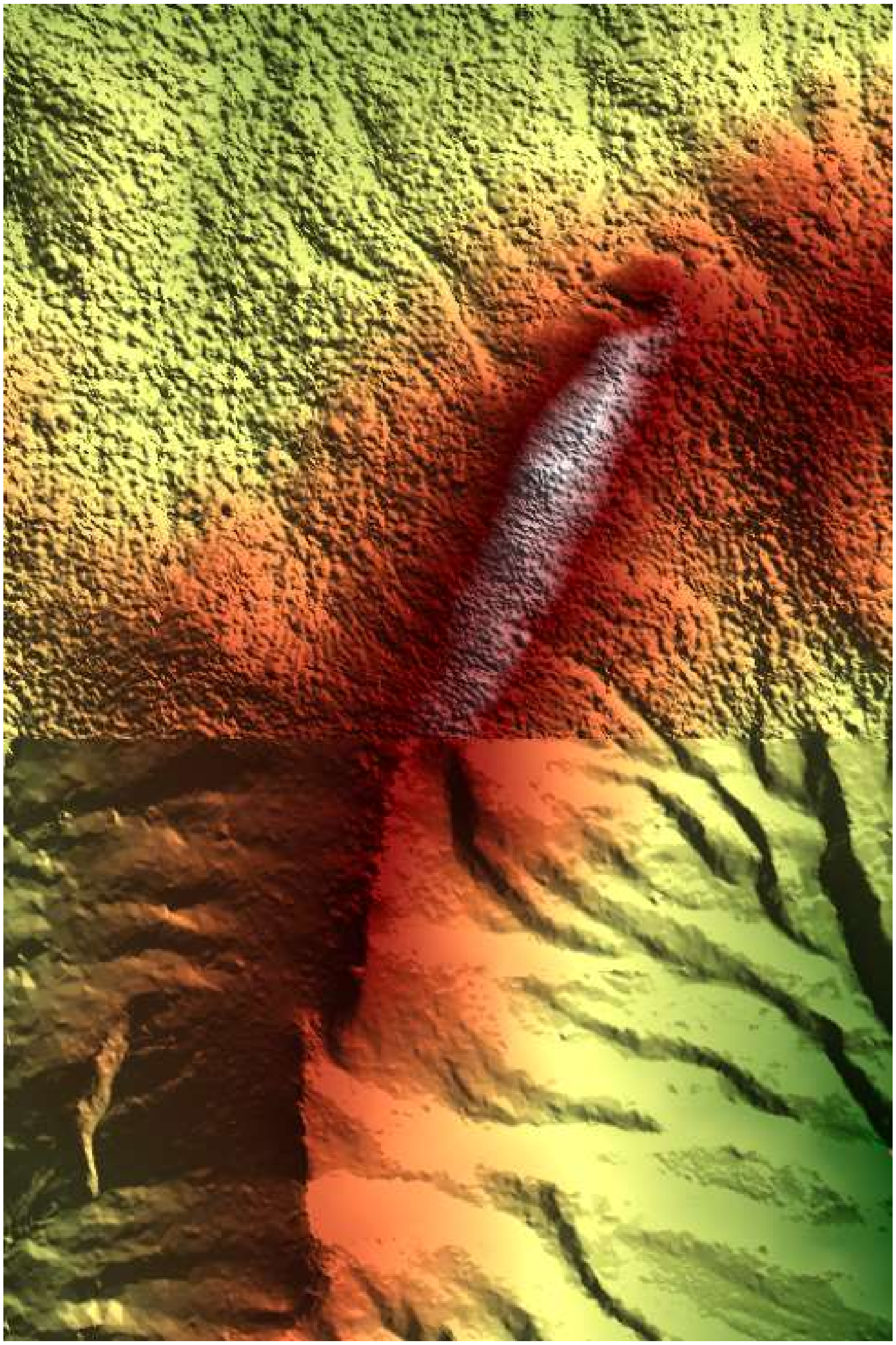
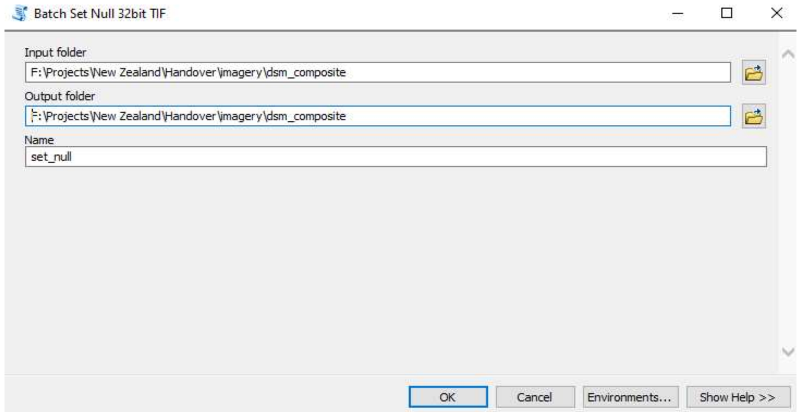


*Figure 42: Difference between DSM and DEM differences in height along ridgeline- Tile BF31_3549.*

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.




| | |
|---|---|
| Format | IMAGINE Image |
| Source Type | Generic |
| Pixel Type | floating point |
| Pixel Depth | 32 Bit |
| NoData Value | -9999 |

*Figure 44: 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.

| File | Format | Big TIFF | NoData Value | Rows | Columns | BPB | Bands | Data Type | .. | Band Types | ). | Pixel Size |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DSM_BF33_2021_1000_0101.tif | GTiff | False | -9999 | 720 | 480 | 32 | 1 | FLOAT | | GrayIndex | 0 | 1.000 |
| DSM_BF33_2021_1000_0102.tif | GTiff | False | -9999 | 720 | 480 | 32 | 1 | FLOAT | | GrayIndex | 0 | 1.000 |
| DSM_BF33_2021_1000_0103.tif | GTiff | False | -9999 | 720 | 480 | 32 | 1 | FLOAT | | GrayIndex | 0 | 1.000 |
| DSM_BF33_2021_1000_0104.tif | GTiff | False | -9999 | 720 | 480 | 32 | 1 | FLOAT | | GrayIndex | 0 | 1.000 |
| DSM_BF33_2021_1000_0105.tif | GTiff | False | -9999 | 720 | 480 | 32 | 1 | FLOAT | | GrayIndex | 0 | 1.000 |
| DSM_BF33_2021_1000_0106.tif | GTiff | False | -9999 | 720 | 480 | 32 | 1 | FLOAT | | GrayIndex | 0 | 1.000 |
| DSM_BF33_2021_1000_0107.tif | GTiff | False | -9999 | 720 | 480 | 32 | 1 | FLOAT | | GrayIndex | 0 | 1.000 |
| DSM_BF33_2021_1000_0108.tif | GTiff | False | -9999 | 720 | 480 | 32 | 1 | FLOAT | | GrayIndex | 0 | 1.000 |
| DSM_BF33_2021_1000_0109.tif | GTiff | False | -9999 | 720 | 480 | 32 | 1 | FLOAT | | GrayIndex | 0 | 1.000 |
| DSM_BF33_2021_1000_0110.tif | GTiff | False | -9999 | 720 | 480 | 32 | 1 | FLOAT | | GrayIndex | 0 | 1.000 |
| DSM_BF33_2021_1000_0111.tif | GTiff | False | -9999 | 720 | 480 | 32 | 1 | FLOAT | | GrayIndex | 0 | 1.000 |

*Table 6: Condensed output from LP360 illustrating DSM file specification compliance – Block C & D*

| File | Form at | Big TIFF | NoDa ta Value | Rows | Columns | BP B | Bands | Data Type | Band Types | Pixel Size |
|---|---|---|---|---|---|---|---|---|---|---|
| DSM_BD32_2021_1000_4646.tif | GTiff | FALSE | -9999 | 720 | 480 | 32 | 1 | FLOAT | GrayIndex | 1 |
| DSM_BD32_2021_1000_4647.tif | GTiff | FALSE | -9999 | 720 | 480 | 32 | 1 | FLOAT | GrayIndex | 1 |
| DSM_BD32_2021_1000_4648.tif | GTiff | FALSE | -9999 | 720 | 480 | 32 | 1 | FLOAT | GrayIndex | 1 |
| DSM_BD32_2021_1000_4649.tif | GTiff | FALSE | -9999 | 720 | 480 | 32 | 1 | FLOAT | GrayIndex | 1 |
| DSM_BD32_2021_1000_4650.tif | GTiff | FALSE | -9999 | 720 | 480 | 32 | 1 | FLOAT | GrayIndex | 1 |
| DSM_BD32_2021_1000_4701.tif | GTiff | FALSE | -9999 | 720 | 480 | 32 | 1 | FLOAT | GrayIndex | 1 |
| DSM_BD32_2021_1000_4702.tif | GTiff | FALSE | -9999 | 720 | 480 | 32 | 1 | FLOAT | GrayIndex | 1 |
| DSM_BD32_2021_1000_4703.tif | GTiff | FALSE | -9999 | 720 | 480 | 32 | 1 | FLOAT | GrayIndex | 1 |
| DSM_BD32_2021_1000_4704.tif | GTiff | FALSE | -9999 | 720 | 480 | 32 | 1 | FLOAT | GrayIndex | 1 |
| DSM_BD32_2021_1000_4705.tif | GTiff | FALSE | -9999 | 720 | 480 | 32 | 1 | FLOAT | GrayIndex | 1 |

*Table 7: LP360 illustrating DSM file specification compliance – Block C & D (Rev1)*

## 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.

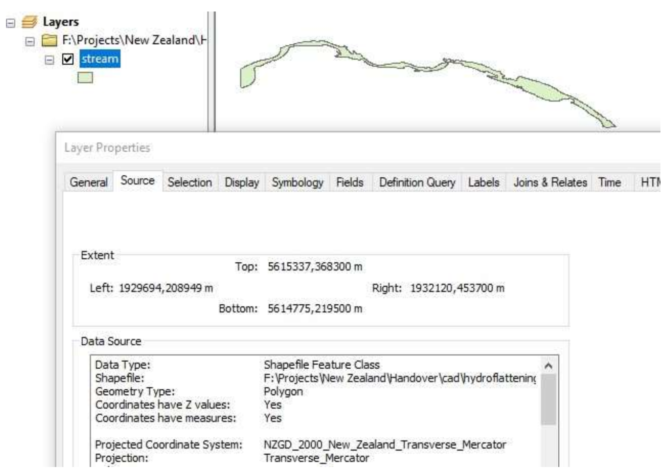



*Figure 45: Stream break line properties in ArcMap.*

## 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 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.

A sample has recently been supplied to WRC for their perusal and comment of what the contours are envisaged to look like.

# 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_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.

| Naming Convention for point clouds, DEMs, and other tiled products<br>*[product]_[sheet]_[year]_[scale]_[tile].[ext]* | | |
|---|---|---|
| **Product** | *DEM* | **CL2-Point Cloud Classification Level 2**<br>**DEM-Bare Earth Digital Elevation Model**<br>**DSM-Digital Surface Model**<br>DTM-Digital Terrain Model<br>UNC-Unclassified Point Cloud<br>INT-Intensity image<br>CHM – Canopy Height Model<br>IMG-Aerial photography<br>etc |
| **Sheet** | *BK34* | LINZ Topo50 identifier (4 characters) |
| **Year** | *2016* | Year of survey commencement |
| **Scale** | *1000* | Nominal scale of NZTopo50 subtiles |
| **Tile** | *4118* | Row number (41), Column number (18) of tile with respect to an upper left origin |
| **ext** | *tif* | File extension according to format conventions<br>las<br>tif<br>shp<br>etc |
| *For example: DEM_BK34_2016_1000_4118.tif* | | |

*Table 8: 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-flatting break line bank line strings
│         │ └───stream_islands – Hydro-flatting 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 Blocks C&D

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 WRC feedback and rework

Data was rejected by LINZ and WRC and a spreadsheet and shapefiles were provided to assist in rework. The spreadsheet was returned and shapefiles were edited to add comments on all the fail and improve items. Below are examples of actions undertaken. These are supplied in full in Appendix – A

| <Feature Name> | NAME | AAM |
|---|---|---|
| Bridge missing from DSM | Bridge missing from DSM | Included |
| Bridge missing from DSM | Bridge missing from DSM | Included (2x) |
| Bridge missing from DSM | Bridge missing from DSM | Included |
| Bridge missing from DSM | Bridge missing from DSM | Included |
| Bridge missing from DSM | Bridge missing from DSM | Included |
| Bridge missing from DSM | Bridge missing from DSM | Included |
| Bridge missing from DSM | Bridge missing from DSM | Included |
| Bridge missing from DSM | Bridge missing from DSM | Bridge included |
| Bridge missing from DSM | Bridge missing from DSM | Bridge included |
| Bridge missing from DSM | Bridge missing from DSM | Included |
| Bridge missing from DSM | Bridge missing from DSM | Included |
| Bridge missing from DSM | Bridge missing from DSM | Included |
| Bridge missing from DSM | Bridge missing from DSM | Included |
| Bridge missing from DSM | Bridge missing from DSM | Included |
| Bridge missing from DSM | Bridge missing from DSM | Included |
| Bridge missing from DSM | Bridge missing from DSM | Included |
| Bridge missing from DSM | Bridge missing from DSM | Included |
| Bridge missing from DSM | Bridge missing from DSM | Included |
| Bridge partially removed- please remove | Bridge partially removed- please remove | Bridge not edited (not in LINZ); hydro-slope added |
| Bridges missing from DSM | Bridges missing from DSM | Included |
| Bridges removed from DSM | Bridges removed from DSM | Included |
| Data void | Data void | Edited - DEM/DSM/LAS |
| Data void - paddock noise versus ground | Data void - paddock noise versus ground | Crops smoothed - DEM/DSM/LAS |
| DEM and DSM artefact - linear | DEM and DSM artefact - linear | Swath 968 matched - DTM/DSM/LAS |
| DEM and DSM artefact - please trim off wave /water so looks like shore | DEM and DSM artefact - please trim off wave /water so looks like shore | Shoreline modified (to WRC request) |
| DEM and DSM artefact - please trim off wave /water so looks like shore | DEM and DSM artefact - please trim off wave /water so looks like shore | Shoreline modified (to WRC request) |

*Table 9: LINZ Shapefile description and fixes employed*

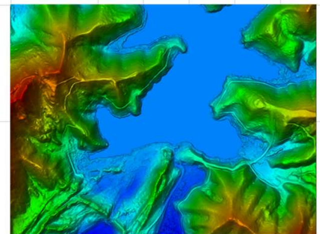
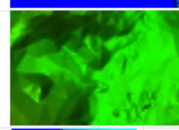
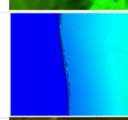
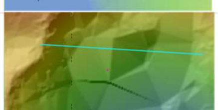
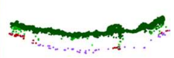
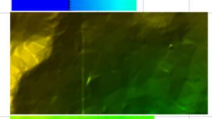
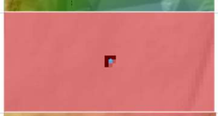
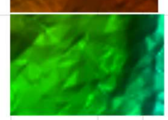
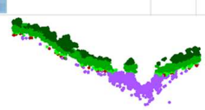
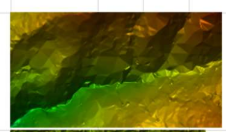
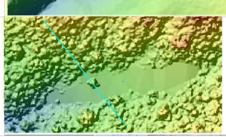
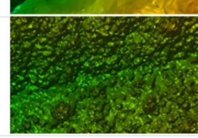
| OBJECTID | Product | IssueDescription | Image | Person | Notes | Woolpert APAC (AAM) | WP Image |
|---|---|---|---|---|---|---|---|
| 1068 | DEM | Pit down to false groundpoint |  | RossM | | Edited |  |
| 1083 | DEM | Pit in DEM |  | DanB | | Edited |  |
| 1085 | DEM | Arm of lake not hydroflattened |  | RossM | | Hydro-flattening data unintentionally excluded (fixed) |  |
| 1086 | DEM | Arm of lake not hydroflattened |  | RossM | | Hydro-flattening data unintentionally excluded (fixed) | |
| 1087 | DEM | DEM glitches on shore where limit goes too far out into surf; relates to LINZ item 10.2; fix |  | RossM | RossM will shortly provide Clipping lines to guide this correction | Shoreline modified to supplied line |  |
| 1088 | DEM | Void at tile boundary; fix error |  | DanB | | Edited |  |
| 1090 | DEM | DEM glitches on shore where limit goes too far out into surf; relates to LINZ item 10.2; fix |  | RossM | RossM will shortly provide Clipping lines to guide this correction | Shoreline modified to supplied line |  |
| 1091 | DEM, PC | Area of large triangles, low ground points but ample cl7 form ground surface; fix patch |   | RossM | (purple noise, brown ground) | Edited |  |
| 1092 | DEM | Pit; fix pixels |  | RossM | | Not found |  |
| 1093 | DEM | Pit; fix patch |  | RossM | | Edited |  |
| 1094 | DEM | Pit, fix pixels |  | RossM | | Edited |  |
| 1095 | DEM | Patch with classifiction error in DEM and especially DSM - ground and vege tiers in wrongposition, fix patch DEM DSM |   | | | Edited |  |
| 1095 | DSM | Patch with classifiction error in DEM and especially DSM - ground and vege tiers in wrongposition, fix patch DEM DSM |  | | | Edited |  |

*Figure 46: WRC Shapefile description and fixes employed*

# 7 Features unique to blocks C & D

## 7.1 Windfarm

The figures below show the Te Uku windfarm. These were classified as vegetation (and/or default or buildings). It was pleasing to see the capture of these at 4ppm2.

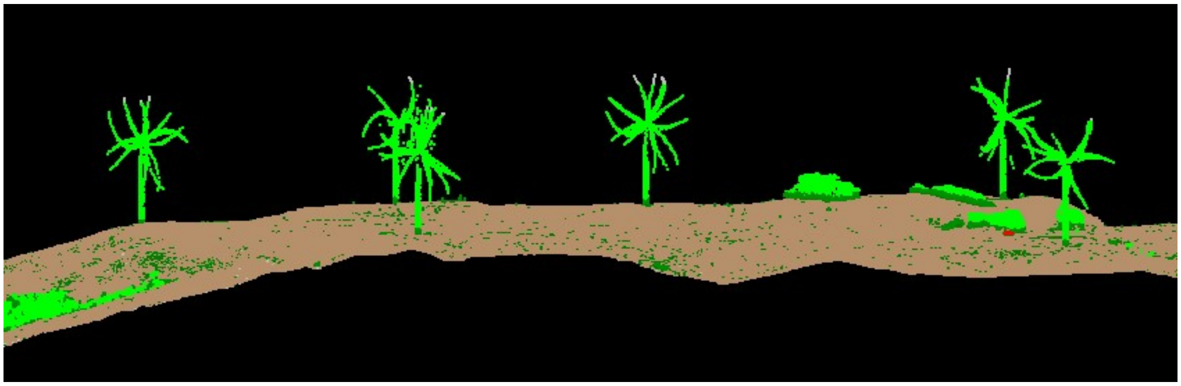


*Figure 47: Te Uku Windfarm – Side profile*

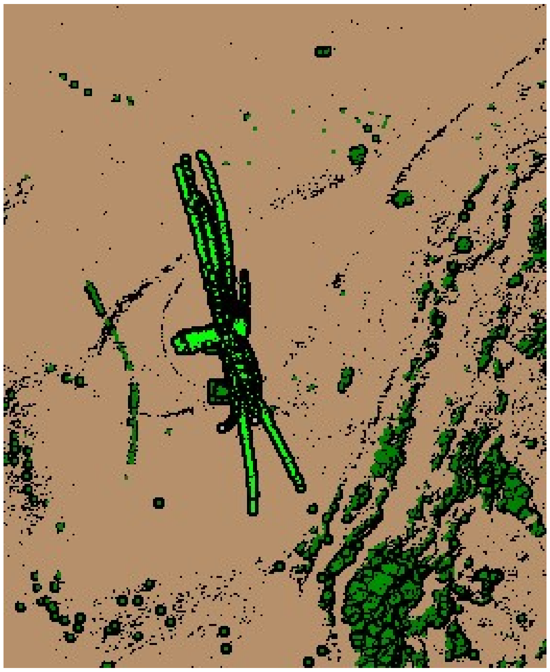


*Figure 48: Te Uku Windfarm – DSM*

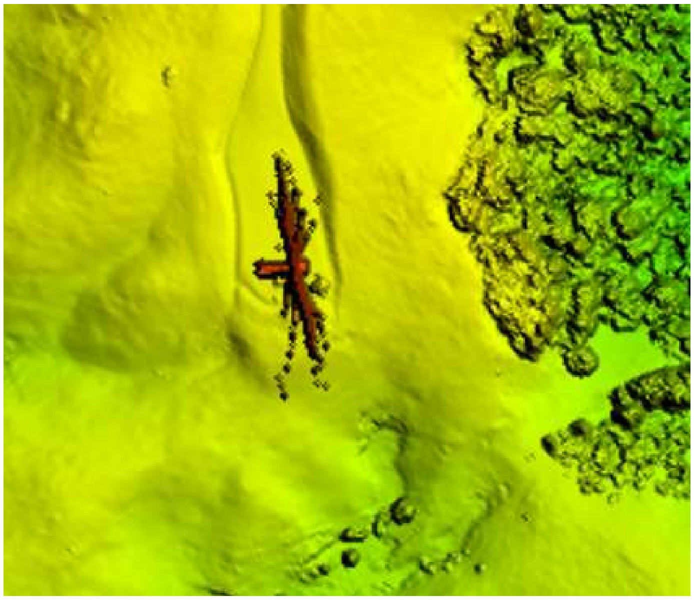


*Figure 49: Te Uku Windfarm*

## 7.2 Change between capture epochs

It was noted that there were changes t othe terrain between flight lines / dates. Below are some examples of what appears to be cropping / market gardening. Whilst these look unnatural this is due to the changes due to harvesting / land use practices.

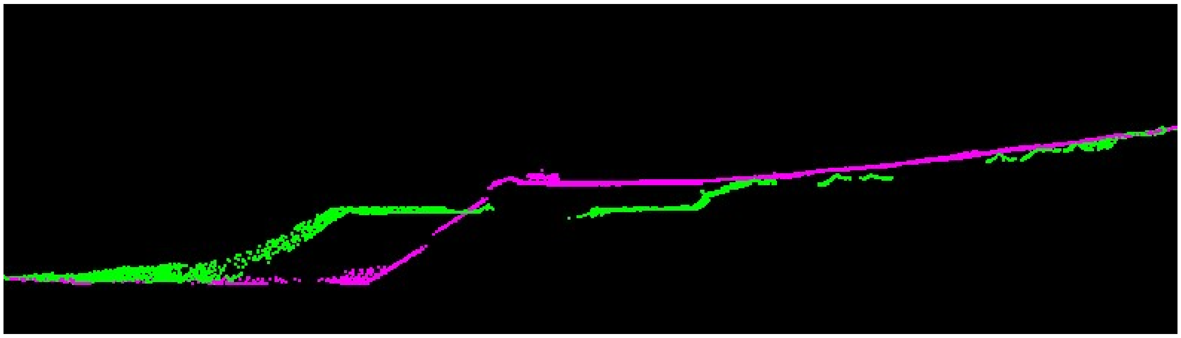


*Figure 50: Terrain. Tile BE31_3839*

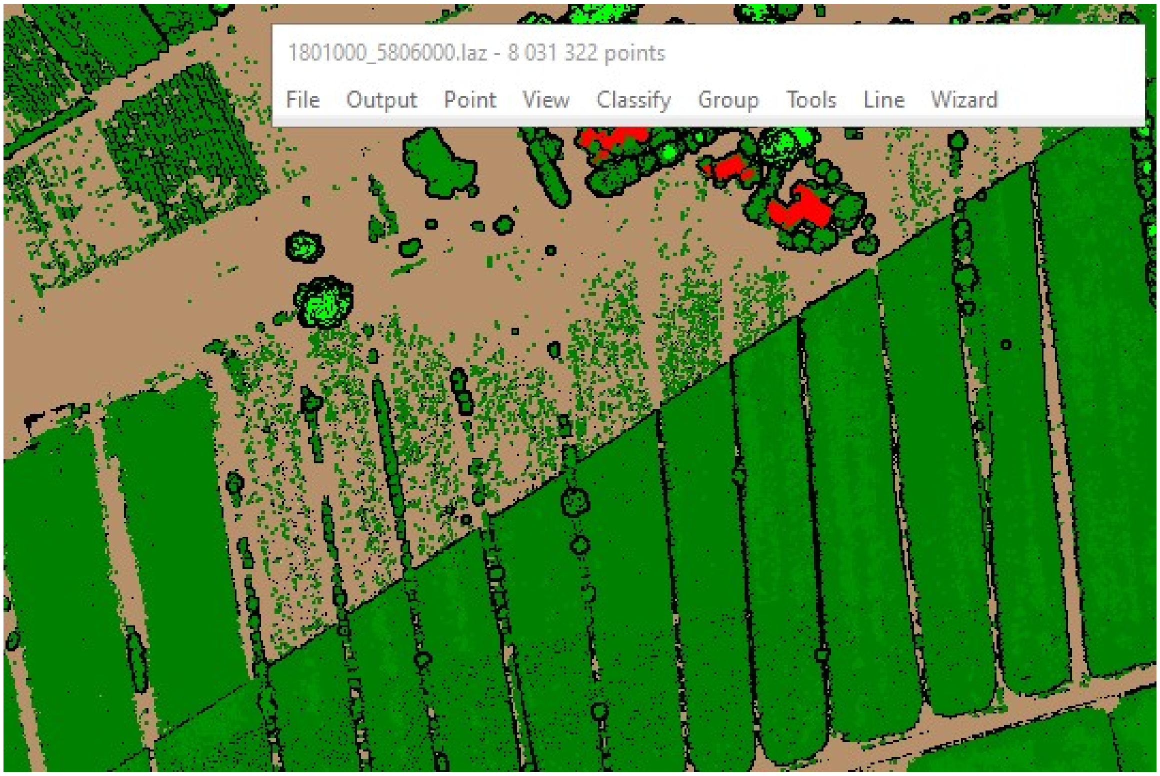



*Figure 51: Vegetation. Tile BE31_3839*

# 8 Results Acceptance & Signoff

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

| Result Acceptance | | | |
|---|---|---|---|
| Assessment Criteria | Status | Completed By | Date |
| Point cloud classification accuracy | Complete | Woolpert/ AAM | 03 July 2023 |
| Point cloud classification consistency | Complete | Woolpert/ AAM | 03 July 2023 |
| Point Cloud LAS tiled deliverables | Complete | Woolpert/ AAM | 03 July 2023 |
| Hydro-flattened Digital Elevation Models | Complete | Woolpert/ AAM | 03 July 2023 |
| Digital Survey Models | Complete | Woolpert/ AAM | 03 July 2023 |
| Contours | Complete | Woolpert/ AAM | 03 July 2023 |
| Extents, Flight Lines, Break lines, Tile Index | Complete | Woolpert/ AAM | 03 July 2023 |
| | | | |
| Project Manager / Supervisor Signoff | Complete | Luke Graham | 03 July 2023 |
| Ocean Infinity Review | Complete | Luke Leydon | 01 August 2023 |

*Table 10: Processing Results Acceptable Signoff*

| Result Acceptance | | | |
|---|---|---|---|
| Assessment Criteria | Status | Completed By | Date |
| Point cloud classification accuracy | Complete | Woolpert/ AAM | 22 September 2023 |
| Point cloud classification consistency | Complete | Woolpert/ AAM | 22 September 2023 |
| Point Cloud LAS tiled deliverables | Complete | Woolpert/ AAM | 22 September 2023 |
| Hydro-flattened Digital Elevation Models | Complete | Woolpert/ AAM | 22 September 2023 |
| Digital Survey Models | Complete | Woolpert/ AAM | 22 September 2023 |
| Contours | Complete | Woolpert/ AAM | 22 September 2023 |
| Extents, Flight Lines, Break lines, Tile Index | Complete | Woolpert/ AAM | 22 September 2023 |
| | | | |
| Project Manager / Supervisor Signoff | Complete | Luke Graham / Brian Foster | 22 September 2023 |
| Ocean Infinity Review | Complete | Luke Leydon | 01 October 2023 |

*Table 11: Processing Results Acceptable Signoff (Rev1)*

# Appendix A: Lidar Quality Assurance Results

Provided as separate Documents

| | | | |
|---|---|---|---|
| AU411 WRC_Raised_Defect_Tracking_Block_CD_v1 | 22/09/2023 4:28 PM | Microsoft Excel W... | 17,712 KB |
| BlockCDr1_LP360_stats | 22/09/2023 4:28 PM | Microsoft Excel W... | 6,417 KB |
| LAS_Statistics_Block-CD_Rev1 | 22/09/2023 4:28 PM | Text Document | 6 KB |
| LINZ_issues_block_CD_with_aam_comments_20230920.dbf | 22/09/2023 4:28 PM | DBF File | 74 KB |
| LINZ_issues_block_CD_with_aam_comments_20230920.prj | 22/09/2023 4:28 PM | PRJ File | 1 KB |
| LINZ_issues_block_CD_with_aam_comments_20230920.shp | 22/09/2023 4:28 PM | SHP File | 20 KB |
| LINZ_issues_block_CD_with_aam_comments_20230920.shx | 22/09/2023 4:28 PM | SHX File | 1 KB |
| WRC_Issues_with_aam_comments_20230920.dbf | 22/09/2023 4:28 PM | DBF File | 117 KB |
| WRC_Issues_with_aam_comments_20230920.prj | 22/09/2023 4:28 PM | PRJ File | 1 KB |
| WRC_Issues_with_aam_comments_20230920.shp | 22/09/2023 4:28 PM | SHP File | 4 KB |
| WRC_Issues_with_aam_comments_20230920.shx | 22/09/2023 4:28 PM | SHX File | 2 KB |

# Waikato Local Authority Shared Services (WLASS) / CoLAB LiDAR Data Capture Services

# LiDAR Processing Report Block E Priority (Rev2)

Contract Number: AU411

Surveyed By: iXblue Pty Ltd / Ocean Infinity

Processing Completed By: WOOLPERT

Prepared For: Waikato Local Authority SHARED SERVICES / COLAB BETTER TOGETHER

Document Date: 2 May 2023

Ocean Infinity (Australia) Pty Ltd
ABN 61 128 811 978
oceaninfinity.com

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## Document Revision

| Revision No | Issue Purpose | Prepared | Checked | Approved |
|---|---|---|---|---|
| 0 | Issue Priority E LiDAR Processing Report | L Leydon | BF/MM | D Field |
| 1 | Re-Issue based on QC Feedback | BF /MM | D Field | L Leydon |
| 2 | Re-Issue to reflect most recent supply | L Leydon | F Field | L Leydon |
| | | | | |

## Approval for Issue

| Name | Signature | Date |
|---|---|---|
| Luke Leydon | | 02 May 2023 |

# Revision History

| Item | Description of change | Section | Revision |
|---|---|---|---|
| 1 | New section on Geometric Calibration inserted | 2.4 | 1 |
| 2 | More detailed explanation of classification process. Figures 8 & 9 added | 2.8 | 1 |
| 3 | Minor update of wording | 2.9, para 6 | 1 |
| 4 | Review and update of section | 4.3.1 | 1 |
| 5 | Review and update of section | 4.3.2 | 1 |
| 6 | Results table dates updated to reflect changes to report | 7 | 1 |
| 7 | Added to Introduction | 1 | 2 |
| 8 | Updated Pointcloud statistics | Figure 10 | 2 |
| 9 | Updated LAS, DEM, DSM LP360 tables, | Tables 2,3,4 | 2 |
| 10 | Added section 2.11 | 2.11 | 2 |
| 11 | Updated report references | 4.1.1 | 2 |
| 12 | Updated DEM generation Methodology | 4.3.1 | 2 |
| 13 | Added to 6.4 Delivery not meeting specification with example figures of how data was corrected | 6.4 | 2 |
| 14 | New appendices | Appendices | 2 |
| | | | |
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# Contents

# Tables

# Figures

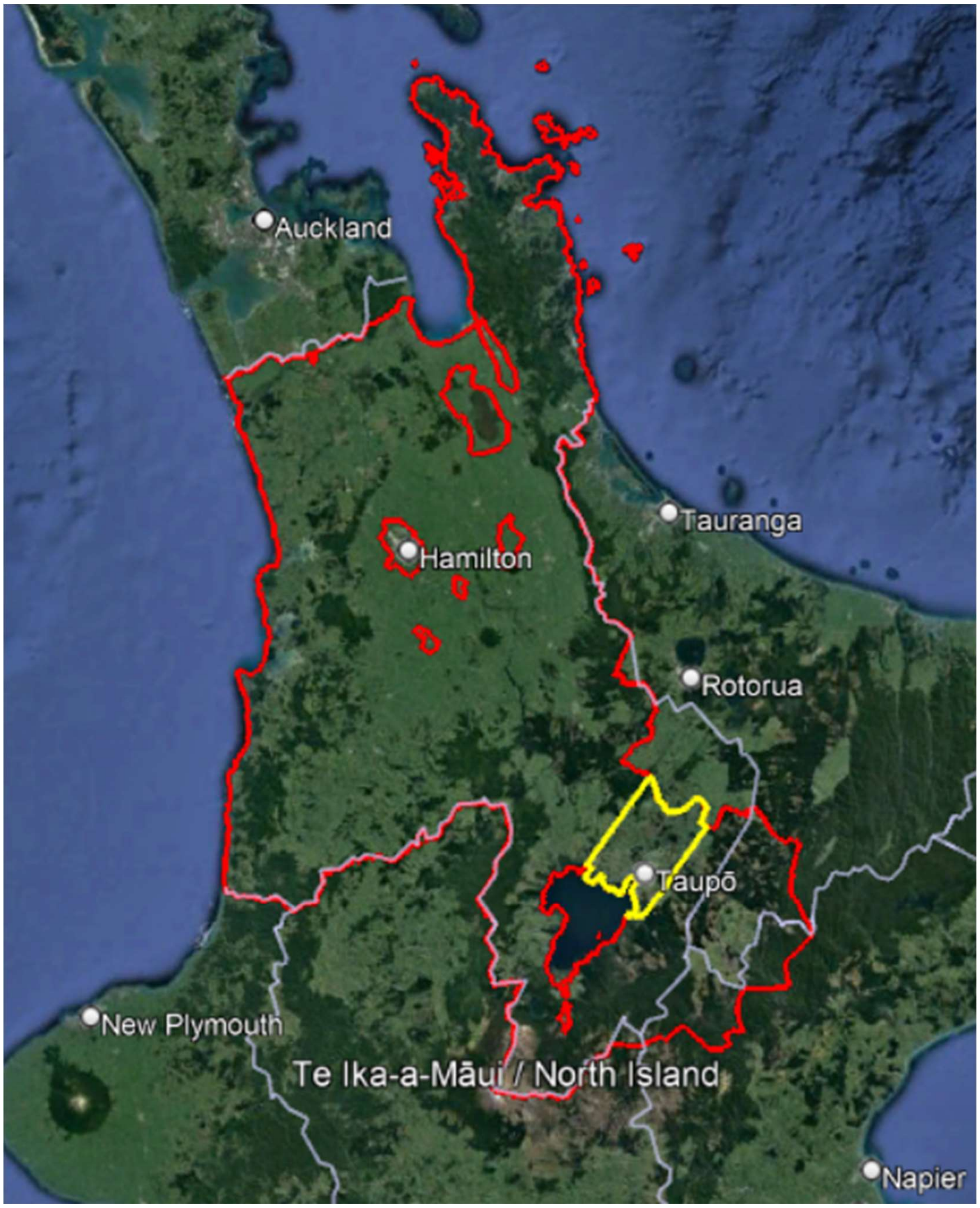



*Figure 1: Waikato Survey Area*

# 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

- AU411_WLASS-Collection_Report-10052021.pdf.

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 Priority E, as illustrated in yellow in Figure 1 - Waikato Survey

It is noted that this Priority Block dataset has been subject to several supplies, rework and resupplies. New Appendices have been supplied along with screenshots showing how the previous datasets were affected and then corrected.

# 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).

https://www.linz.govt.nz/system/files_force/media/doc/pgf_version_new_zealand_national_aerial_lidar_base_specification.pdf?download=1

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 (example)*

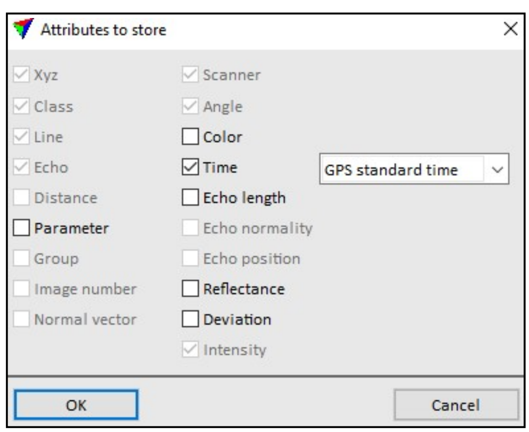



*Figure 3: Project settings used in TerraScan project when importing points into the project.*

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.

```
file source ID:              0
global_encoding:             17
project ID GUID data 1-4:    00000000-0000-0000-0000-000000000000
version major.minor:         1.4
```

*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)

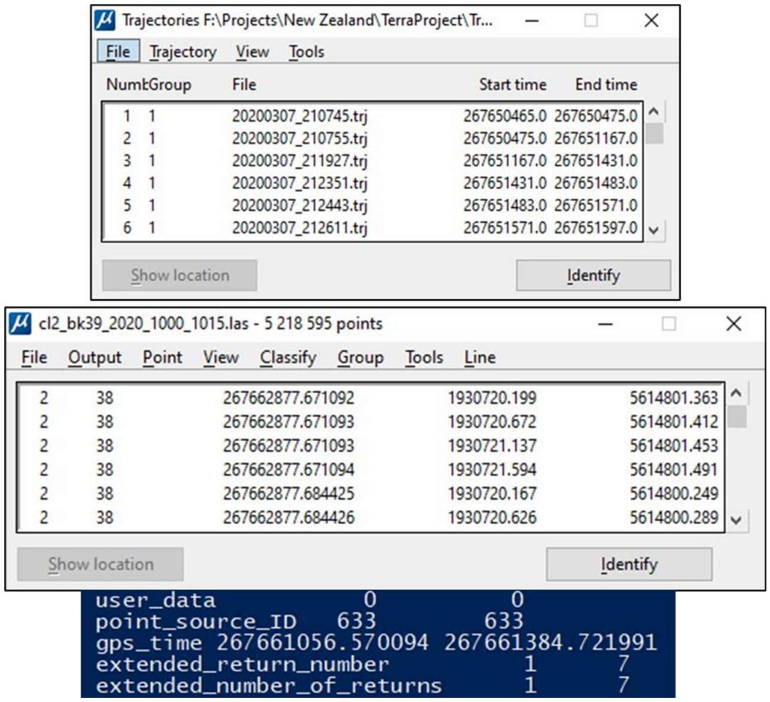



*Figure 5: Representative examples of LAS point attributes*

## 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”.

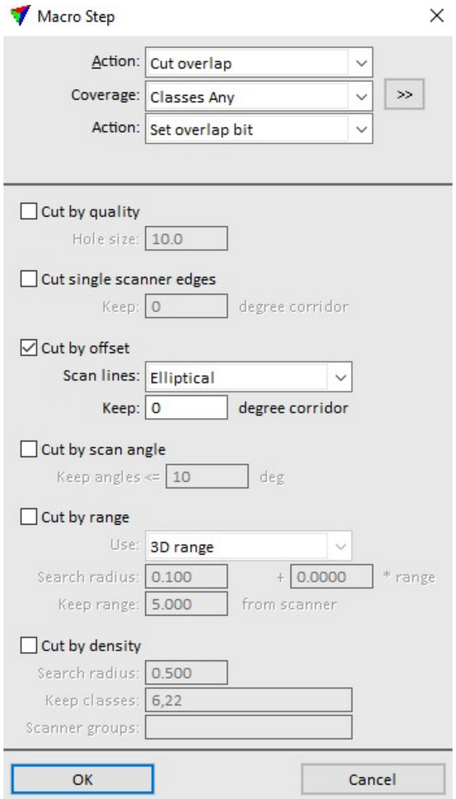



*Figure 6: Settings used when cutting overlap in Microstation.*

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:

| Code | Description |
|---|---|
| 1 | Processed, but unclassified |
| 2 | Ground |
| 3 | Low vegetation <2m |
| 4 | Medium vegetation |
| 5 | High vegetation >8m |
| 6 | Building |
| 7 | Low noise |
| 9 | Water |
| 17 | Bridge deck |
| 18 | High noise |

*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.

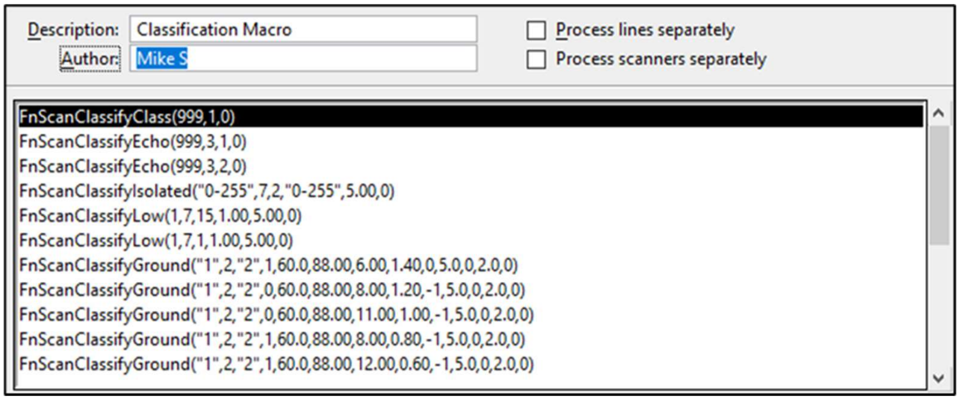



*Figure 7: Automatic classification macro developed for the project area.*

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 moulds 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.

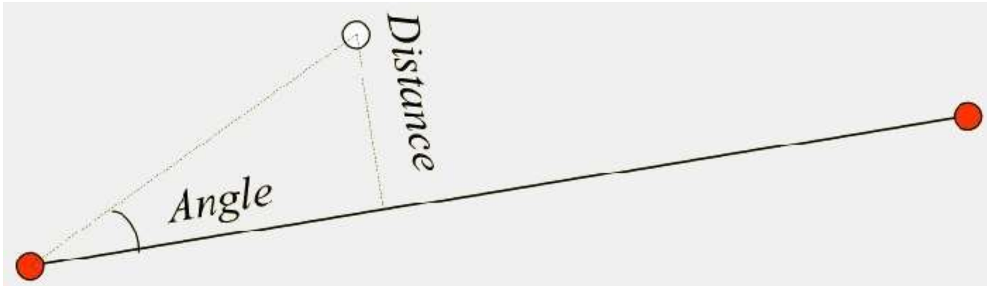



*Figure 8: Illustration of iteration angle and iteration distance parameters in the ground routine.*

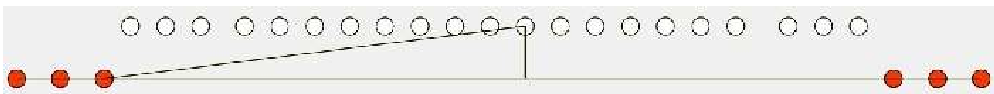


*Figure 9: A smaller iteration distance value avoids classification of ground points on low objects.*

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.

| Class | Classification | Count | Min Z | Max Z |
|---|---|---|---|---|
| 1 | Unclassified | 484039831 | 285.603 | 1087.073 |
| 2 | Ground | 1503417285 | 284.139 | 1087.243 |
| 3 | Low Veg | 192564631 | 285.738 | 1088.921 |
| 4 | Medium Veg | 514208171 | 286.141 | 1089.2 |
| 5 | High Veg | 795857367 | 293.294 | 1076.542 |
| 6 | Building | 19116240 | 290.211 | 705.265 |
| 9 | Water | 1246634 | -303.851 | 501.789 |
| 17 | Bridge Deck | 73179 | 291.618 | 610.229 |
| W7 | Witheld Low Noise | 616247170 | -386.304 | 2546.199 |
| W18 | Witheld High Noise | 38125933 | 261.817 | 2621.78 |
| O1 | Overlap Unclassified | 367645102 | 285.591 | 1063.11 |
| O2 | Overlap Ground | 812962217 | 284.433 | 1062.934 |
| O3 | Overlap Low Veg | 122089693 | 285.749 | 1064.843 |
| O4 | Overlap Medium Veg | 331978938 | 286.253 | 1068.231 |
| O5 | Overlap High Veg | 617845181 | 293.408 | 1062.404 |
| O6 | Overlap Building | 13295054 | 291.144 | 680.983 |
| O9 | Overlap Water | 438606 | 238.67 | 470.305 |
| O17 | Overlap Bridge Deck | 46397 | 293.135 | 532.471 |
| OW7 | Overlap/Witheld Low Noise | 427433094 | -772.194 | 2517.106 |
| OW18 | Overlap/Witheld High | 14157164 | 285.968 | 2585.14 |

*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.

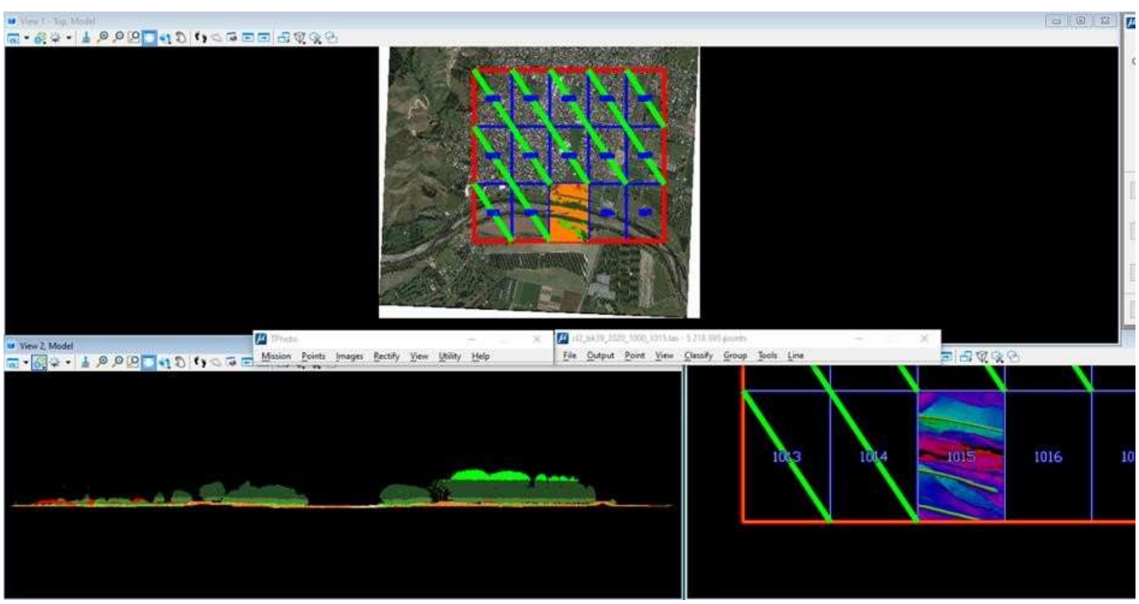



*Figure 11: The green diagonal hatching seen above shows blocks which have been fully checked.*

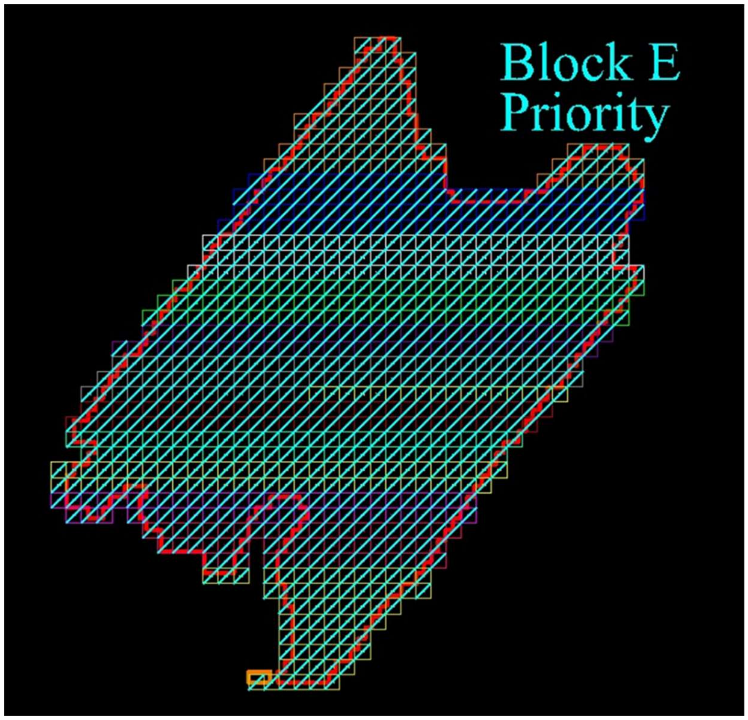



*Figure 12: The diagonal hatching seen above shows how the progress was tracked*

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.

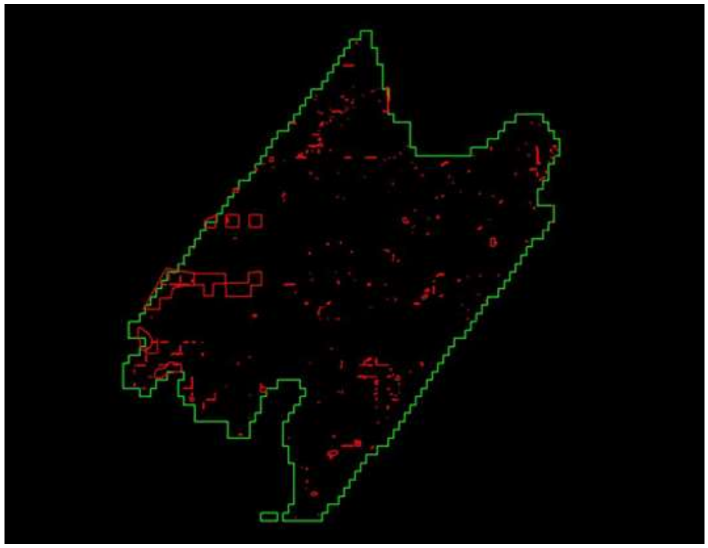


*Figure 13: The polygons are areas for further investigation*

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 that appear to have a rough surface.

The figures below illustrate such an 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.

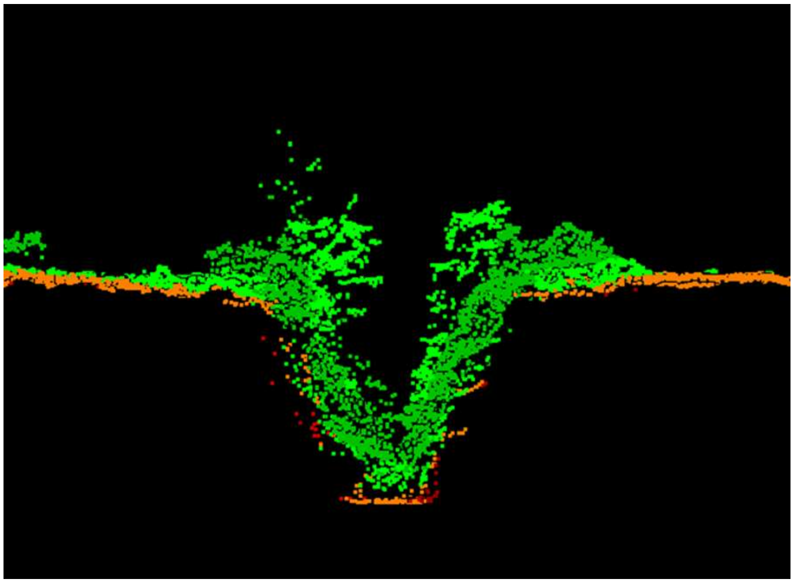


*Figure 14: Pre-filter profile view (ground, noise, and vegetation displayed)*

*Figure 15: Pre-filter profile view (just ground points displayed)*

*Figure 16: Post-filter profile view (just ground displayed)*

- Note some additional ground points were reclassified from noise to ground. As this is a thin profile the affects appear minimal but as shown in the figures below, this process was able to help alleviate this situation

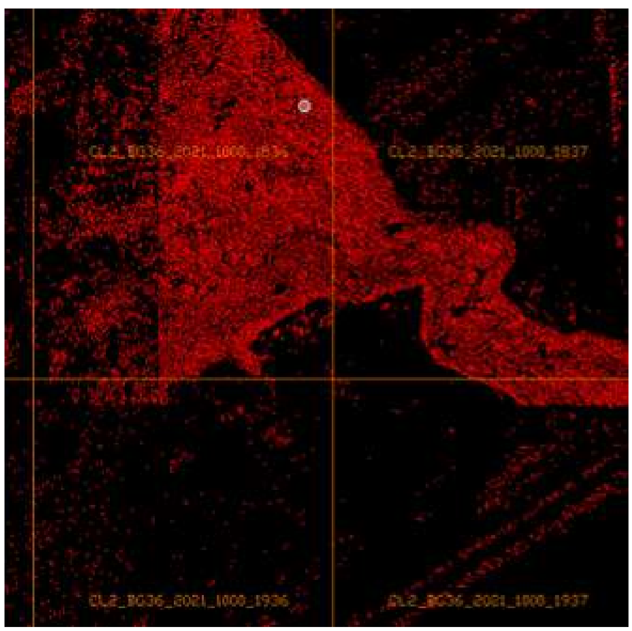



*Figure 17: Pre-filter overhead view (just noise points displayed)*

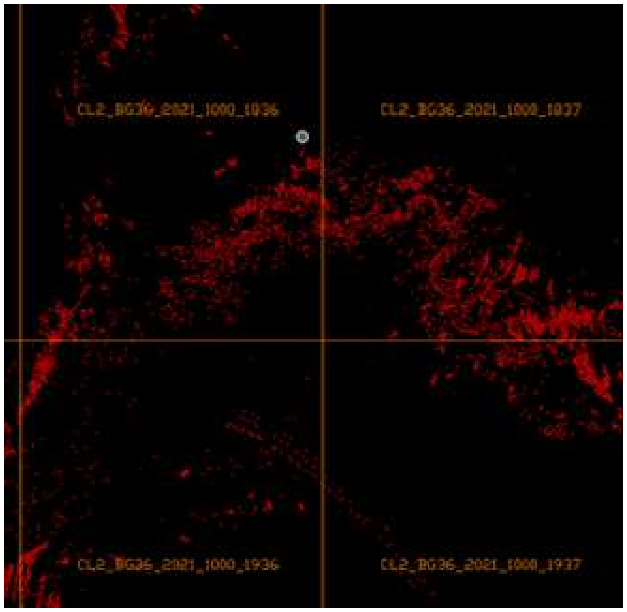



*Figure 18: Post-filter overhead view (just noise points displayed)*

## 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 is evident in places 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 Remainder Blocks. 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 5 000m$^2$ or larger in size.

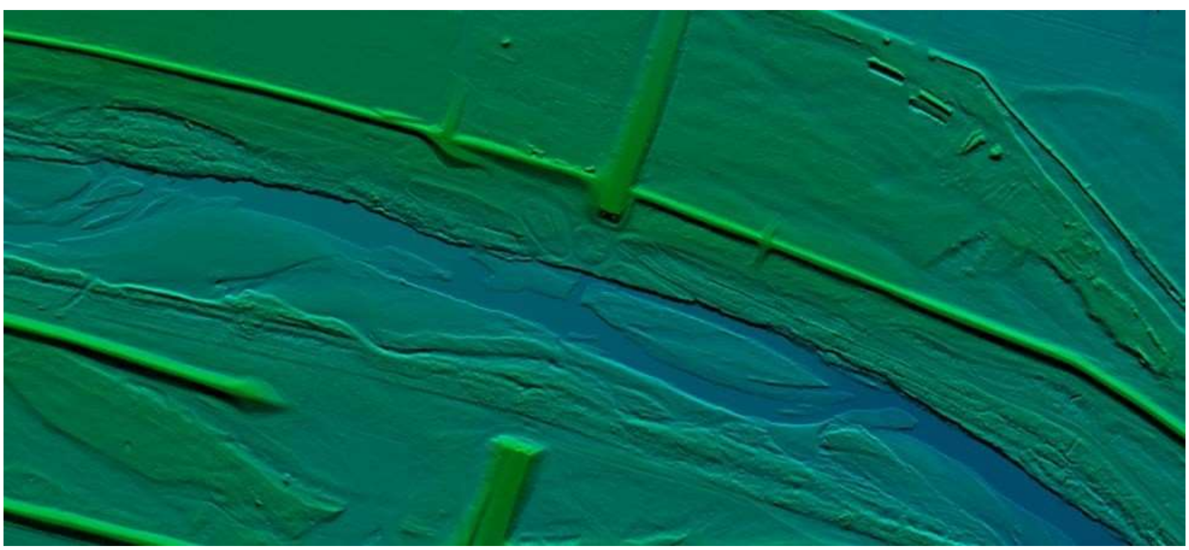


*Figure 19: Example of a hydro-flattened stream with a stream-island.*

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 20 shows the example excerpt of river points used to create the centreline after downstream flow was enforced. Figure 21 shows the example highlighted script was used to generate the centreline for the stream within the project's survey.

| | | | |
|---|---|---|---|
| 1 | 1929744.8358 | 5615128.2638 | 7.7096 |
| 2 | 1929746.0769 | 5615130.8498 | 7.6863 |
| 3 | 1929746.4280 | 5615131.5996 | 7.6796 |
| 4 | 1929746.5107 | 5615131.7727 | 7.678 |
| 5 | 1929746.7841 | 5615132.3591 | 7.6728 |
| 6 | 1929748.0794 | 5615135.0799 | 7.6483 |
| 7 | 1929748.5703 | 5615136.1455 | 7.6388 |
| 8 | 1929749.4246 | 5615138.0643 | 7.622 |
| 9 | 1929749.8587 | 5615139.0742 | 7.6132 |
| 10 | 1929750.6288 | 5615140.9327 | 7.5973 |
| 11 | 1929751.0393 | 5615141.7916 | 7.5896 |
| 12 | 1929751.5292 | 5615142.7809 | 7.5805 |
| 13 | 1929754.3861 | 5615148.3485 | 7.529 |
| 14 | 1929754.7868 | 5615149.1041 | 7.5219 |
| 15 | 1929754.7991 | 5615149.1267 | 7.5217 |
| 16 | 1929757.3347 | 5615152.1834 | 7.4808 |
| 17 | 1929757.8445 | 5615152.7752 | 7.4594 |

*Figure 20: Excerpt of river points used to create the centreline*

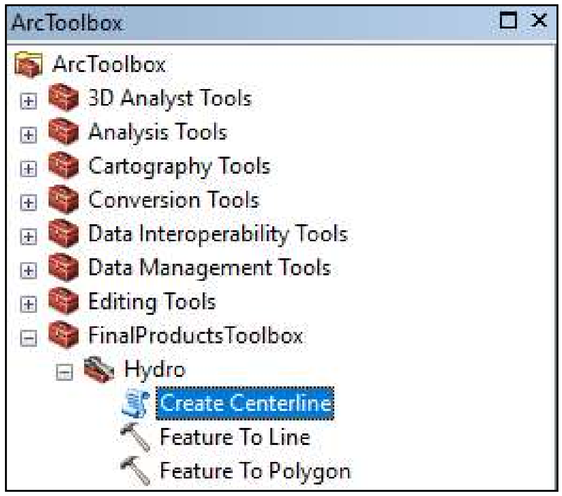



*Figure 21: Centreline for the stream within the project's survey*

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:

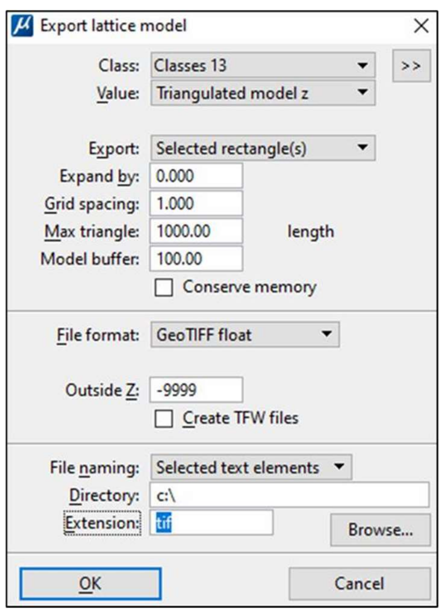



*Figure 22: Settings used to export lattice models.*

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.

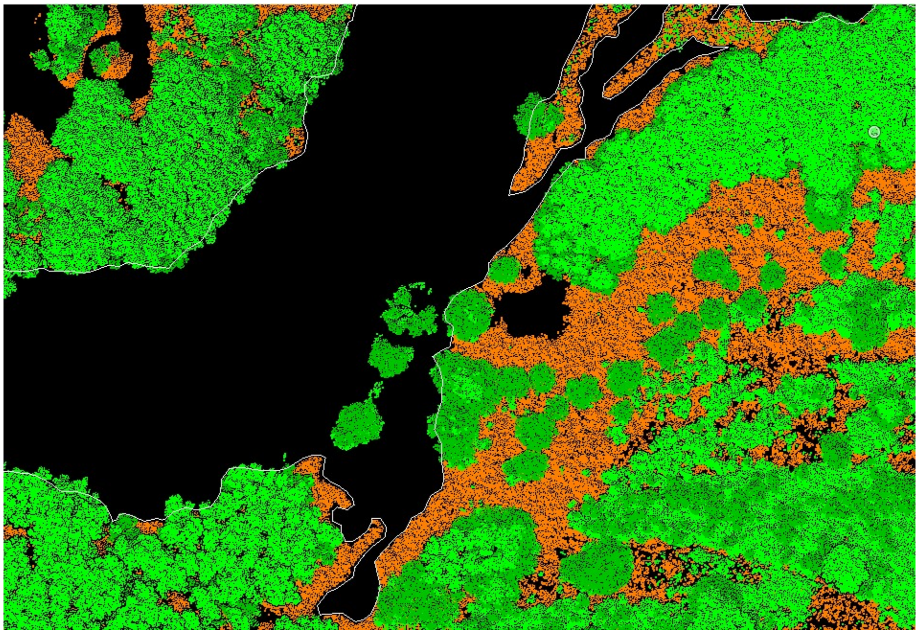


*Figure 23: Pre-filter, overhead view of ground and veg points with hydro lines*

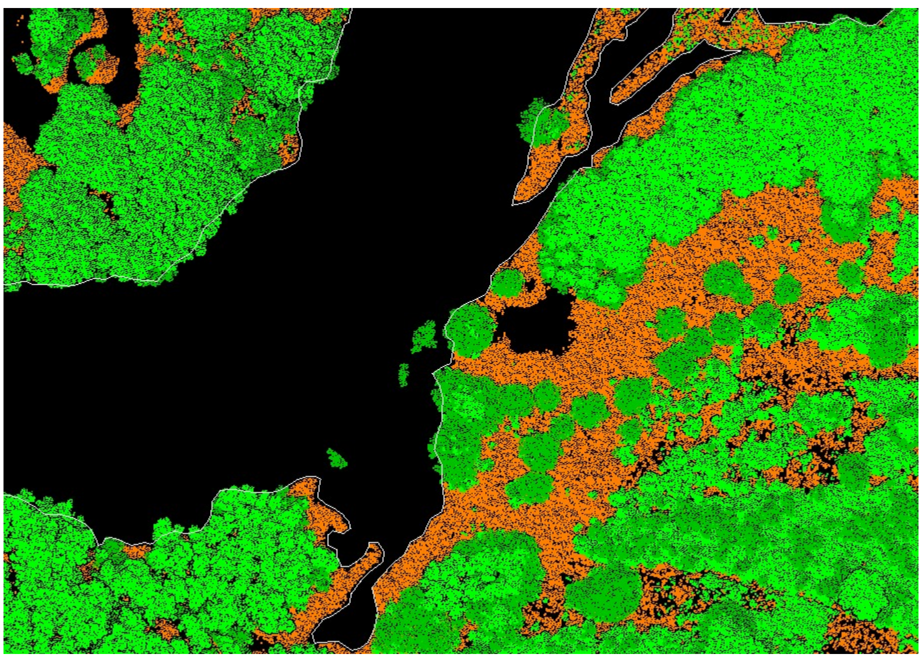


*Figure 24: Post-filter, overhead view of ground and veg points with hydro lines*

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 25: Point cloud – boulder filled stream*


*Figure 26: 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 8.1.3 requires that a geo-referenced, digital spatial representation of the detailed extents of each delivered dataset.

The data for Priority E was captured using Leica TerrainMapper sensors 513 and 559, flown on days 6th, 10th, 11th, 14th, 15th, 25th and 26th January 2021 and days 1st and 3rd of February 2021. The extent of Priority E can be seen in Figure 25. The flight lines relating to the expanded area can be seen in Figure 26.

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.

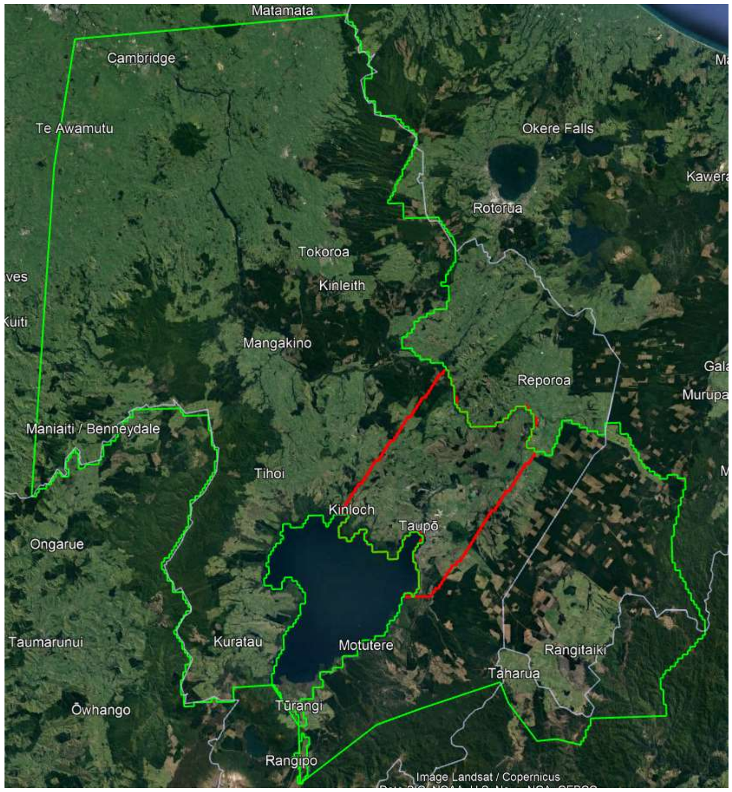



*Figure 27: Extent of deliverable data for Priority E (red outline)*

### 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.

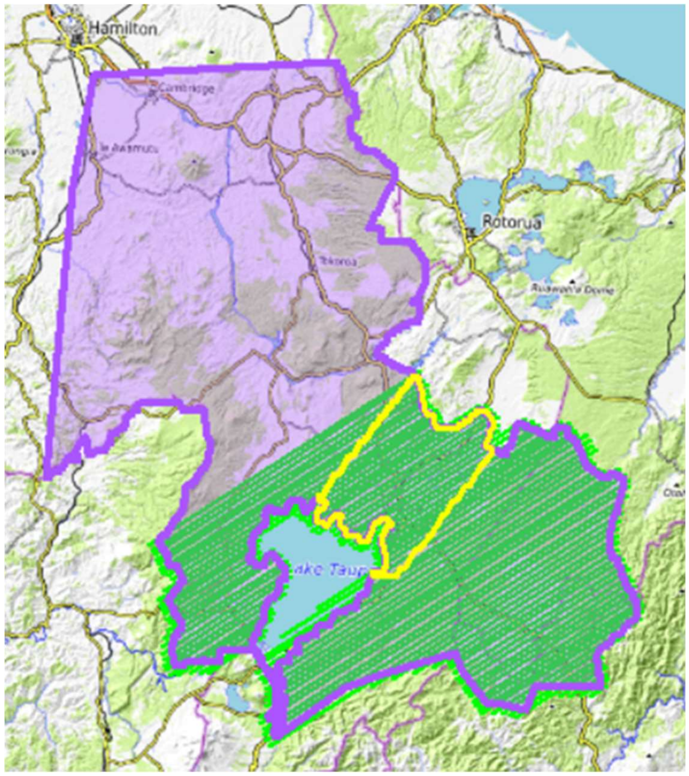



*Figure 28: Flight lines for 4ppm2 data coverage over Priority E South*

## 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 29: WKT of a LAS file shown by LASTools.*

Intensity valued scaled from a range of 100 – 10000 outputs 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.

| File | Points | Version | File Signature | File Source ID | SRS Source | System Identifier |
|---|---|---|---|---|---|---|
| CL2_BG36_2021_1000_0636.las | 2,785,258 | 1.4 | LASF | 0 | WKT | Leica Terrain Mapper |
| CL2_BG36_2021_1000_0637.las | 2,074,119 | 1.4 | LASF | 0 | WKT | Leica Terrain Mapper |
| CL2_BG36_2021_1000_0638.las | 2,495,908 | 1.4 | LASF | 0 | WKT | Leica Terrain Mapper |
| CL2_BG36_2021_1000_0639.las | 3,892,799 | 1.4 | LASF | 0 | WKT | Leica Terrain Mapper |
| CL2_BG36_2021_1000_0640.las | 4,588,724 | 1.4 | LASF | 0 | WKT | Leica Terrain Mapper |
| CL2_BG36_2021_1000_0641.las | 3,451,847 | 1.4 | LASF | 0 | WKT | Leica Terrain Mapper |
| CL2_BG36_2021_1000_0642.las | 3,767,550 | 1.4 | LASF | 0 | WKT | Leica Terrain Mapper |
| CL2_BG36_2021_1000_0643.las | 4,619,041 | 1.4 | LASF | 0 | WKT | Leica Terrain Mapper |
| CL2_BG36_2021_1000_0644.las | 3,490,797 | 1.4 | LASF | 0 | WKT | Leica Terrain Mapper |
| CL2_BG36_2021_1000_0645.las | 2,658,490 | 1.4 | LASF | 0 | WKT | Leica Terrain Mapper |
| CL2_BG36_2021_1000_0646.las | 2,421,845 | 1.4 | LASF | 0 | WKT | Leica Terrain Mapper |
| CL2_BG36_2021_1000_0647.las | 3,051,765 | 1.4 | LASF | 0 | WKT | Leica Terrain Mapper |

*Table 2: Condensed output from LP360 illustrating LAS file specification compliance*

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 analysist 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 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 condensed version of LP360's findings can be found in the table below. A complete listing of the LP360 results is included as an embedded document in Appendix 1.

| File | Format | NoData Value | BPB | Bands | Data Type | Pixel Size | Coordinate System |
|---|---|---|---|---|---|---|---|
| DEM_BF37_2021_1000_4817.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BF37_2021_1000_4818.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BF37_2021_1000_4819.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BF37_2021_1000_4820.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BF37_2021_1000_4821.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BF37_2021_1000_4822.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BF37_2021_1000_4823.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BF37_2021_1000_4824.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BF37_2021_1000_4825.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BF37_2021_1000_4826.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BF37_2021_1000_4827.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BF37_2021_1000_4828.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BF37_2021_1000_4901.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BF37_2021_1000_4902.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |

*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.

As part of the DSM development, hydro features used to create the DEM deliverables were included in the production of the 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. This process allows for natural and man-made features to be incorporated to the DSM while helping to develop an aesthetically pleasing water surface similar to that developed for the DEM deliverable.

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 30 is an excerpt of one of the DSM tiles created for the project area.

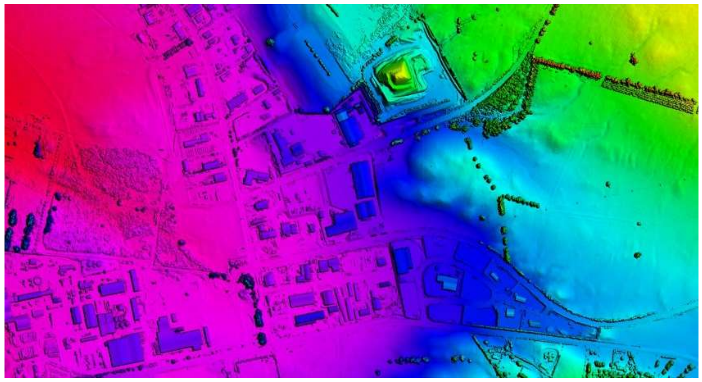


*Figure 30: Excerpt from DSM_BG36_2020_1000_2042.*

The tiles created are in GeoTiff floating 32-bit format and have been adjusted to display a NoData value of -9999 (Figure 31). 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.

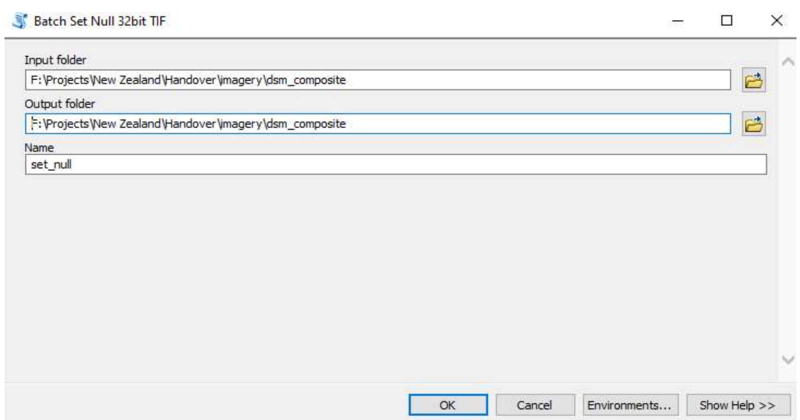



*Figure 31: Script used in ArcMap to achieve a NoData value of -9999.*

| | |
|---|---|
| Format | IMAGINE Image |
| Source Type | Generic |
| Pixel Type | floating point |
| Pixel Depth | 32 Bit |
| NoData Value | -9999 |

*Figure 32: 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.

| File | Format | NoData Value | BPB | Bands | Data Type | Coordinate System |
|---|---|---|---|---|---|---|
| DSM_BG36_2021_1000_2117.tif | GTiff | -9999 | 32 | 1 | FLOAT | EPSG: 2193 |
| DSM_BG36_2021_1000_2118.tif | GTiff | -9999 | 32 | 1 | FLOAT | EPSG: 2193 |
| DSM_BG36_2021_1000_2119.tif | GTiff | -9999 | 32 | 1 | FLOAT | EPSG: 2193 |
| DSM_BG36_2021_1000_2120.tif | GTiff | -9999 | 32 | 1 | FLOAT | EPSG: 2193 |
| DSM_BG36_2021_1000_2121.tif | GTiff | -9999 | 32 | 1 | FLOAT | EPSG: 2193 |
| DSM_BG36_2021_1000_2122.tif | GTiff | -9999 | 32 | 1 | FLOAT | EPSG: 2193 |
| DSM_BG36_2021_1000_2123.tif | GTiff | -9999 | 32 | 1 | FLOAT | EPSG: 2193 |
| DSM_BG36_2021_1000_2124.tif | GTiff | -9999 | 32 | 1 | FLOAT | EPSG: 2193 |
| DSM_BG36_2021_1000_2125.tif | GTiff | -9999 | 32 | 1 | FLOAT | EPSG: 2193 |
| DSM_BG36_2021_1000_2126.tif | GTiff | -9999 | 32 | 1 | FLOAT | EPSG: 2193 |
| DSM_BG36_2021_1000_2127.tif | GTiff | -9999 | 32 | 1 | FLOAT | EPSG: 2193 |
| DSM_BG36_2021_1000_2128.tif | GTiff | -9999 | 32 | 1 | FLOAT | EPSG: 2193 |
| DSM_BG36_2021_1000_2129.tif | GTiff | -9999 | 32 | 1 | FLOAT | EPSG: 2193 |
| DSM_BG36_2021_1000_2130.tif | GTiff | -9999 | 32 | 1 | FLOAT | EPSG: 2193 |
| DSM_BG36_2021_1000_2131.tif | GTiff | -9999 | 32 | 1 | FLOAT | EPSG: 2193 |
| DSM_BG36_2021_1000_2132.tif | GTiff | -9999 | 32 | 1 | FLOAT | EPSG: 2193 |
| DSM_BG36_2021_1000_2133.tif | GTiff | -9999 | 32 | 1 | FLOAT | EPSG: 2193 |
| DSM_BG36_2021_1000_2134.tif | GTiff | -9999 | 32 | 1 | FLOAT | EPSG: 2193 |

*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.

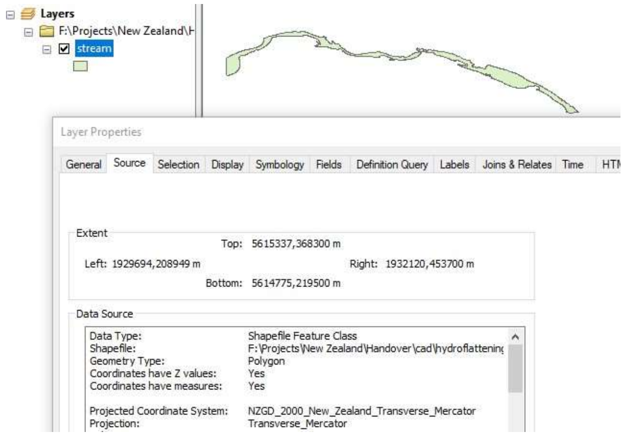



*Figure 33: Stream break line properties in ArcMap.*

## 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.

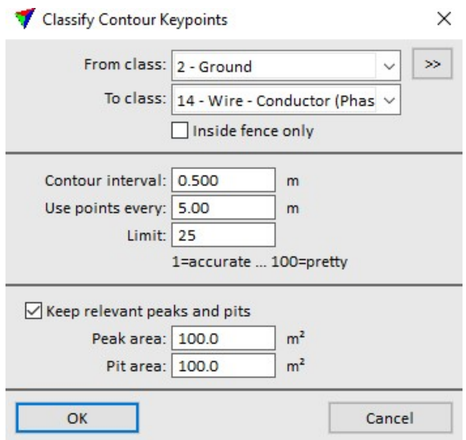



*Figure 34: Contour key points settings used in Terrascan.*

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_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.

| Naming Convention for point clouds, DEMs, and other tiled products<br>*[product]_[sheet]_[year]_[scale]_[tile].[ext]* | | |
|---|---|---|
| **Product** | *DEM* | **CL2-Point Cloud Classification Level 2**<br>**DEM-Bare Earth Digital Elevation Model**<br>**DSM-Digital Surface Model**<br>DTM-Digital Terrain Model<br>UNC-Unclassified Point Cloud<br>INT-Intensity image<br>CHM – Canopy Height Model<br>IMG-Aerial photography<br>etc |
| **Sheet** | *BK34* | LINZ Topo50 identifier (4 characters) |
| **Year** | *2016* | Year of survey commencement |
| **Scale** | *1000* | Nominal scale of NZTopo50 subtiles |
| **Tile** | *4118* | Row number (41), Column number (18) of tile with respect to an upper left origin |
| **ext** | *tif* | File extension according to format conventions<br>las<br>tif<br>shp<br>etc |
| *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-flatting break line bank line strings
│     │ └──stream_islands – Hydro-flatting 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 Priority E 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 Waikato Block E and Priority E 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 Area E – Priority E

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.

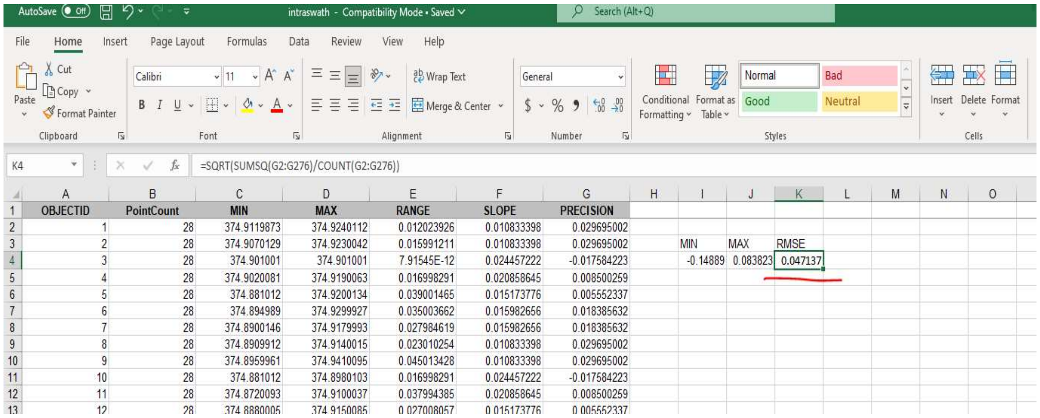
## 6.3 Review Process

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 Further review and changes

The original and subsequent supplies of data did not meet specification. There were issues with classification, intensity and interblock consistency. This has been corrected in the latest supply. The following section and associated figures illustrate how the data did not meet specification as identified by both Waikato Regional Council and LINZ and the fixes employed to remedy.

1. Priority E Intraswath- Woolpert tested 9 sample areas for Priority E. Based on these random samples we are meeting intraswath accuracy. The RMSE for these 9 areas computes to 0.047137 m.


K4 =SQRT(SUMSQ(G2:G276)/COUNT(G2:G276))

| OBJECTID | PointCount | MIN | MAX | RANGE | SLOPE | PRECISION |
|---|---|---|---|---|---|---|
| 1 | 28 | 374.9119873 | 374.9240112 | 0.012023926 | 0.010833398 | 0.029695002 |
| 2 | 28 | 374.9070129 | 374.9230042 | 0.015991211 | 0.010833398 | 0.029695002 |
| 3 | 28 | 374.901001 | 374.901001 | 7.91545E-12 | 0.024457222 | -0.017584223 |
| 4 | 28 | 374.9020081 | 374.9190063 | 0.016998291 | 0.020858645 | 0.008500259 |
| 5 | 28 | 374.881012 | 374.9200134 | 0.039001465 | 0.015173776 | 0.005552337 |
| 6 | 28 | 374.894989 | 374.9299927 | 0.035003662 | 0.015982656 | 0.018385632 |
| 7 | 28 | 374.8900146 | 374.9179993 | 0.027984619 | 0.015982656 | 0.018385632 |
| 8 | 28 | 374.8909912 | 374.9140015 | 0.023010254 | 0.010833398 | 0.029695002 |
| 9 | 28 | 374.8959961 | 374.9410095 | 0.045013428 | 0.010833398 | 0.029695002 |
| 10 | 28 | 374.881012 | 374.8980103 | 0.016998291 | 0.024457222 | -0.017584223 |
| 11 | 28 | 374.8720093 | 374.9100037 | 0.037994385 | 0.020858645 | 0.008500259 |
| 12 | 28 | 374.8880005 | 374.9150085 | 0.027008057 | 0.015173776 | 0.005552337 |

| MIN | MAX | RMSE |
|---|---|---|
| -0.14889 | 0.083823 | 0.047137 |

*Figure 35: Intrawath analysis*

2. Vegetation removed from ground class

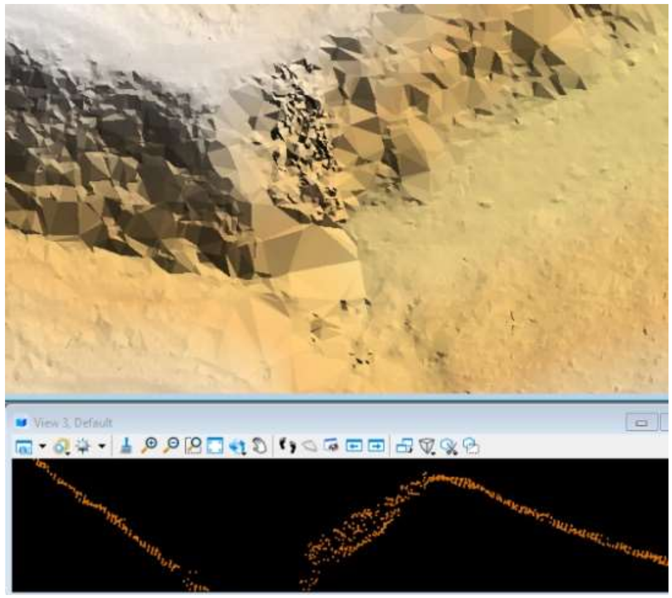



*Figure 36: Vegetation shown in ground. Tile CL2_BD32_2021_1000_0205.las*

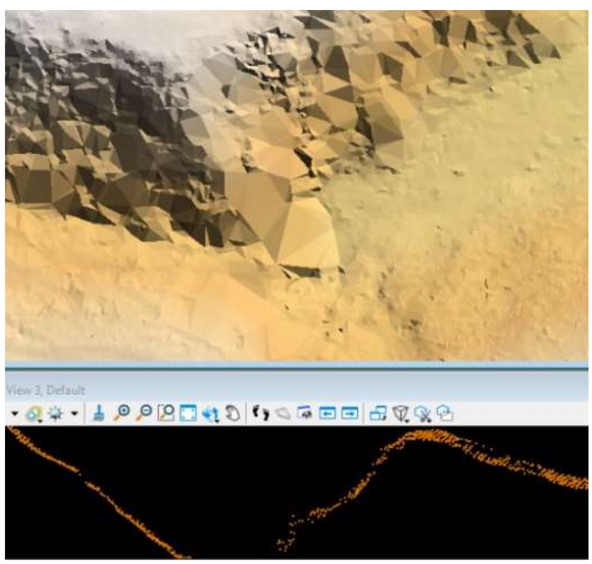



*Figure 37: Tile CL2_BD32_2021_1000_0205.las after vegetation removed from ground*

3. Spikes. Reclassed points from ground class to vegetation

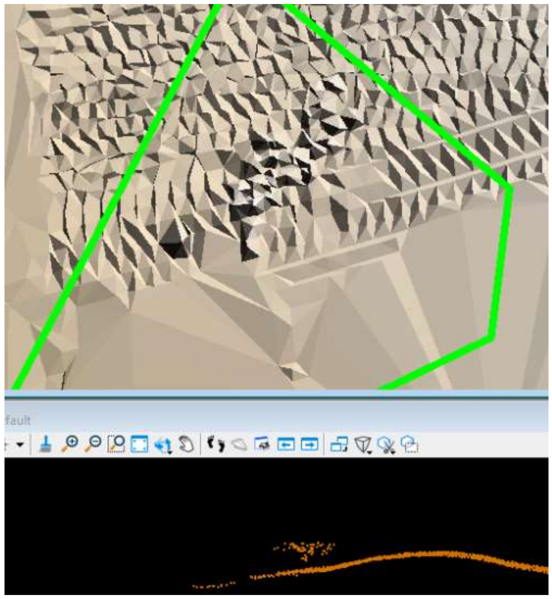


*Figure 38: Vegetation in ground class. Tile CL2_BD32_2021_1000_0540.las*

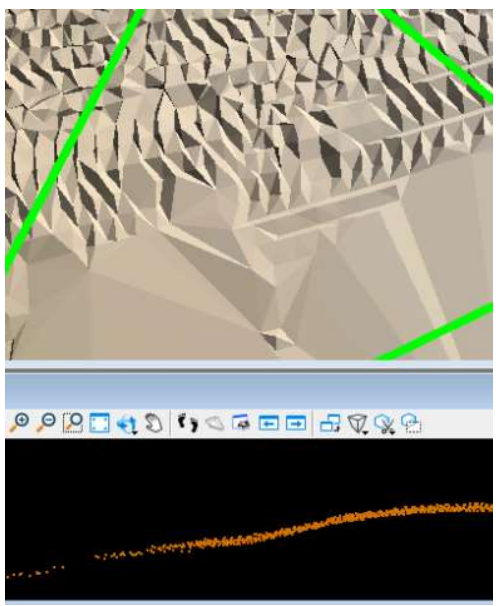


*Figure 39: Vegetation removed from ground class. Tile CL2_BD32_2021_1000_0540.las*

4. Reclassify low points to noise and added to ground class to better define DEM/DSM surface

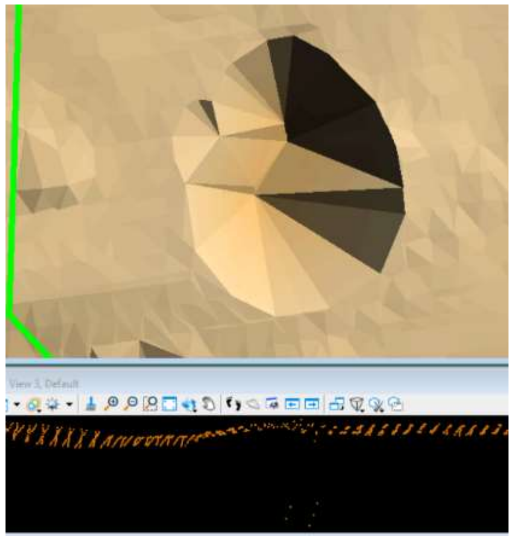


*Figure 40: Pit shown in CL2_BD32_2021_1000_0445.las*

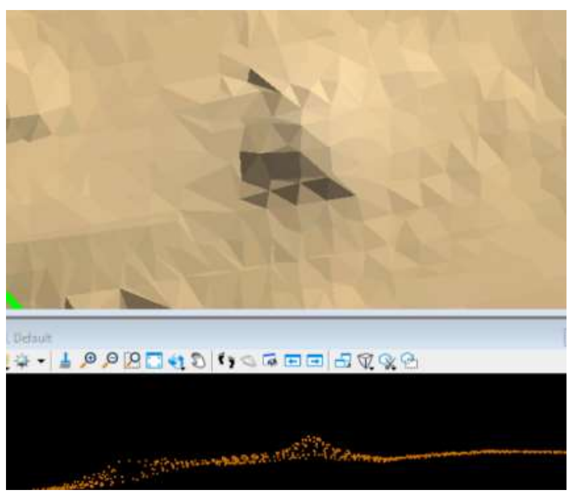


*Figure 41: Tile CL2_BD32_2021_1000_0445.las after repair*

5. Added additional points into ground to better define DEM surface

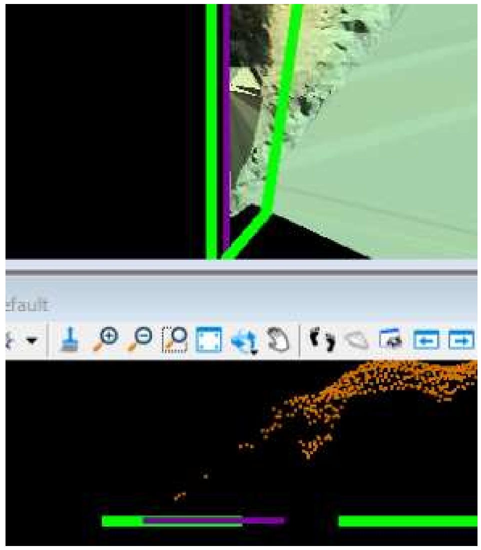



*Figure 42: Tile CL2_BC32_2021_1000_4601.las showing few ground points on slope*

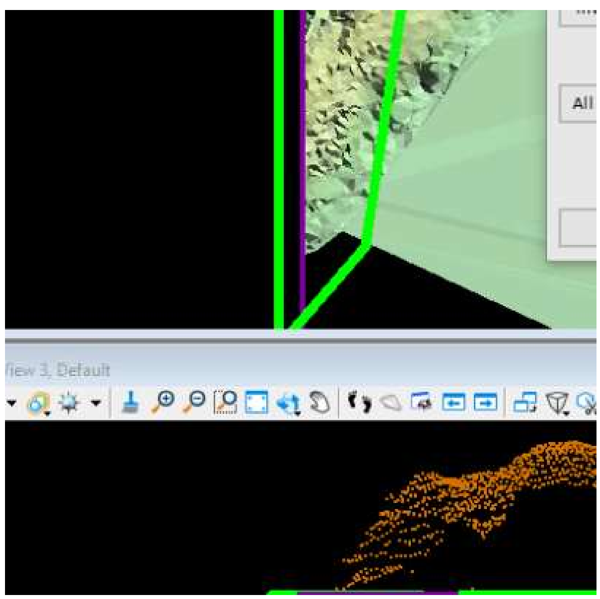



*Figure 43: Tile CL2_BC32_2021_1000_4601.las with additional ground points on slope*

6. Reclassed ground points on bridge deck to class 17

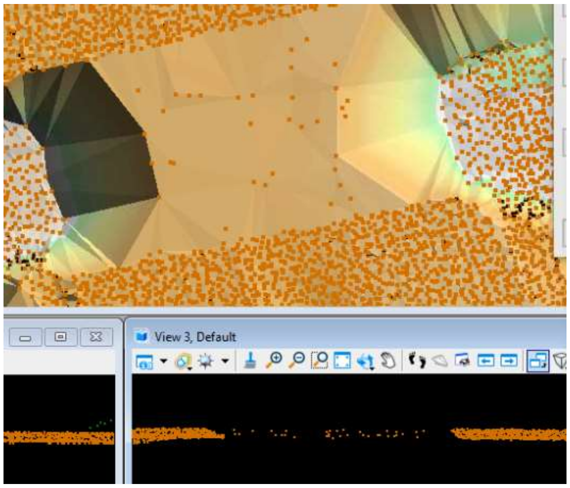



*Figure 44: Tile CL2_BB32_2021_1000_4850.las showing ground points on bridge deck*

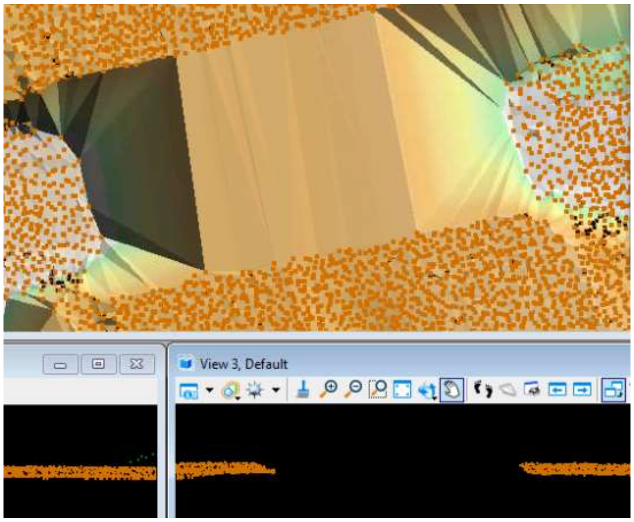



*Figure 45: Tile CL2_BB32_2021_1000_4850.las ground points removed*

7. Pitting removed by classifying noise and adding default to ground class.

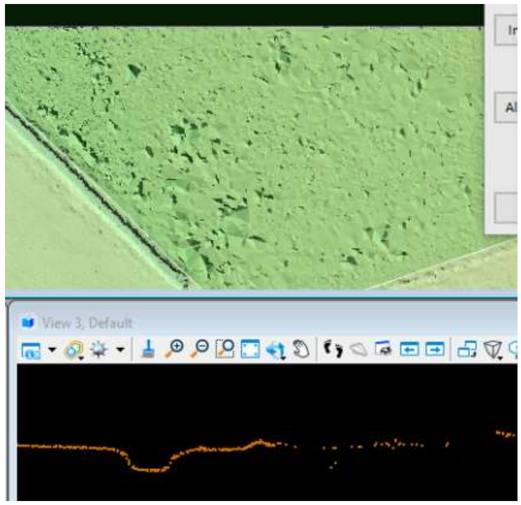



*Figure 46: Tile showing pitting*

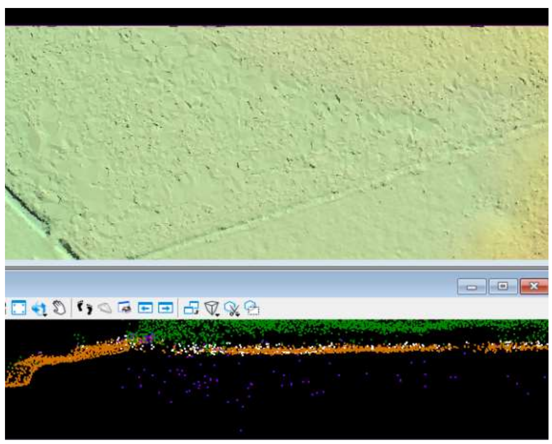


*Figure 47: Tile after repair*

8. It is noted that there will be sporadic low spots within farm fields where there is little point penetration

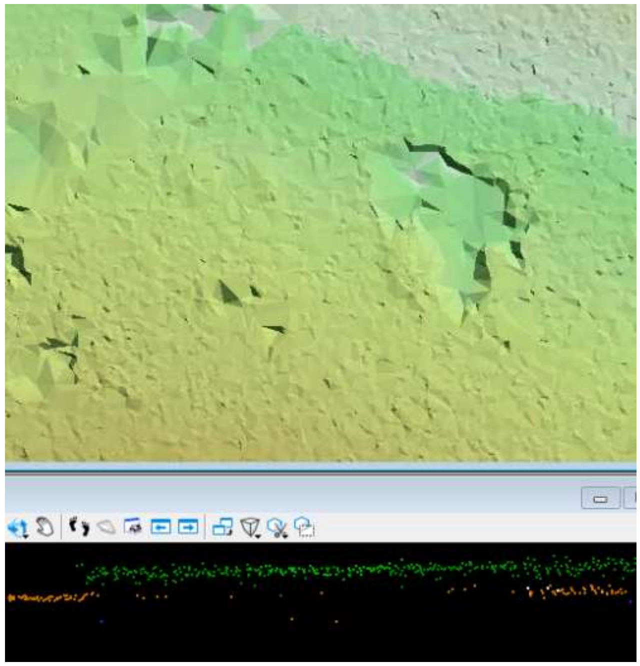


*Figure 48: Illustrating lack of available ground points*

9. Corduroy Texture in DEM/DSM. Additional filtering efforts were made to classify low points into noise class to address this patterning/texture in the DEM/DSM.

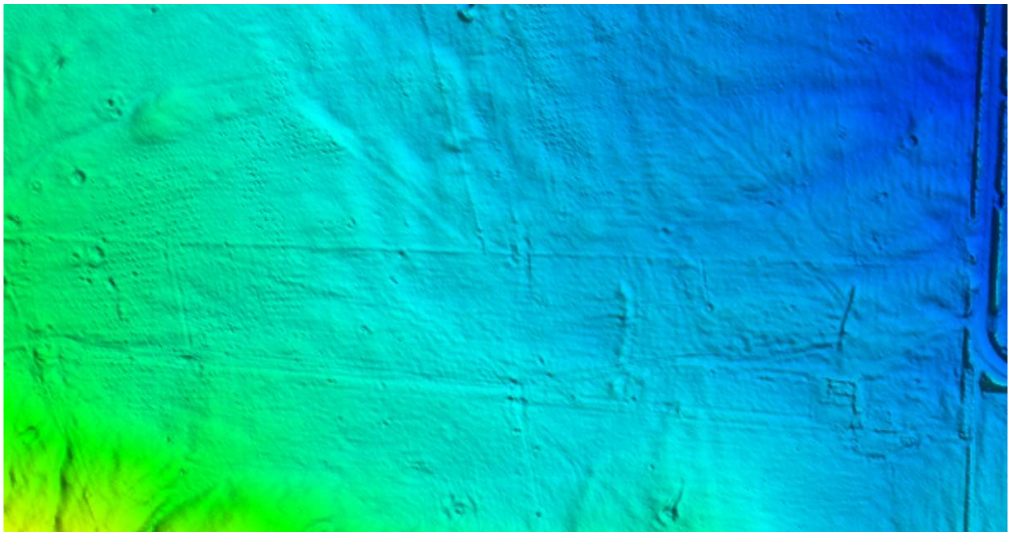


*Figure 49: DEM before filter*

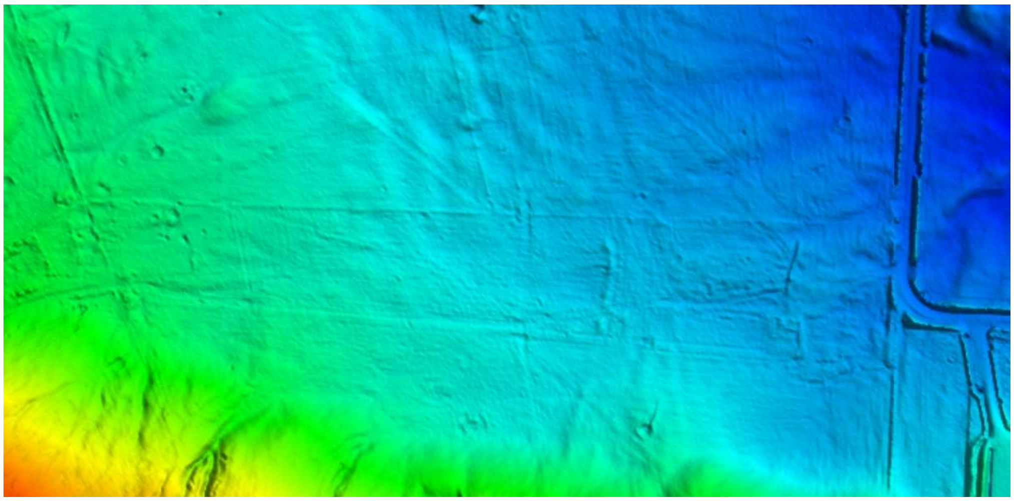


*Figure 50: DEM after filter*

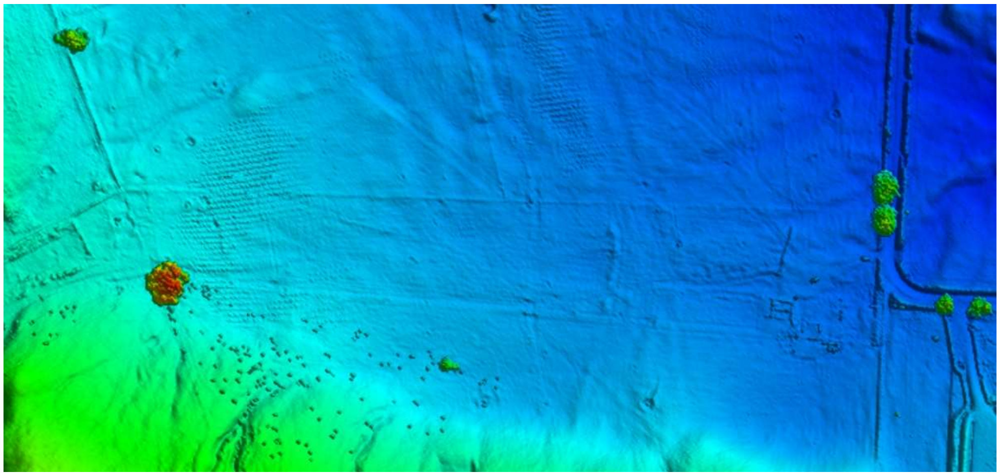


*Figure 51: DSM before filter*

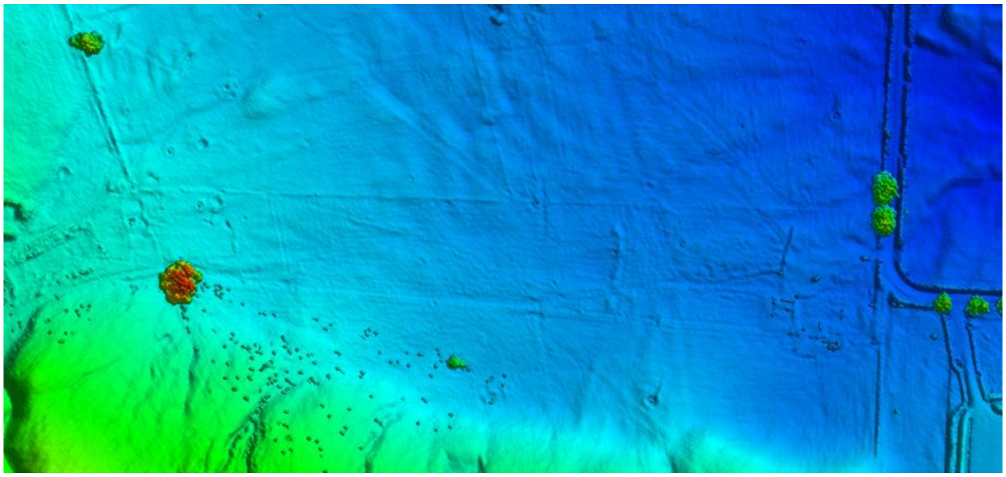


*Figure 52: DSM after filter*

# 7 Results Acceptance & Signoff

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

| Result Acceptance | | | |
|---|---|---|---|
| Assessment Criteria | Status | Completed By | Date |
| Point cloud classification accuracy | Complete | Woolpert | 18 July 2022 |
| Point cloud classification consistency | Complete | Woolpert | 18 July 2022 |
| Point Cloud LAS tiled deliverables | Complete | Woolpert | 18 July 2022 |
| Hydro-flattened Digital Elevation Models | Complete | Woolpert | 18 July 2022 |
| Digital Survey Models | Complete | Woolpert | 18 July 2022 |
| Contours | Complete | Woolpert | 18 July 2022 |
| Extents, Flight Lines, Break lines, Tile Index | Complete | Woolpert | 18 July 2022 |
| | | | |
| Project Manager / Supervisor Signoff | Complete | Brian Foster | 18 July 2022 |
| Ocean Infinity Review | Complete | Luke Leydon | 27 July 2022 |

*Table 6: Processing Results Acceptable Signoff*

| Result Acceptance | | | |
|---|---|---|---|
| Assessment Criteria | Status | Completed By | Date |
| Point cloud classification accuracy | Complete | Woolpert | 07 April 2023 |
| Point cloud classification consistency | Complete | Woolpert | 07 April 2023 |
| Point Cloud LAS tiled deliverables | Complete | Woolpert | 07 April 2023 |
| Hydro-flattened Digital Elevation Models | Complete | Woolpert | 07 April 2023 |
| Digital Survey Models | Complete | Woolpert | 07 April 2023 |
| Contours | Complete | Woolpert | 07 April 2023 |
| Extents, Flight Lines, Break lines, Tile Index | Complete | Woolpert | 07 April 2023 |
| | | | |
| Project Manager / Supervisor Signoff | Complete | Brian Foster | 07 April 2023 |
| Ocean Infinity Review | Complete | Luke Leydon | 01 May 2023 |

*Table 7: Processing Results Acceptable Signoff*

# Appendix A: Lidar Quality Assurance Results

| | | | |
|---|---|---|---|
| Priority_E_LASQC_Waikato | 2/05/2023 11:44 AM | Microsoft Excel M... | 15,845 KB |
| Priority_E_LP360_Results_for_DEMs | 2/05/2023 11:44 AM | Microsoft Excel W... | 219 KB |
| Priority_E_LP360_Results_for_DSMs | 2/05/2023 11:44 AM | Microsoft Excel W... | 216 KB |
| Priority_E_TSCAN_classes | 2/05/2023 11:44 AM | Microsoft Excel W... | 10 KB |
| PriorityE_LP360_stats | 2/05/2023 11:44 AM | Microsoft Excel W... | 1,621 KB |

Provided as separate documents

# Waikato Local Authority Shared Services (WLASS) / CoLAB LiDAR Data Capture Services

# LiDAR Processing Report Block E North (1)

Contract Number: AU411

Surveyed By: iXblue Pty Ltd / Ocean Infinity

Processing Completed By: Woolpert USA and Woolpert Australia

Prepared For: Colab (formerly WLASS)

Document Date: 14 October 2023

Ocean Infinity (Australia) Pty Ltd
ABN 61 128 811 978
oceaninfinity.com

OCEAN INFINITY®

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## Document Revision

| Revision No | Issue Purpose | Prepared | Checked | Approved |
|---|---|---|---|---|
| 0 | Issue LiDAR Processing Report | L Leydon | L Graham | D Field |
| | | | | |
| | | | | |
| | | | | |

## Approval for Issue

| Name | Signature | Date |
|---|---|---|
| Luke Leydon |  | 14 October 2023 |

# Revision History

| Item | Description of change | Section | Revision |
|---|---|---|---|
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# Contents

# Tables

# Figures

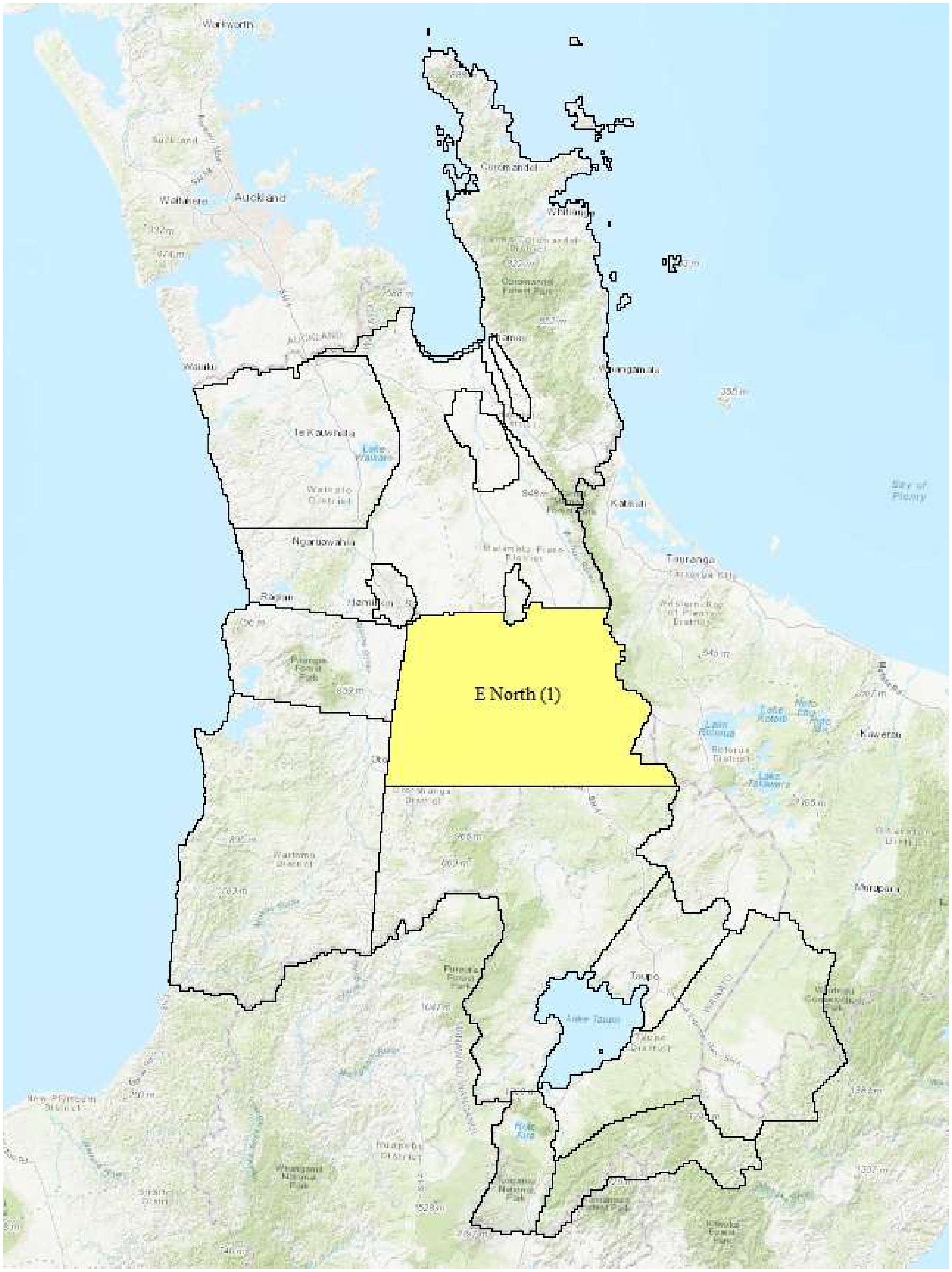



*Figure 1: Waikato Survey Area*

# 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

- AU411_WLASS-Collection_Report-10052021.pdf.

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 E North (1), as illustrated in yellow in Figure 1 - Waikato Survey. Block E was split into three during processing due to the size, 10,180km$^2$. Block E North (1), Block E North (2) and Block E South are the splits.

This dataset was uploaded by Woolpert Australia Saturday 07 October 2023. This was transferred to Waikato Regional Council (WRC) Monday 09 October 2023.

# 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).

https://www.linz.govt.nz/system/files_force/media/doc/pgf_version_new_zealand_national_aerial_lidar_base_specification.pdf?download=1

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:

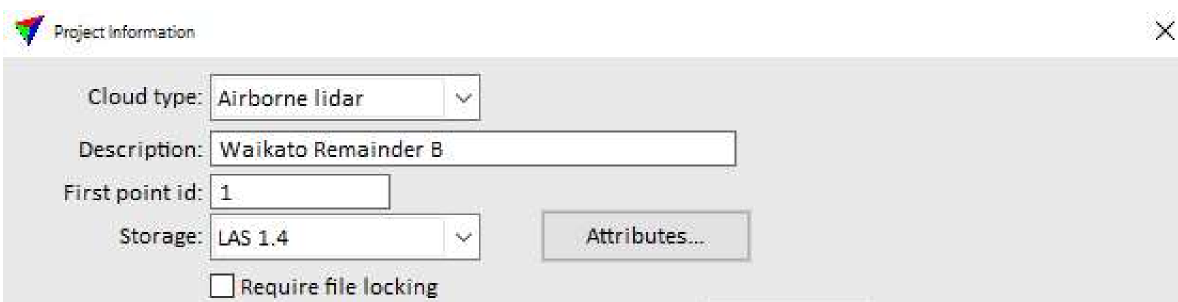



*Figure 2: LAS 1.4 being specified during project – example*

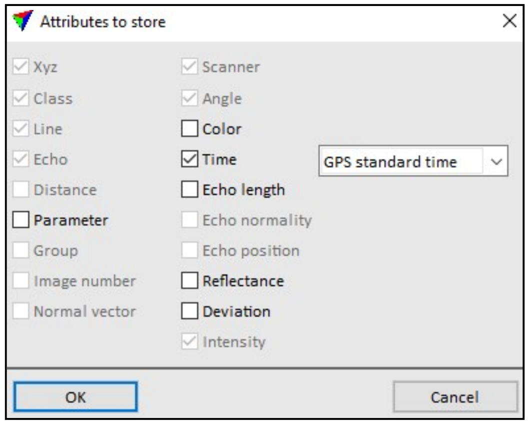



*Figure 3: Project settings used in TerraScan project when importing points into the project.*

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.

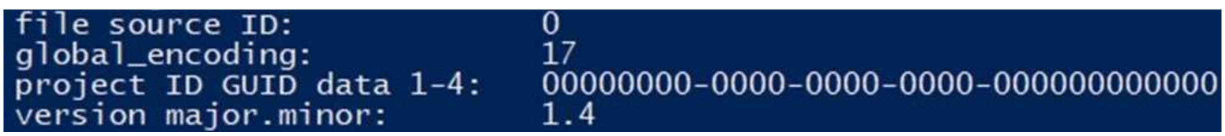



*Figure 4: Confirmation of LAS 1.4 being the file format of handover laser point files using LASTools*

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)

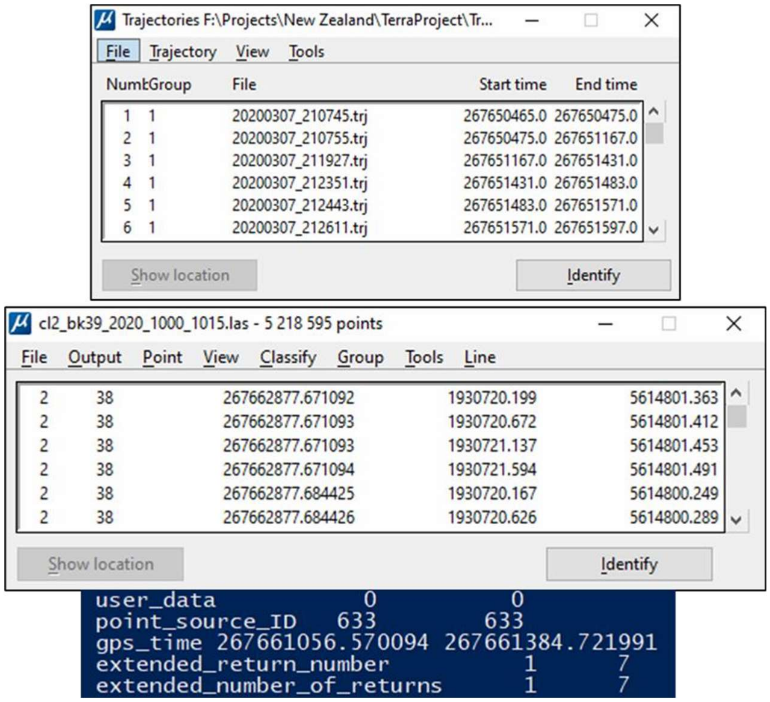



*Figure 5: Representative examples of LAS point attributes*

## 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.

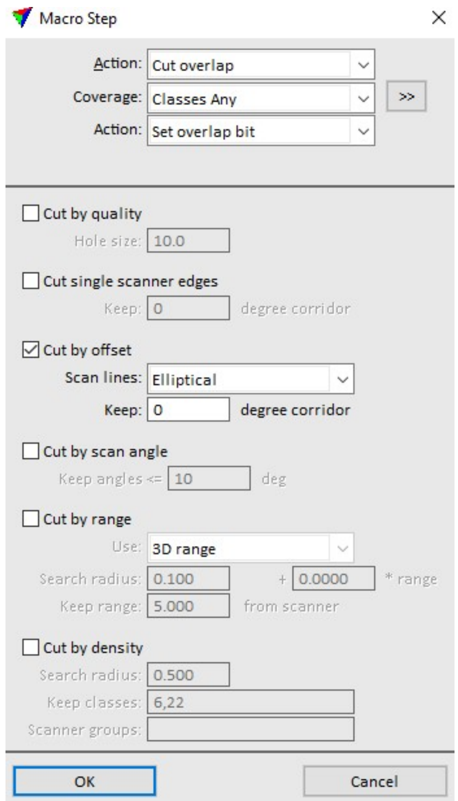



*Figure 6: Settings used when cutting overlap in Microstation.*

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:

| Code | Description |
|---|---|
| 1 | Processed, but unclassified |
| 2 | Ground |
| 3 | Low vegetation <2m |
| 4 | Medium vegetation |
| 5 | High vegetation >8m |
| 6 | Building |
| 7 | Low noise |
| 9 | Water |
| 17 | Bridge deck |
| 18 | High noise |

*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.

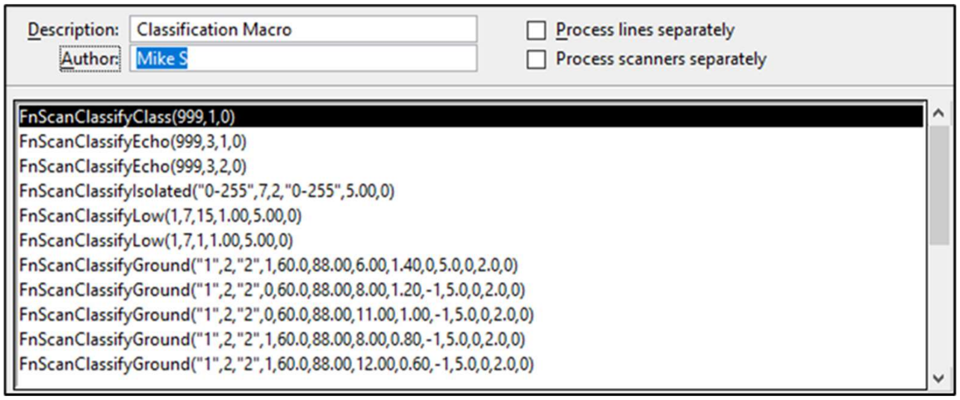



*Figure 7: Automatic classification macro developed for the project area.*

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.

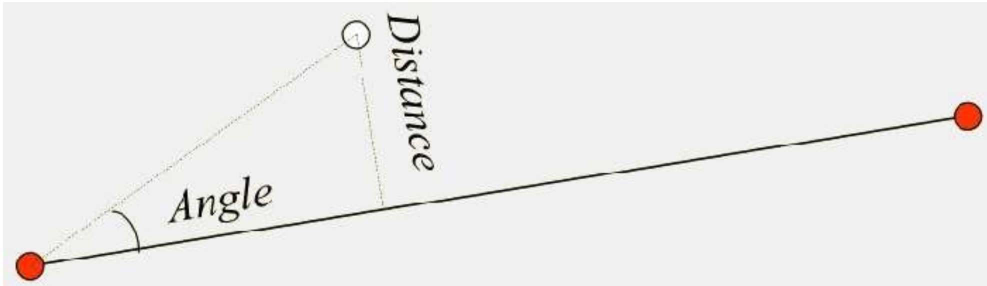



*Figure 8: Illustration of iteration angle and iteration distance parameters in the ground routine.*

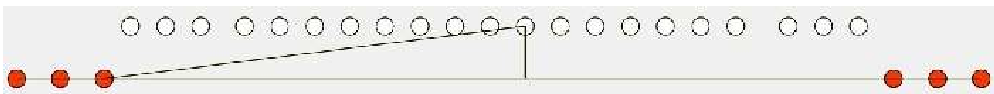


*Figure 9: A smaller iteration distance value avoids classification of ground points on low objects.*

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 or LASTools as illustrated in the figure below.

```
histogram of classification of points:
          565103  unclassified (1)
     14660276577  ground (2)
      1370869654  low vegetation (3)
      2589919867  medium vegetation (4)
      5927103164  high vegetation (5)
       118308724  building (6)
      3130355591  noise (7)
          937614  water (9)
          547522  bridge deck (17)
        47558385  Reserved for ASPRS Definition (18)
 +-> flagged as withheld:  3177913976
  +--->      3130355591 of those are noise (7)
  +--->        47558385 of those are Reserved for ASPRS Definition (18)
 +-> flagged as extended overlap: 11549770021
  +--->           89921 of those are unclassified (1)
  +--->      6111676555 of those are ground (2)
  +--->       568022545 of those are low vegetation (3)
  +--->      1025053902 of those are medium vegetation (4)
  +--->      2112997748 of those are high vegetation (5)
  +--->        59730777 of those are building (6)
  +--->      1664356168 of those are noise (7)
  +--->          313149 of those are water (9)
  +--->          276901 of those are bridge deck (17)
  +--->         7252355 of those are Reserved for ASPRS Definition (18)
```

*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.

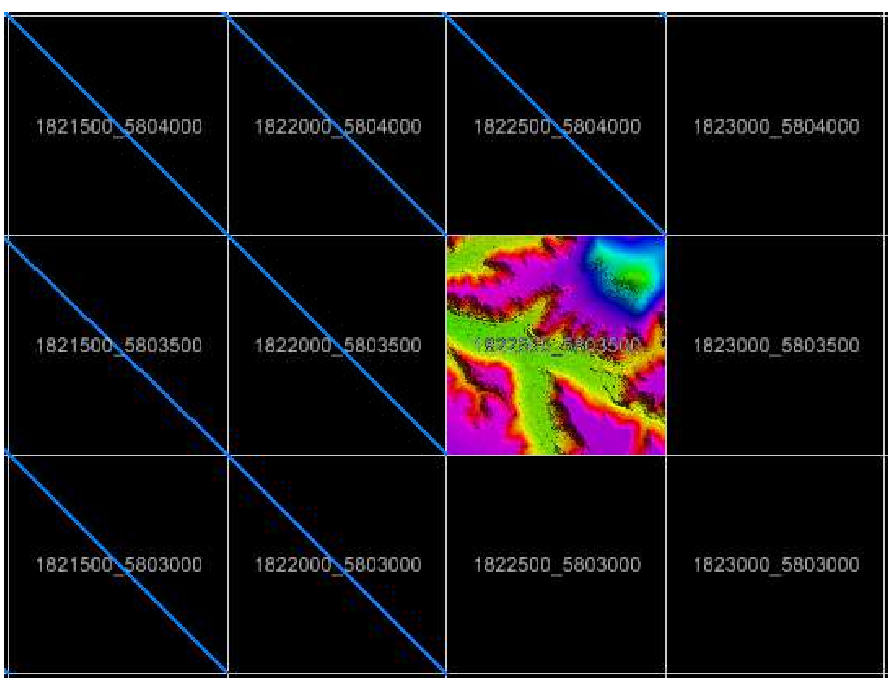



*Figure 11: The diagonal hatching seen above shows how the progress was tracked*

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.

### 2.8.1 Building Classification

The classification of building points has been undertaken by utilizing the TerraScan *buildings* routine. This routine classifies points on buildings which form a planar surface, several rules can be set to fine tune these results including the minimum building size/footprint, z tolerance of the point alignment along the roof line and use of echo information.

The use of echo information can further support the classification as points on roofs mostly belong to the echo type 'only echo' whereas vegetation usually contains a lot of 'first of many' and 'intermediate' echoes.

Additionally, the LINZ building footprint was also integrated into the building classification workflow to further constrain the classification and improve the overall output.

### 2.8.2 Vegetation & Low-Level Noise Classification:

In agreeance with all parties, Woolpert have classified the lower 0 – 0.3m of the low vegetation class to class 7 (low noise).

This was done to effectively remove the lower noise stratification points and unused ground points from class 3 over areas which do not represent vegetation e.g. man-made surfaces and structures (sealed roads).

The remaining vegetation points were classified using TerraScan's classify *by height from ground* which uses the ground surface to calculate the distance of each point above and below ground. All identified vegetation points were classified to the nominated classes using the height ranges specified in the *New Zealand Nation Aerial LiDAR Base Specification* (See below).

**Table 4 Minimum LAS point cloud classification scheme**

| Code | Description |
|---|---|
| 1 | Processed, but unclassified |
| 2 | Ground |
| 3 | Low vegetation <2m |
| 4 | Medium vegetation |
| 5 | High vegetation >8m |
| 6 | Building |
| 7 | Low noise |
| 9 | Water |
| 18 | High noise |

## 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.

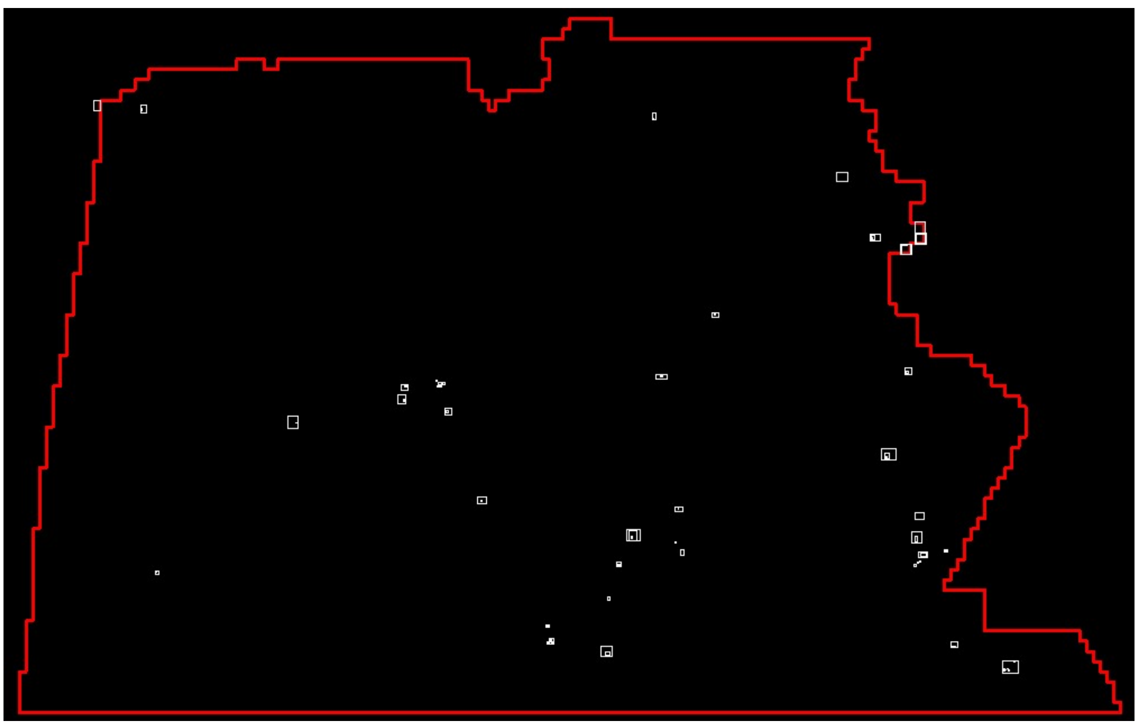


*Figure 12: The polygons are areas for further investigation*

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 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.

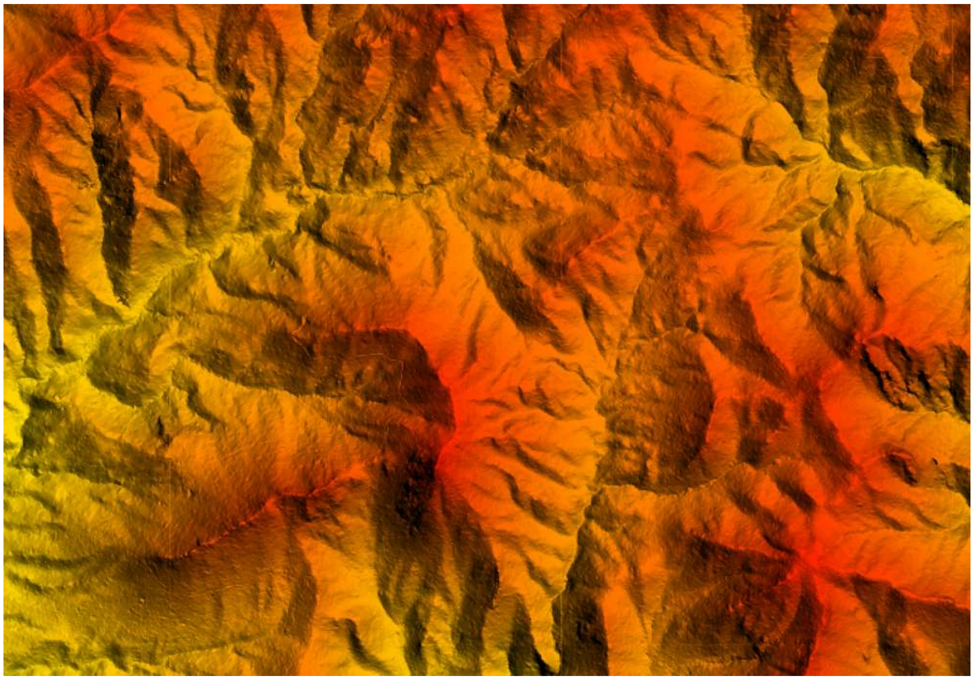


*Figure 13: Example overhead image of DEM over cliffs*

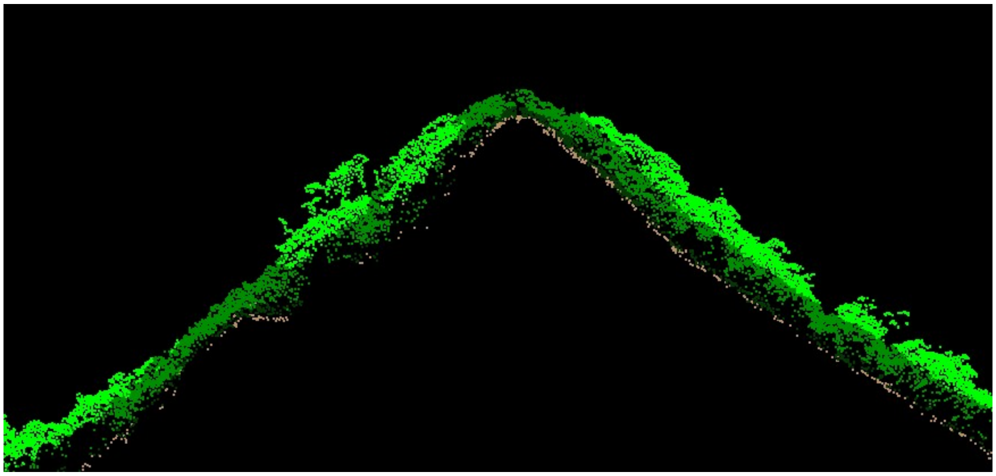


*Figure 14: LAS point cloud profile view from previous figure*

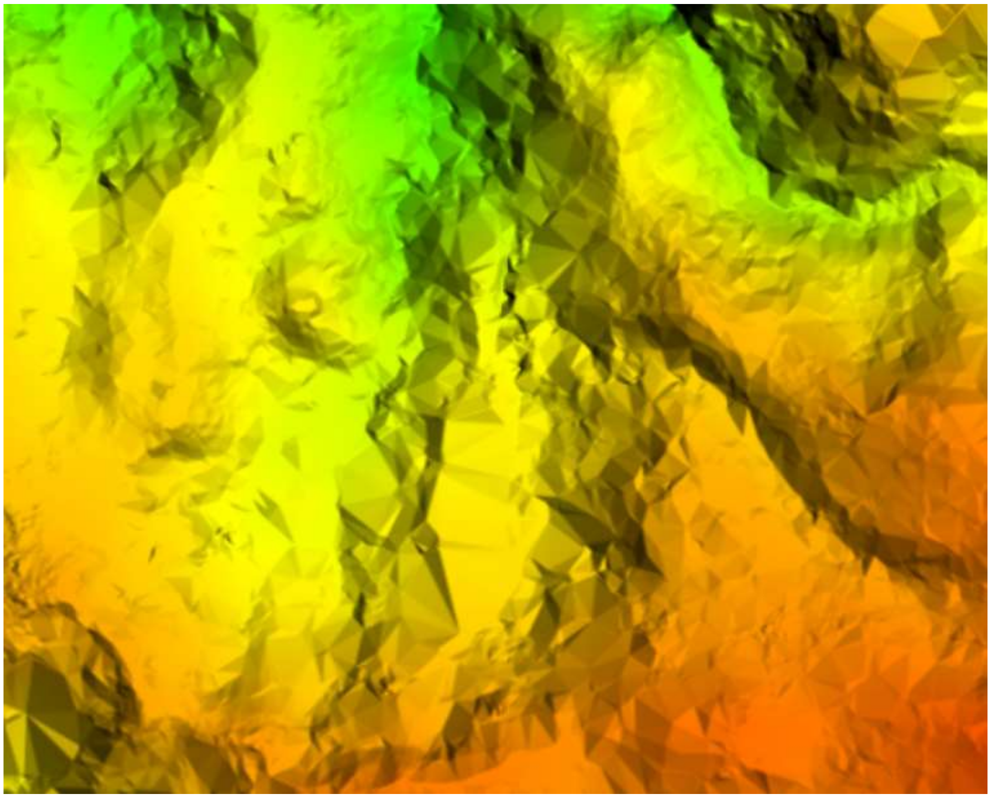


*Figure 15: Example overhead image of DEM interpolation*

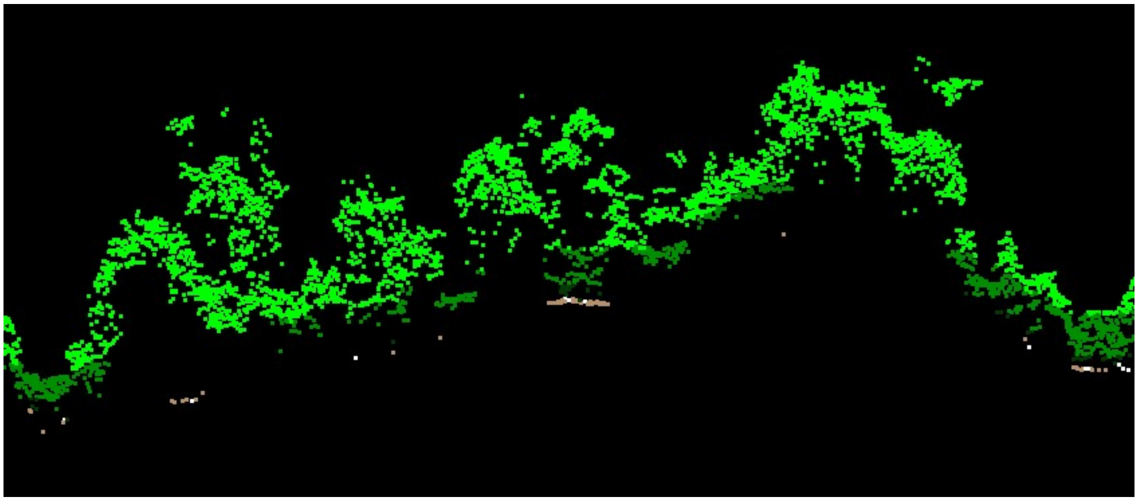


*Figure 16: LAS Point cloud view from previous figure*

## 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 – 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 examples shows the DEM where a bridge has been removed.

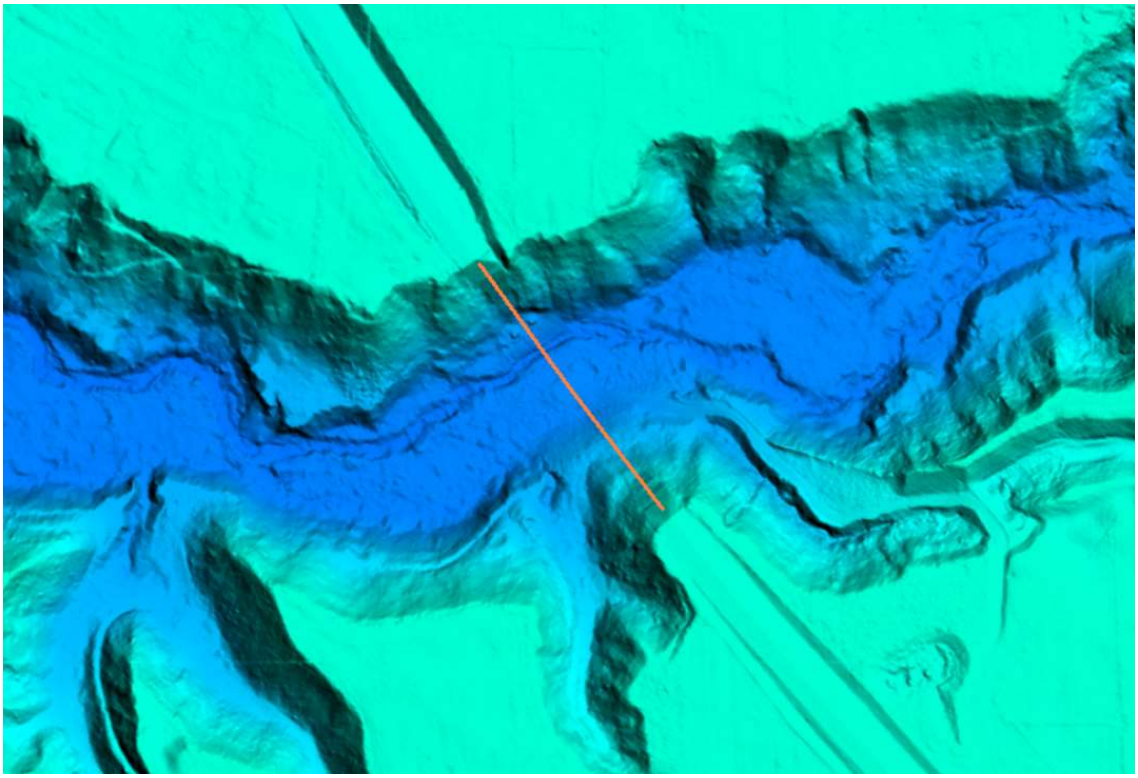


Figure 17: Tile DEM_BD34_2021_1000_4833 with LINZ bridge centreline

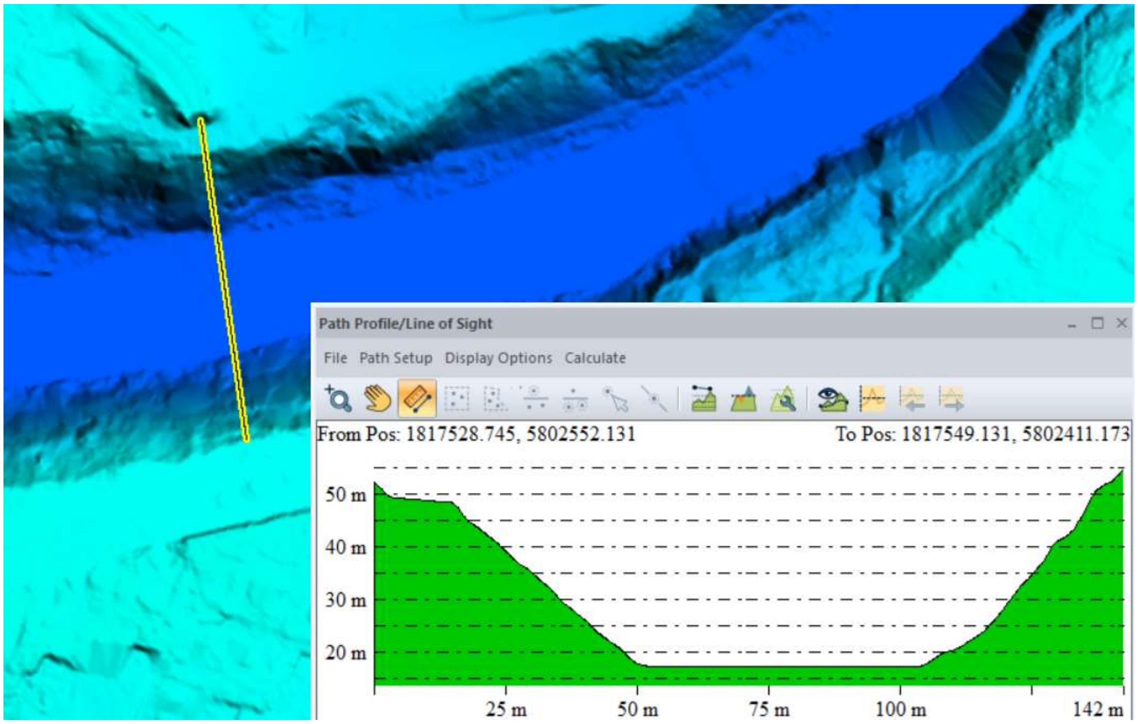



*Figure 18: DEM Tile BD34_2021_1000_5029*

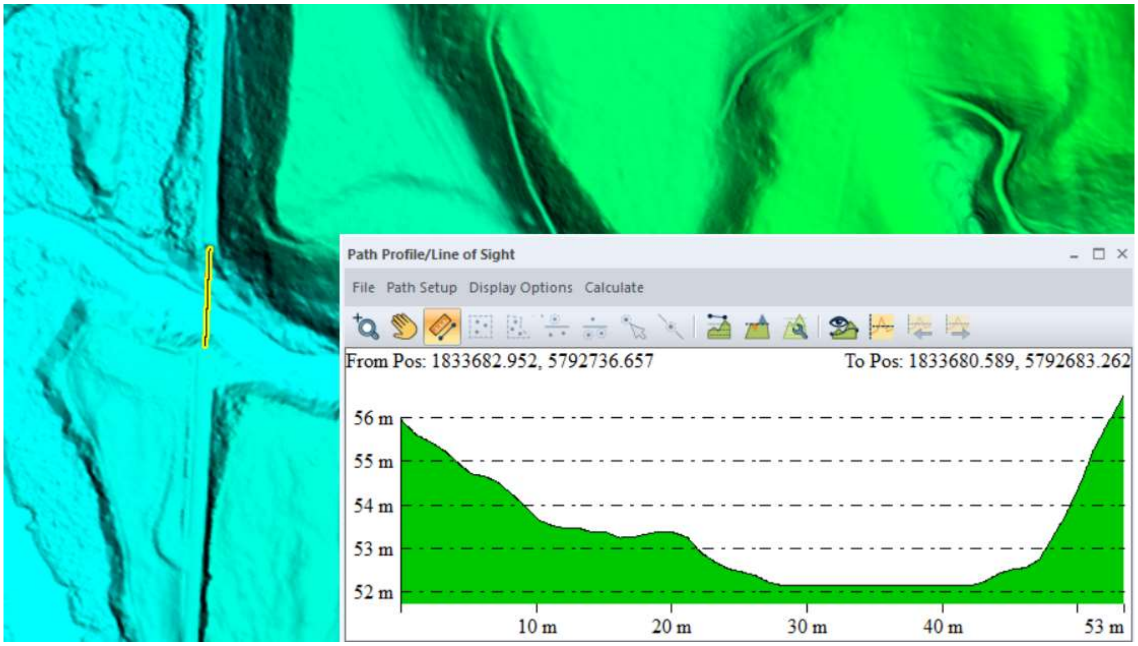



*Figure 19: DEM Tile BH35_2021_1000_1312*

The example below shows a road cut into a slope rather than a bridge.

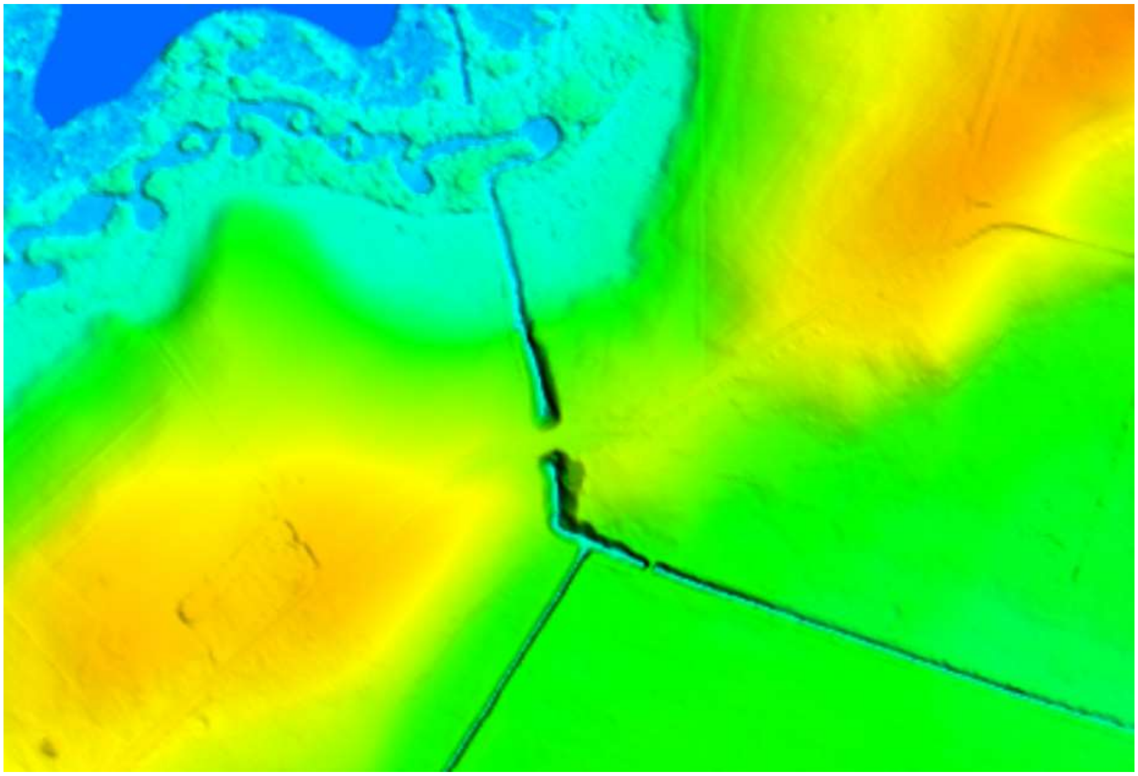


*Figure 20: DEM Tile BE33_2021_1000_0450*

The example below shows a Bridge that appears in the LINZ shapefile that has been classified to class 17 but is really a culvert. No breakline added.

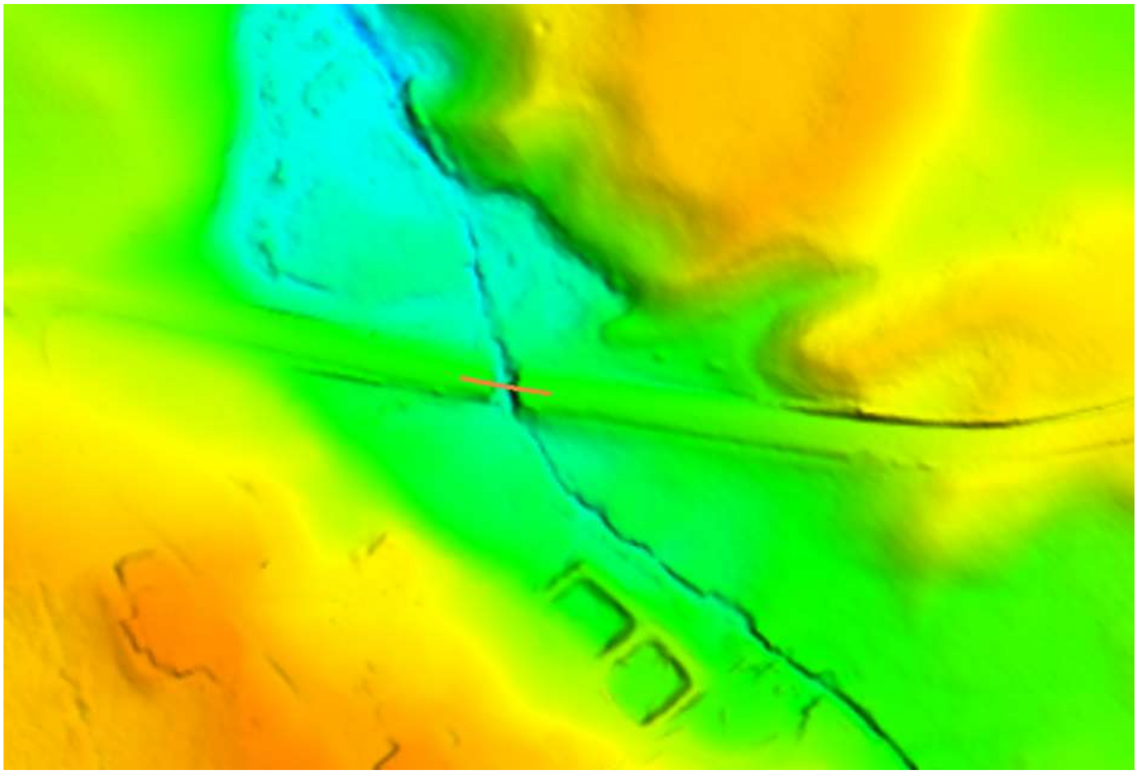


Figure 21: DEM Tile BE34_1000_5020

The example below shows a Bridge in the LINZ shapefile that is a culvert and is therefore not edited to class 17.

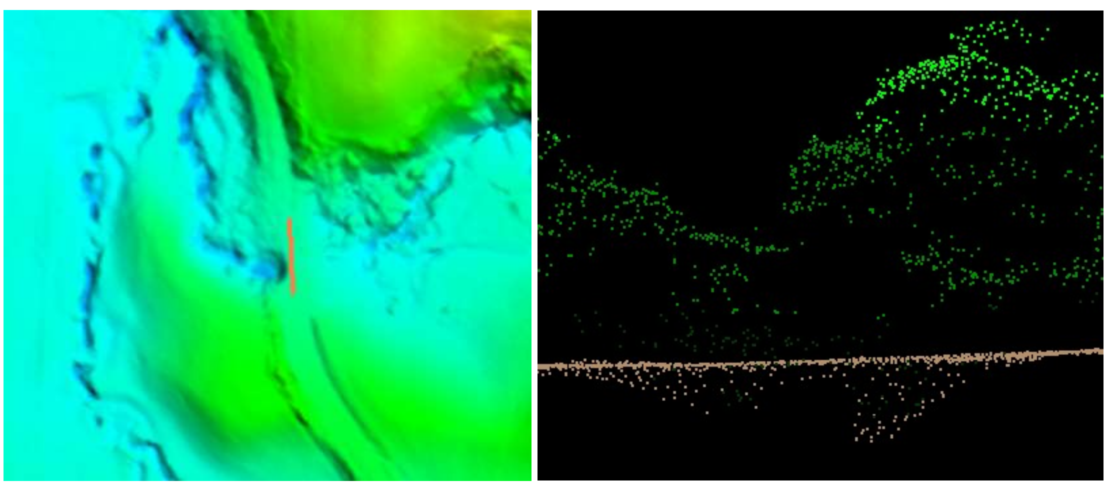


Figure 22: DEM Tile BE34_1000_1331

# 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 000m$^2$ or larger in size.

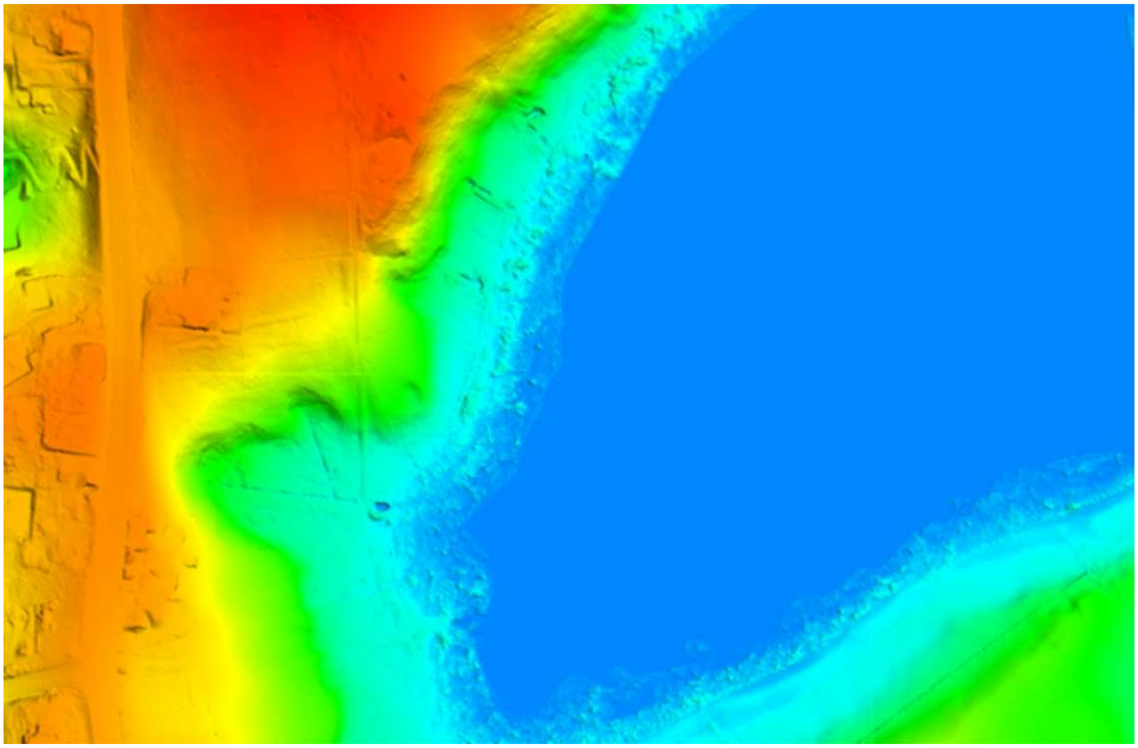


*Figure 23: Example of a hydro-flattened DEM Lake Tile DEM_BE33_2021_1000_0449*

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.

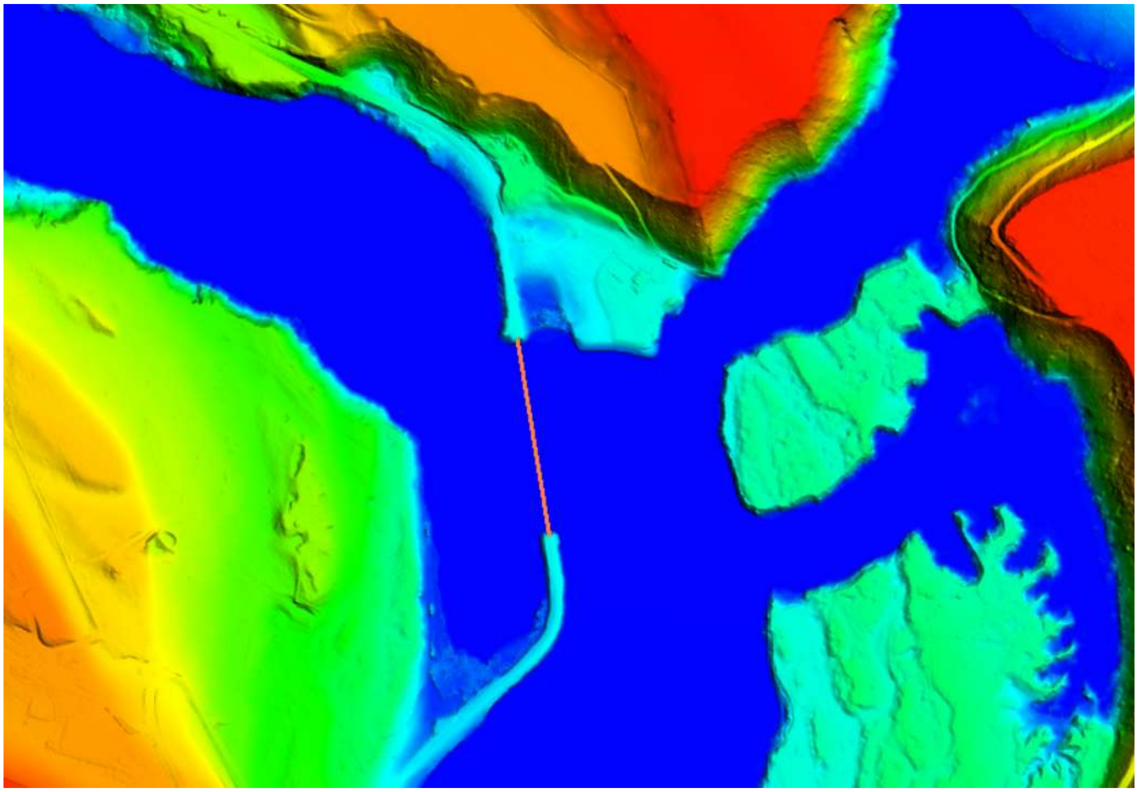


Figure 24: Example of Bridge with LINZ bridge centreline

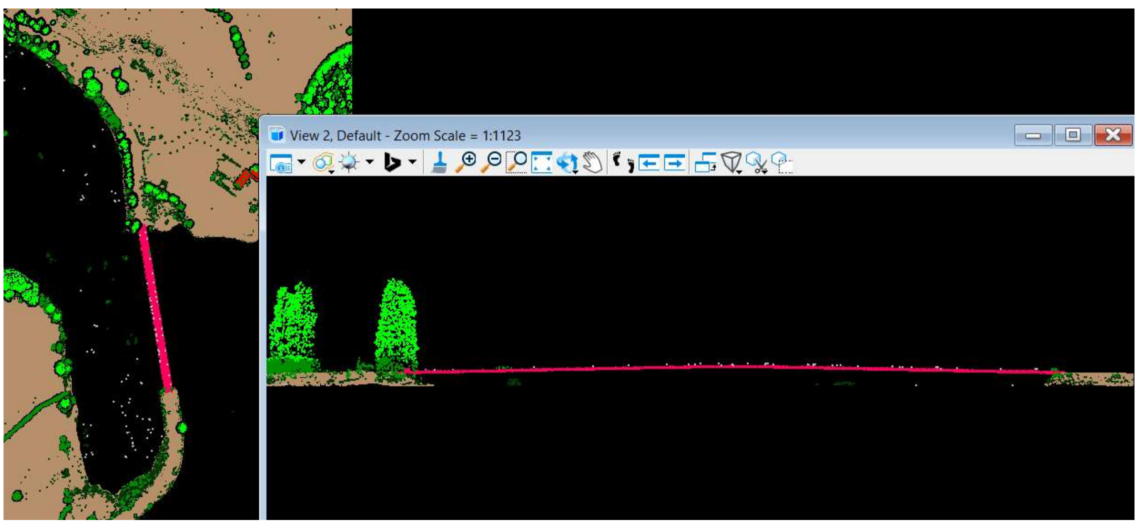



Figure 25: Same location as above DEM.

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.

| | | | |
|---|---|---|---|
| 1 | 1929744.8358 | 5615128.2638 | 7.7096 |
| 2 | 1929746.0769 | 5615130.8498 | 7.6863 |
| 3 | 1929746.4280 | 5615131.5996 | 7.6796 |
| 4 | 1929746.5107 | 5615131.7727 | 7.678 |
| 5 | 1929746.7841 | 5615132.3591 | 7.6728 |
| 6 | 1929748.0794 | 5615135.0799 | 7.6483 |
| 7 | 1929748.5703 | 5615136.1455 | 7.6388 |
| 8 | 1929749.4246 | 5615138.0643 | 7.622 |
| 9 | 1929749.8587 | 5615139.0742 | 7.6132 |
| 10 | 1929750.6288 | 5615140.9327 | 7.5973 |
| 11 | 1929751.0393 | 5615141.7916 | 7.5896 |
| 12 | 1929751.5292 | 5615142.7809 | 7.5805 |
| 13 | 1929754.3861 | 5615148.3485 | 7.529 |
| 14 | 1929754.7868 | 5615149.1041 | 7.5219 |
| 15 | 1929754.7991 | 5615149.1267 | 7.5217 |
| 16 | 1929757.3347 | 5615152.1834 | 7.4808 |
| 17 | 1929757.8445 | 5615152.7752 | 7.4594 |

*Figure 26: Excerpt of river points used to create the centreline*

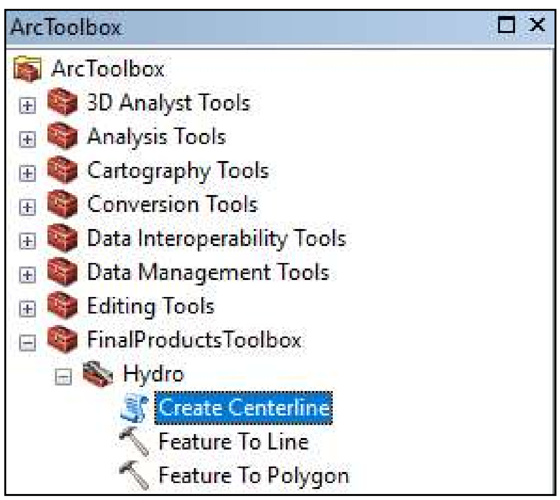



*Figure 27: Centreline for the stream within the project's survey*

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:

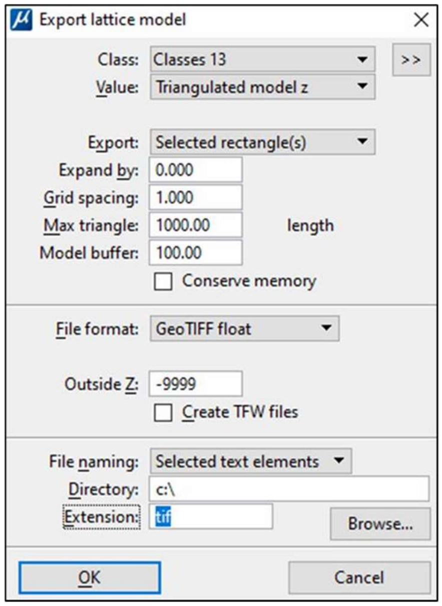



*Figure 28: Settings used to export lattice models.*

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.

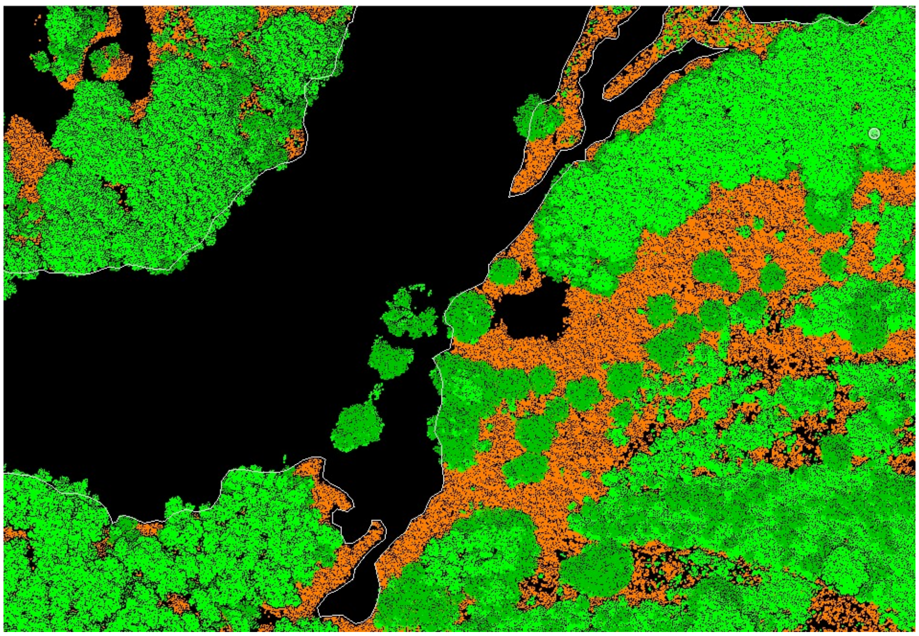


*Figure 29: Pre-filter, overhead view of ground and veg points with hydro lines*

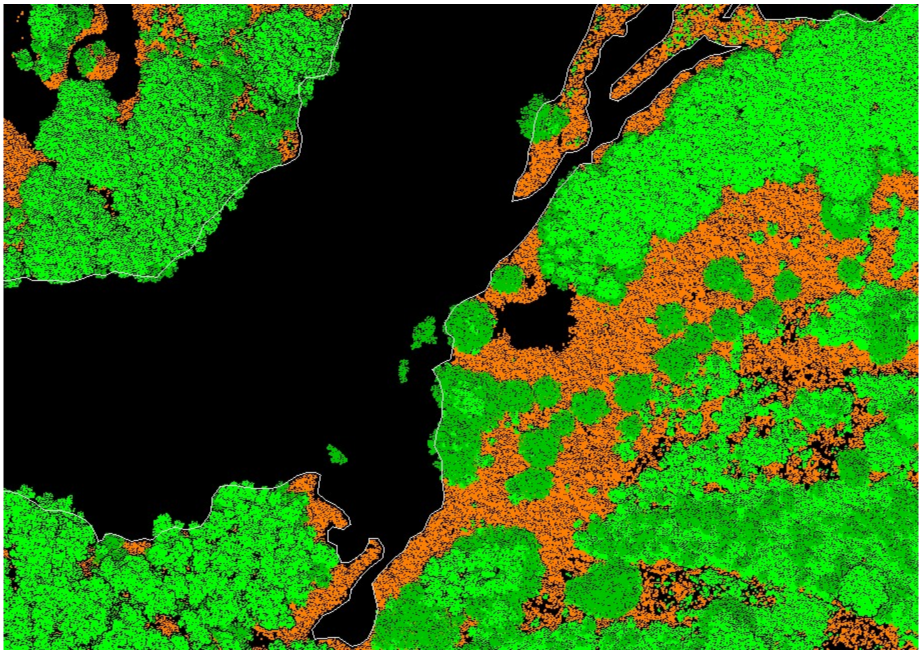


*Figure 30: Post-filter, overhead view of ground and veg points with hydro lines*

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 31: Point cloud – boulder filled stream*


*Figure 32: Imagery – boulder filled stream*

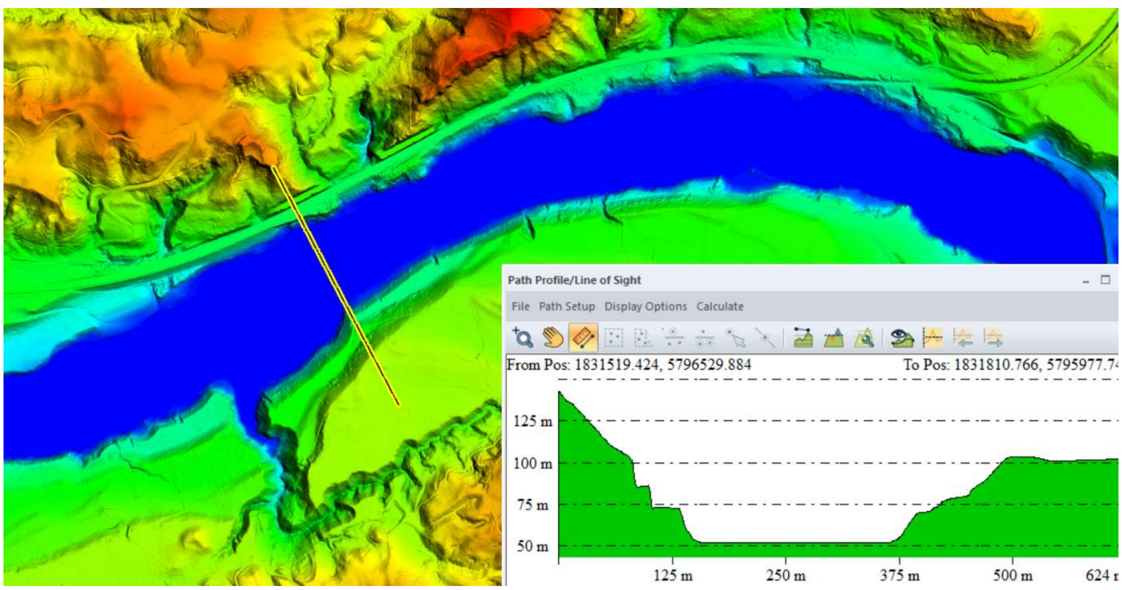



*Figure 33: Example of hydroflattened DEM: DEM_BE35_2021_1000_0808*

# 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 E was captured using Leica TerrainMapper sensor 513 and 559, flown on days 05th, 06th, 10th, 11th, 14th, 15th, 25th, 26th, 29th, 30th, 31st January, 1st, 3rd, 11th, 12th, 16th, 18th, 19th, 20th February, 11th, 13th, 21st, 22nd, 23rd, 24th March 2021.

Please note the dates above refer to all dates flown for the entirety of Block E inclusive of North (1), North (2) and South.

The extent of Block E can be seen in Figure 34. The flight lines relating to the area can be seen in Figure 35.

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 figure 41.

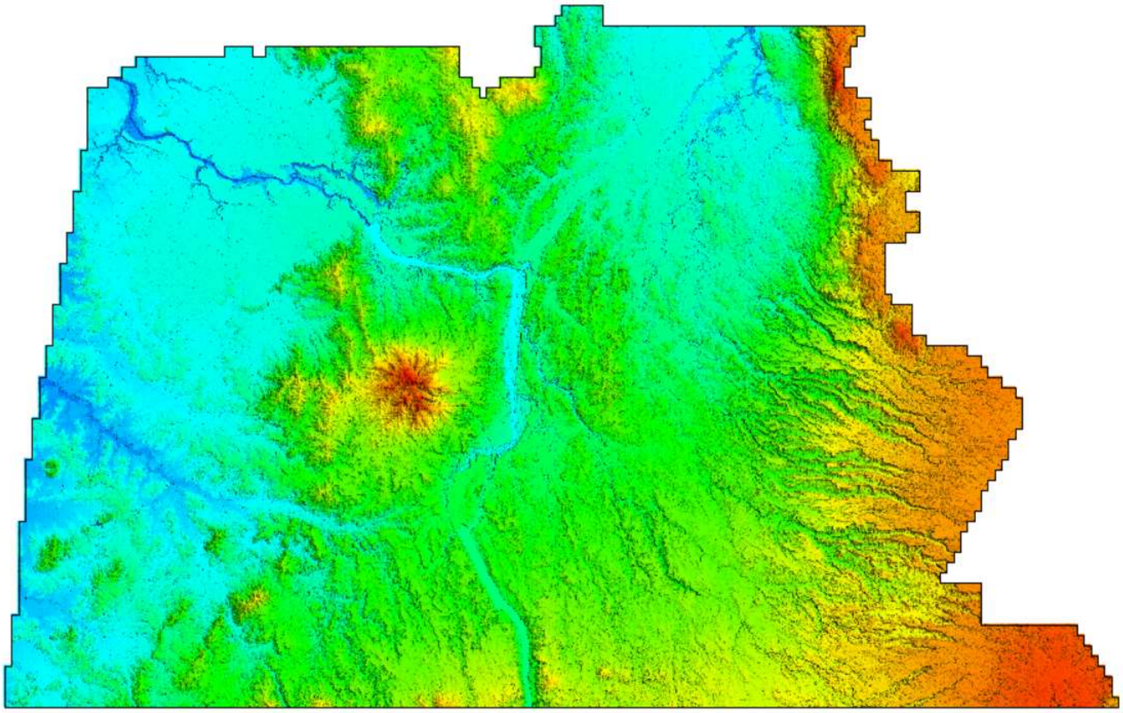


*Figure 34: Extent of deliverable data for Block E North (1)*

### 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. Refer to the purple polygon illustrating Block E North (1).

OCEAN INFINITY®


*Figure 35: Flight lines for 4ppm2 data coverage over Block E North (1)*

## 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.


```
variable length header record 1 of 1:
  reserved             0
  user ID              'LASF_Projection'
  record ID            2112
  length after header  951
  description          'by LAStools of rapidlasso GmbH'
    WKT OGC COORDINATE SYSTEM:
    COMPD_CS["NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016",PROJCS["NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000",GEOGCS["NZGD2000",DATUM["New_Zealan
d_Geodetic_Datum_2000",SPHEROID["GRS 1980",6378137,298.257222101,AUTHORITY["EPSG","7019"]],AUTHORITY["EPSG","6167"]],PRIMEM["Greenwich",0,AUTHORITY["EPSG","8901"]],UNIT["degree",0.0174532
251994328,AUTHORITY["EPSG","9122"]],AUTHORITY["EPSG","4167"]],PROJECTION["Transverse_Mercator"],PARAMETER["latitude_of_origin",0],PARAMETER["central_meridian",173],PARAMETER["scale_factor
,0.9996],PARAMETER["false_easting",1600000],PARAMETER["false_northing",10000000],UNIT["metre",1,AUTHORITY["EPSG","9001"]],AXIS["Easting",EAST],AXIS["Northing",NORTH],AUTHORITY["EPSG","219
"]],VERT_CS["NZVD2016",VERT_DATUM["New Zealand Vertical Datum 2016",2005,AUTHORITY["EPSG","7839"]],UNIT["metre",1.0,AUTHORITY["EPSG","9001"]],AXIS["Gravity-related height",UP],AUTHORITY["
PSG","7839"]]]
```

*Figure 36: WKT of a LAS file shown by LASTools.*

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.

| File | Points | Version | File Signature | File Source ID | CRS is WKT | Coordinate System |
|---|---|---|---|---|---|---|
| CL2_BE34_2021_1000_3249.las | 2,628,818 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BE34_2021_1000_3250.las | 3,075,493 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BE34_2021_1000_3301.las | 3,058,625 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BE34_2021_1000_3302.las | 2,847,758 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BE34_2021_1000_3303.las | 2,245,407 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BE34_2021_1000_3304.las | 2,281,342 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BE34_2021_1000_3305.las | 2,876,792 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BE34_2021_1000_3306.las | 2,947,885 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BE34_2021_1000_3307.las | 2,464,339 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BE34_2021_1000_3308.las | 2,538,516 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BE34_2021_1000_3309.las | 3,135,543 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BE34_2021_1000_3310.las | 3,108,486 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BE34_2021_1000_3311.las | 2,517,025 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BE34_2021_1000_3312.las | 2,575,474 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BE34_2021_1000_3313.las | 3,056,965 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BE34_2021_1000_3314.las | 2,915,947 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BE34_2021_1000_3315.las | 2,389,815 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BE34_2021_1000_3316.las | 2,988,451 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BE34_2021_1000_3317.las | 4,431,744 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BE34_2021_1000_3318.las | 4,265,639 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |

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

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 analysist 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.

It is noted for Blocks F & G due to the dense vegetation and steep terrain the penetration of the LiDAR to the ground in some areas is minimal (Figure 18 is a good example). This will show in the DEM as large, triangulated areas or give the impression of pitting where only isolated ground returns have been identified.
For these areas it is recommended to compare any potential DEM discrepancies with the point cloud to confirm the absence of available ground points.

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.

| File | Format | NoData Value | BPB | Bands | Data Type | Pixel Size | Coordinate System |
|---|---|---|---|---|---|---|---|
| DEM_BE34_2021_1000_1819.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BE34_2021_1000_1820.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BE34_2021_1000_1821.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BE34_2021_1000_1822.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BE34_2021_1000_1823.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BE34_2021_1000_1824.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BE34_2021_1000_1825.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BE34_2021_1000_1826.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BE34_2021_1000_1827.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BE34_2021_1000_1828.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BE34_2021_1000_1829.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BE34_2021_1000_1830.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BE34_2021_1000_1831.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BE34_2021_1000_1832.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BE34_2021_1000_1833.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BE34_2021_1000_1834.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BE34_2021_1000_1835.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BE34_2021_1000_1836.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BE34_2021_1000_1837.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BE34_2021_1000_1838.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |

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

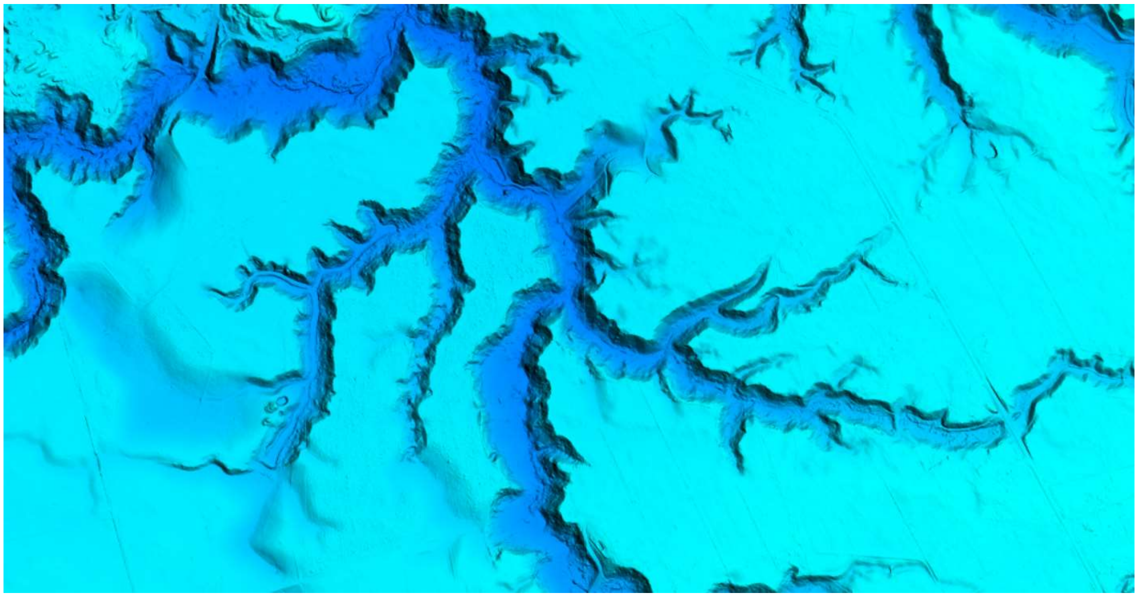


*Figure 37: DEM Example Tile DEM_BD34_2021_1000_4604*

### 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.

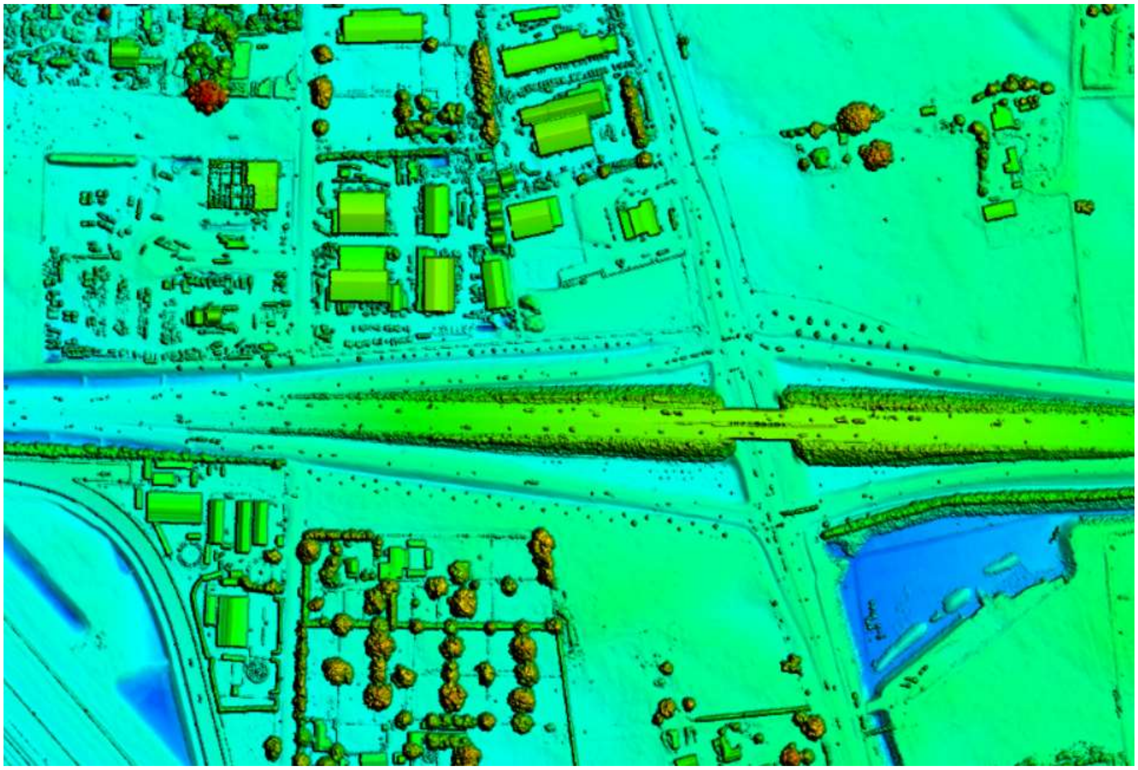


*Figure 38: Excerpt from DSM_BD34_2021_1000_4525 and 4526*

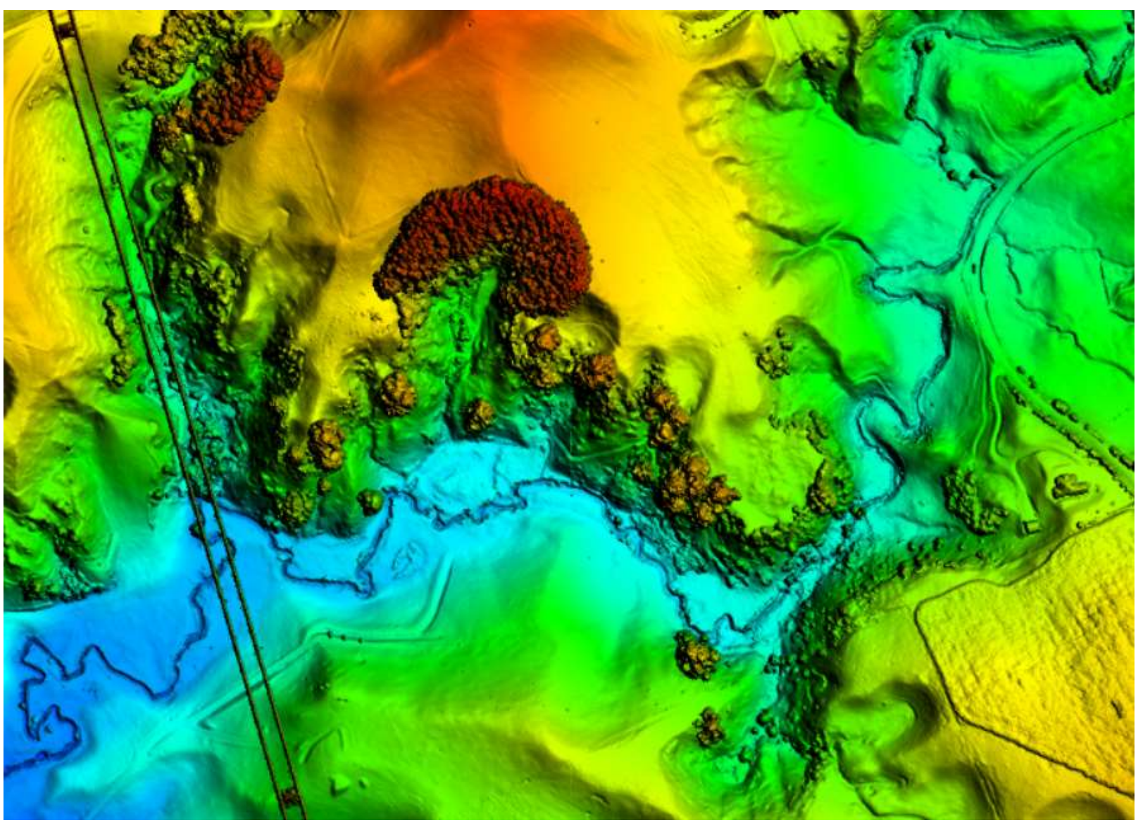


*Figure 39: Excerpt from DSM_BD34_2021_1000_445*

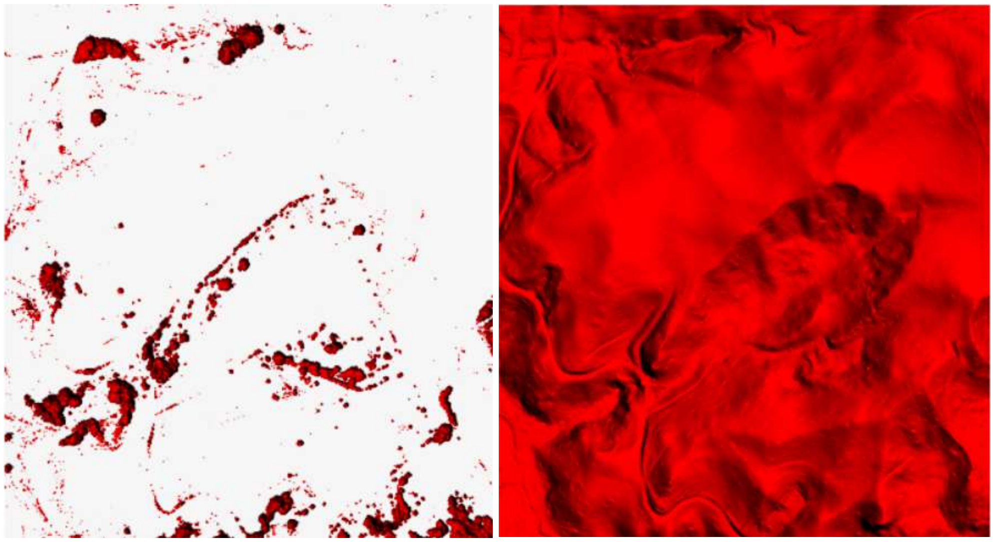
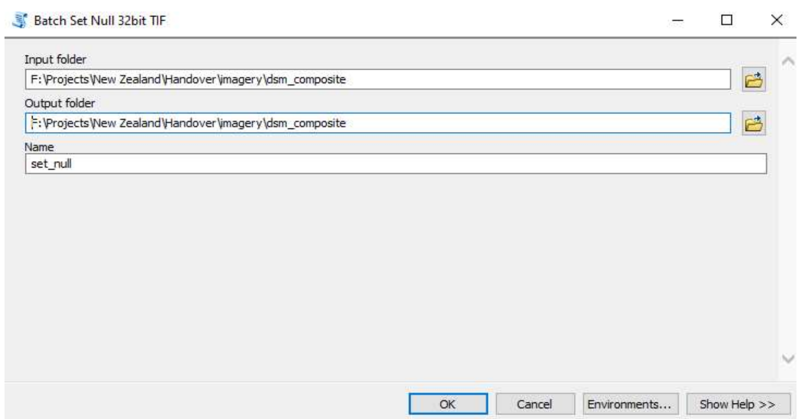


*Figure 40: Difference between DSM and DEM differences in height along cliff lines*

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.




| | |
|---|---|
| Format | IMAGINE Image |
| Source Type | Generic |
| Pixel Type | floating point |
| Pixel Depth | 32 Bit |
| NoData Value | -9999 |

*Figure 42: 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.

| File | Format | NoData Value | BPB | Bands | Data Type | Pixel Size | Coordinate System |
|---|---|---|---|---|---|---|---|
| DSM_BE35_2021_1000_1003.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BE35_2021_1000_1004.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BE35_2021_1000_1005.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BE35_2021_1000_1006.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BE35_2021_1000_1007.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BE35_2021_1000_1008.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BE35_2021_1000_1009.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BE35_2021_1000_1010.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BE35_2021_1000_1011.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BE35_2021_1000_1012.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BE35_2021_1000_1013.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BE35_2021_1000_1014.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BE35_2021_1000_1015.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BE35_2021_1000_1016.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BE35_2021_1000_1017.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |

*Table 4: LP360 DSM Results example table*

## 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.

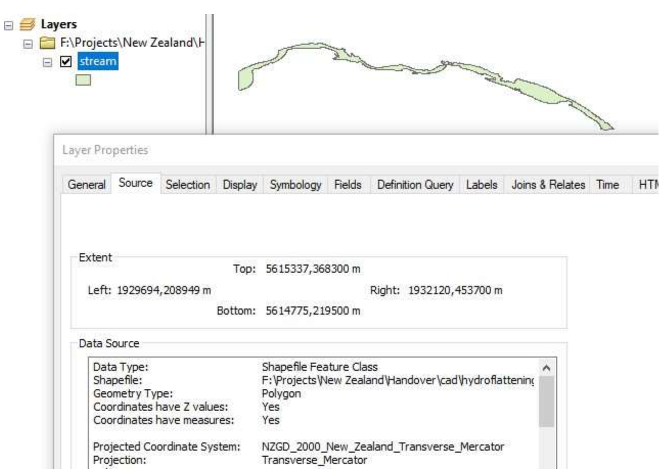



*Figure 43: Stream break line properties in ArcMap.*

## 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 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.

# 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_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.

o Check for presence of correct ESPG Codes for geodetic & vertical datums, and map projection

o 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.

| Naming Convention for point clouds, DEMs, and other tiled products<br>*[product]_[sheet]_[year]_[scale]_[tile].[ext]* | | |
|---|---|---|
| **Product** | *DEM* | **CL2-Point Cloud Classification Level 2**<br>**DEM-Bare Earth Digital Elevation Model**<br>**DSM-Digital Surface Model**<br>DTM-Digital Terrain Model<br>UNC-Unclassified Point Cloud<br>INT-Intensity image<br>CHM – Canopy Height Model<br>IMG-Aerial photography<br>etc |
| **Sheet** | *BK34* | LINZ Topo50 identifier (4 characters) |
| **Year** | *2016* | Year of survey commencement |
| **Scale** | *1000* | Nominal scale of NZTopo50 subtiles |
| **Tile** | *4118* | Row number (41), Column number (18) of tile with respect to an upper left origin |
| **ext** | *tif* | File extension according to format conventions<br>las<br>tif<br>shp<br>etc |
| *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-flatting break line bank line strings
│       │ └───stream_islands – Hydro-flatting 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

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 Lessons learned and collaboration

Thanks goes to the team at WRC for providing inputs to previous blocks that has informed decisions on processing for this block and the entirety of Block E. There is some challenging terrain and dense vegetation that hindered penetration is some parts and made for some difficult processing with significant manual editing.

# 7 Results Acceptance & Signoff

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

| Result Acceptance | | | |
|---|---|---|---|
| Assessment Criteria | Status | Completed By | Date |
| Point cloud classification accuracy | Complete | Woolpert/ AAM | 09 October 2023 |
| Point cloud classification consistency | Complete | Woolpert/ AAM | 09 October 2023 |
| Point Cloud LAS tiled deliverables | Complete | Woolpert/ AAM | 09 October 2023 |
| Hydro-flattened Digital Elevation Models | Complete | Woolpert/ AAM | 09 October 2023 |
| Digital Survey Models | Complete | Woolpert/ AAM | 09 October 2023 |
| Contours | Complete | Woolpert/ AAM | 09 October 2023 |
| Extents, Flight Lines, Break lines, Tile Index | Complete | Woolpert/ AAM | 09 October 2023 |
| | | | |
| Project Manager / Supervisor Signoff | Complete | Luke Graham | 09 October 2023 |
| Ocean Infinity Review | Complete | Luke Leydon | 14 October 2023 |

*Table 6: Processing Results Acceptable Signoff*

# Appendix A: Lidar Quality Assurance Results

Provided as separate Documents in Appendix A upload

# Waikato Local Authority Shared Services (WLASS) / CoLAB LiDAR Data Capture Services

# LiDAR Processing Report Block E North (2) (Rev 1)

Contract Number: AU411

Surveyed By: iXblue Pty Ltd / Ocean Infinity

Processing Completed By: Woolpert USA and Woolpert Australia

Prepared For: Colab (formerly WLASS)

Document Date: 1 June 2024

Ocean Infinity (Australia) Pty Ltd
ABN 61 128 811 978
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OCEAN INFINITY®

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## Document Revision

| Revision No | Issue Purpose | Prepared | Checked | Approved |
|---|---|---|---|---|
| 0 | Issue LiDAR Processing Report | L Leydon | L Graham | D Field |
| | | | | |
| | | | | |
| | | | | |

## Approval for Issue

| Name | Signature | Date |
|---|---|---|
| Luke Leydon | | 01 June 2024 |

# Revision History

| Item | Description of change | Section | Revision |
|---|---|---|---|
| 1 | New Section added to Introduction | 1.1 | 1 |
| 2 | New Pointcloud statistics added | Figure 11 | 1 |
| 3 | New LP360 tables added | 4.2, 4.3 | 1 |
| 4 | New Sections added to setbacks and solutions | 6.5 | 1 |
| 5 | Examples of corrections included | 6.6 | 1 |
| 6 | New results signoff table added | 7 | 1 |
| | | | 1 |
| | | | 1 |
| | | | 1 |
| | | | 1 |
| | | | 1 |
| | | | 1 |
| | | | 1 |
| | | | 1 |

# Contents

# Figures

# Tables


*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

- AU411_WLASS-Collection_Report-10052021.pdf.

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 E North (2), as illustrated in yellow in Figure 1 - Waikato Survey. Block E was split into three during processing due to the size, 10,180km$^2$. Block E North (1), Block E North (2) and Block E South are the splits.

This dataset was uploaded by Woolpert Australia Friday 15 December 2023. This was transferred to Waikato Regional Council (WRC) Monday 18 December 2023.

The dataset was subsequently failed during QAQC and returned for rework. This was supported by a number of technical meetings where calls were discussed and mitigation strategies were developed. The defects were tracked using AU411 WRC_Raised_Defect_Tracking_Block_EN2_v1.

The dataset was redelivered to Ocean Infinity on Tuesday 12$^{th}$ March 2024. The dataset was transferred to Waikato Regional Council and LINZ on the same day.

## 1.1 Rev 1 Introduction

Block E North 2 was resupplied to LINZ and WRC on 15 May 2024. The failure and subsequent resupply was accompanied by a spreadsheet and returned with comments. 'LINZQC_Waikato_Block_E_P2_North_220524'

This listed the failures and improvements required. It was supported by Geospatial files which showed the areas of failures.

Thanks go to Emory Beck at LINZ for assistance with corrections to this dataset allowing publication.

# 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).

https://www.linz.govt.nz/system/files_force/media/doc/pgf_version_new_zealand_national_aerial_lidar_base_specification.pdf?download=1

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:

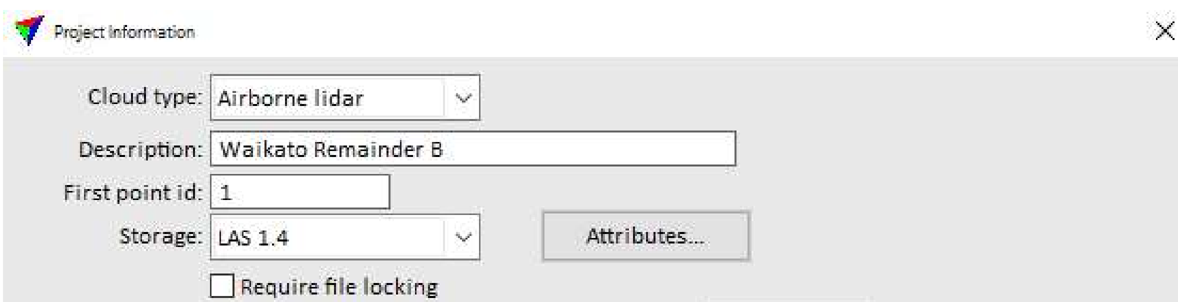


*Figure 2: LAS 1.4 being specified during project – example*

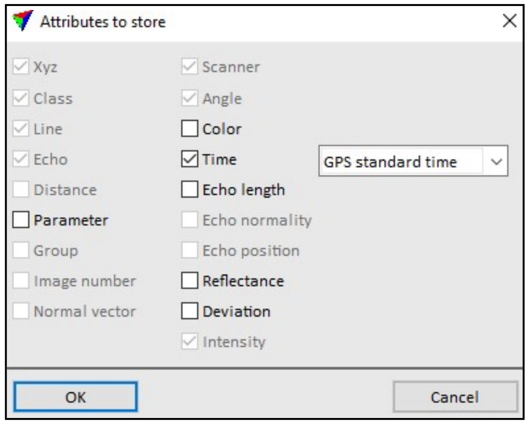


*Figure 3: Project settings used in TerraScan project when importing points into the project.*

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.

```
file source ID:              0
global_encoding:             17
project ID GUID data 1-4:    00000000-0000-0000-0000-000000000000
version major.minor:         1.4
```

*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)

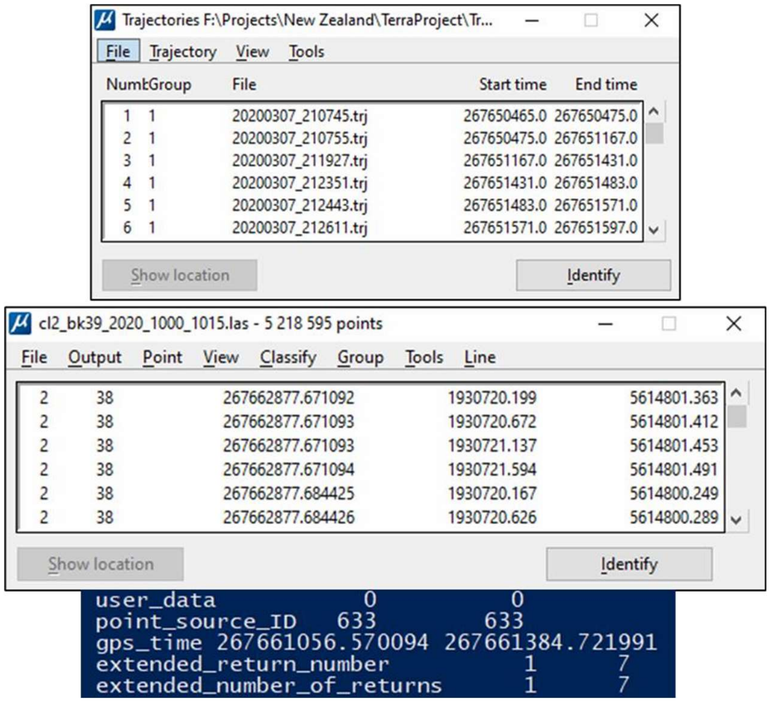


*Figure 5: Representative examples of LAS point attributes*

## 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.

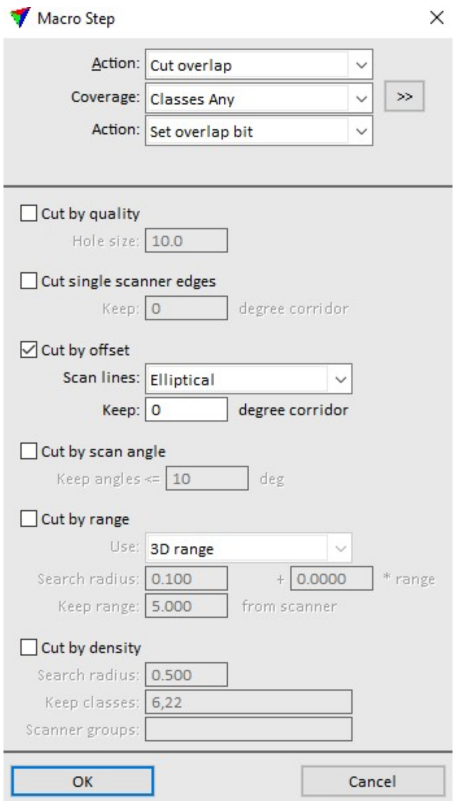


*Figure 6: Settings used when cutting overlap in Microstation.*

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:

| Code | Description |
|---|---|
| 1 | Processed, but unclassified |
| 2 | Ground |
| 3 | Low vegetation <2m |
| 4 | Medium vegetation |
| 5 | High vegetation >8m |
| 6 | Building |
| 7 | Low noise |
| 9 | Water |
| 17 | Bridge deck |
| 18 | High noise |

*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.

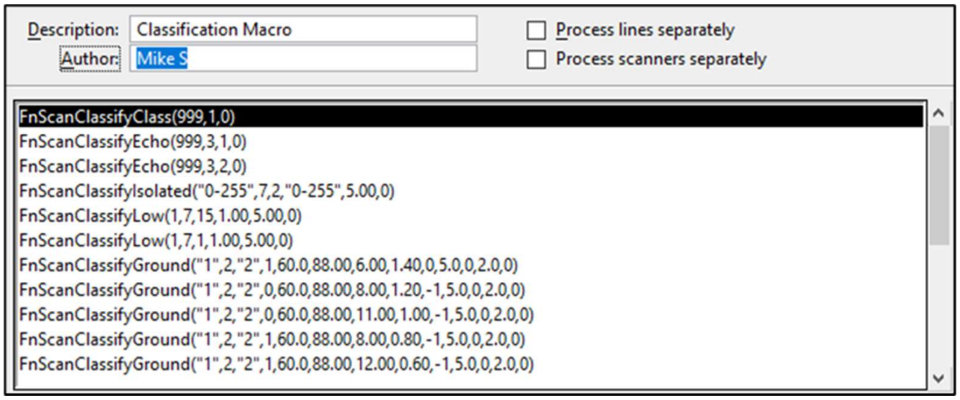


*Figure 7: Automatic classification macro developed for the project area.*

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.

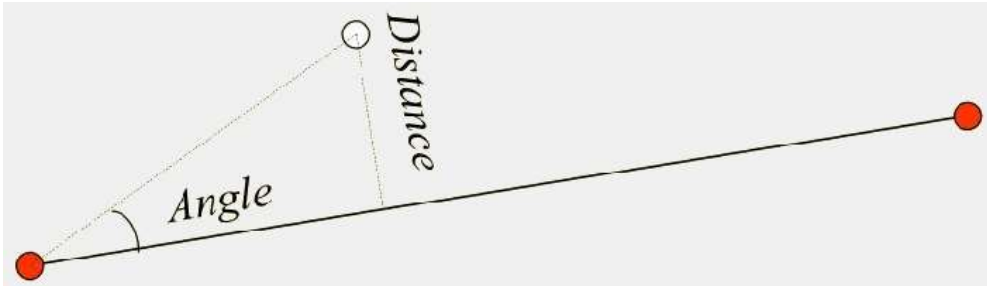


*Figure 8: Illustration of iteration angle and iteration distance parameters in the ground routine.*

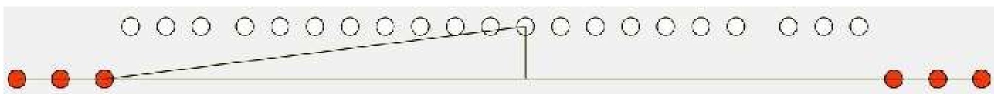

*Figure 9: A smaller iteration distance value avoids classification of ground points on low objects.*

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 or LASTools as illustrated in the figure below.

```
histogram of classification of points:
          54198  unclassified (1)
    12872414641  ground (2)
     2311851002  low vegetation (3)
     6555652803  medium vegetation (4)
    15178923028  high vegetation (5)
       21252051  building (6)
     2145979115  noise (7)
        3207815  water (9)
         201355  bridge deck (17)
       44117428  Reserved for ASPRS Definition (18)
 +-> flagged as withheld:  2190096543
  +--->      2145979115 of those are noise (7)
  +--->        44117428 of those are Reserved for ASPRS Definition (18)
 +-> flagged as extended overlap: 13994852991
  +--->           16933 of those are unclassified (1)
  +--->      4615468343 of those are ground (2)
  +--->       869790257 of those are low vegetation (3)
  +--->      2364384666 of those are medium vegetation (4)
  +--->      5222698975 of those are high vegetation (5)
  +--->         8092219 of those are building (6)
  +--->       903245524 of those are noise (7)
  +--->         1083323 of those are water (9)
  +--->           76769 of those are bridge deck (17)
  +--->         9995982 of those are Reserved for ASPRS Definition (18)
```

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

```
          46946  unclassified (1)
     3932159489  ground (2)
      756806998  low vegetation (3)
     2306316662  medium vegetation (4)
     3870845242  high vegetation (5)
        6389805  building (6)
      584780708  noise (7)
        2529537  water (9)
         130850  bridge deck (17)
       16457364  Reserved for ASPRS Definition (18)
 +-> flagged as withheld:  601238072
  +--->       584780708 of those are noise (7)
  +--->        16457364 of those are Reserved for ASPRS Definition (18)
 +-> flagged as extended overlap: 4235543962
  +--->           14098 of those are unclassified (1)
  +--->      1439812157 of those are ground (2)
  +--->       301553412 of those are low vegetation (3)
  +--->       872176189 of those are medium vegetation (4)
  +--->      1363200082 of those are high vegetation (5)
  +--->         2478095 of those are building (6)
  +--->       250924525 of those are noise (7)
  +--->          897071 of those are water (9)
  +--->           48284 of those are bridge deck (17)
  +--->         4440049 of those are Reserved for ASPRS Definition (18)
```

*Figure 11: Statistics showing the classes of all the LAS points within the project area (rev1)*

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.

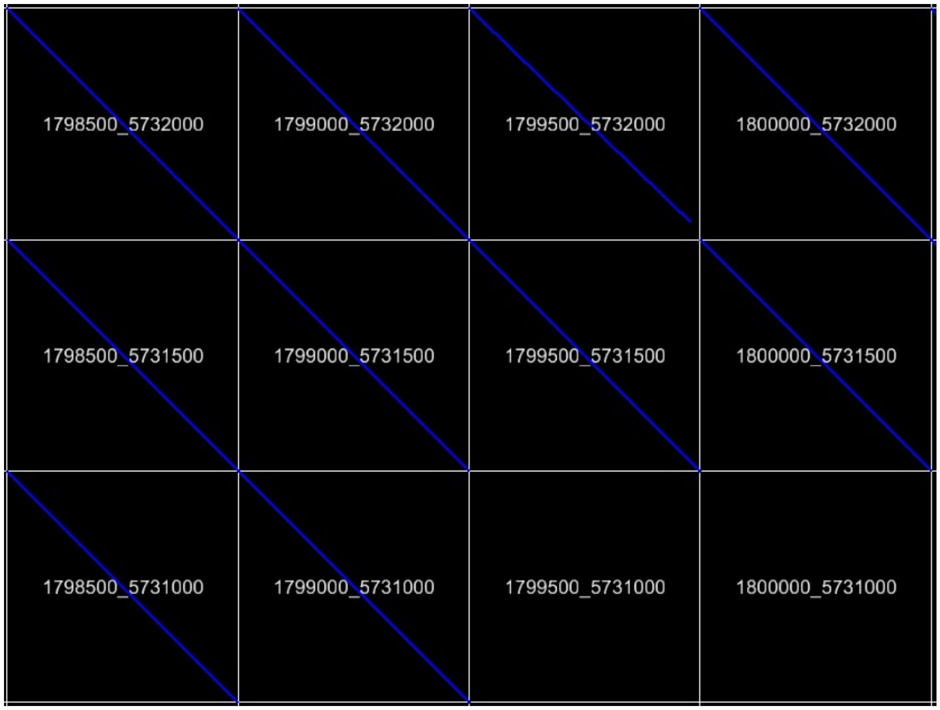


*Figure 12: The diagonal hatching seen above shows how the progress was tracked*

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.

### 2.8.1 Building Classification

The classification of building points has been undertaken by utilizing the TerraScan *buildings* routine. This routine classifies points on buildings which form a planar surface, several rules can be set to fine tune these results including the minimum building size/footprint, z tolerance of the point alignment along the roof line and use of echo information.

The use of echo information can further support the classification as points on roofs mostly belong to the echo type 'only echo' whereas vegetation usually contains a lot of 'first of many' and 'intermediate' echoes.

Additionally, the LINZ building footprint was also integrated into the building classification workflow to further constrain the classification and improve the overall output.

### 2.8.2 Vegetation & Low-Level Noise Classification:

In agreeance with all parties, Woolpert have classified the lower 0 – 0.3m of the low vegetation class to class 7 (low noise).

This was done to effectively remove the lower noise stratification points and unused ground points from class 3 over areas which do not represent vegetation e.g. man-made surfaces and structures (sealed roads).

The remaining vegetation points were classified using TerraScan's classify *by height from ground* which uses the ground surface to calculate the distance of each point above and below ground. All identified vegetation points were classified to the nominated classes using the height ranges specified in the *New Zealand Nation Aerial LiDAR Base Specification* (See below).

**Table 4 Minimum LAS point cloud classification scheme**

| Code | Description |
|---|---|
| 1 | Processed, but unclassified |
| 2 | Ground |
| 3 | Low vegetation <2m |
| 4 | Medium vegetation |
| 5 | High vegetation >8m |
| 6 | Building |
| 7 | Low noise |
| 9 | Water |
| 18 | High noise |

## 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.

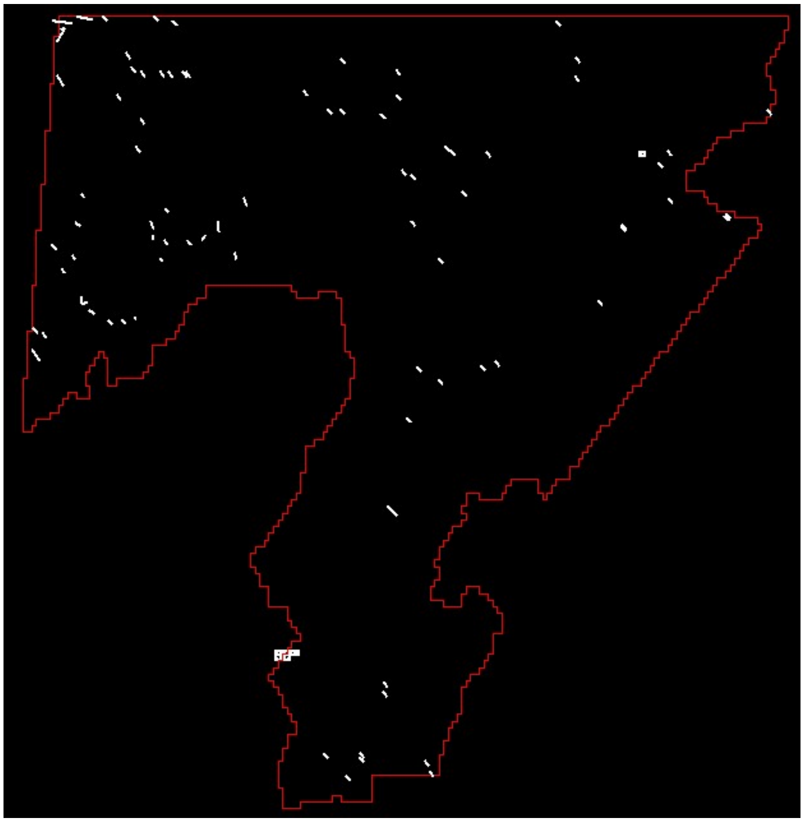

*Figure 13: The polygons are areas for further investigation*

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 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.

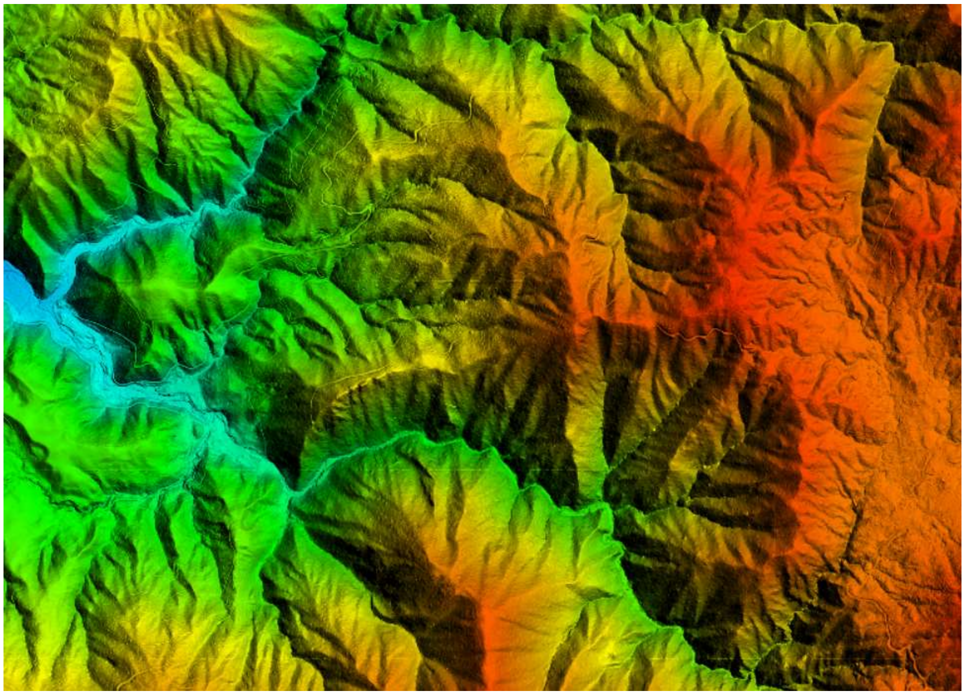

*Figure 14: Example overhead image of DEM over cliffs*

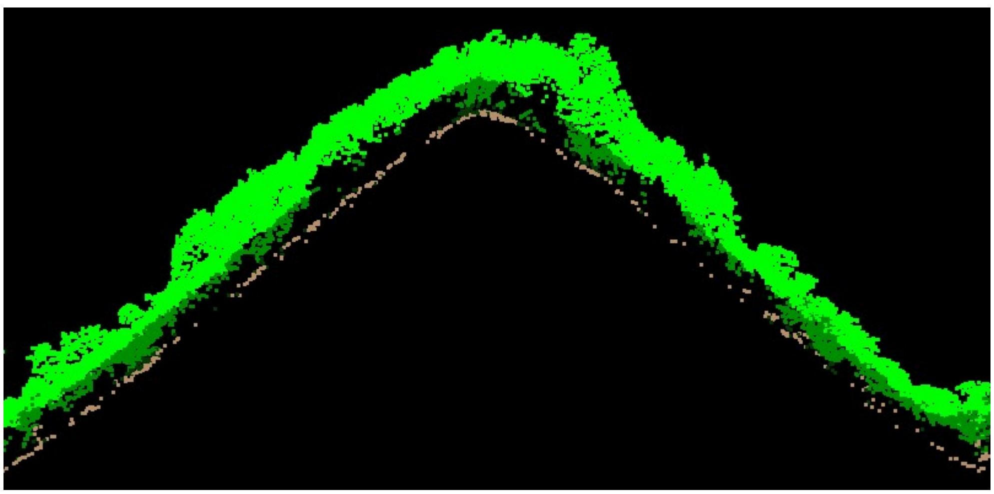

*Figure 15: LAS point cloud profile view from previous figure*

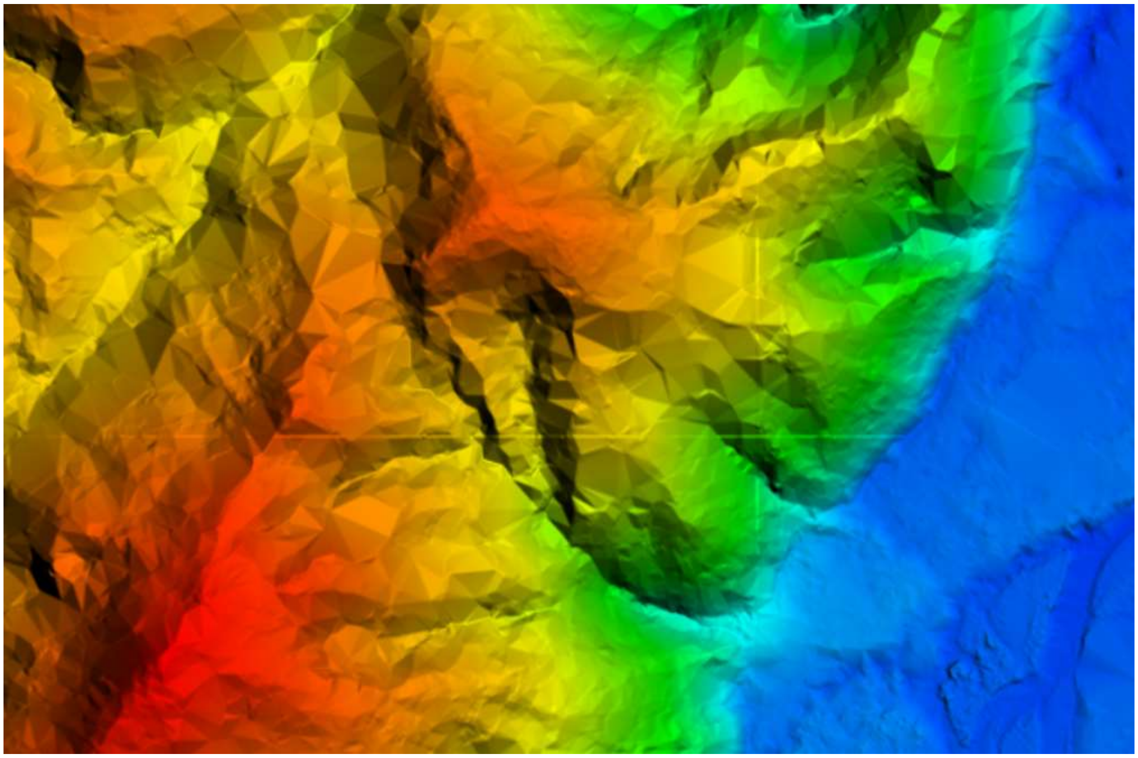

*Figure 16: Example overhead image of DEM interpolation*

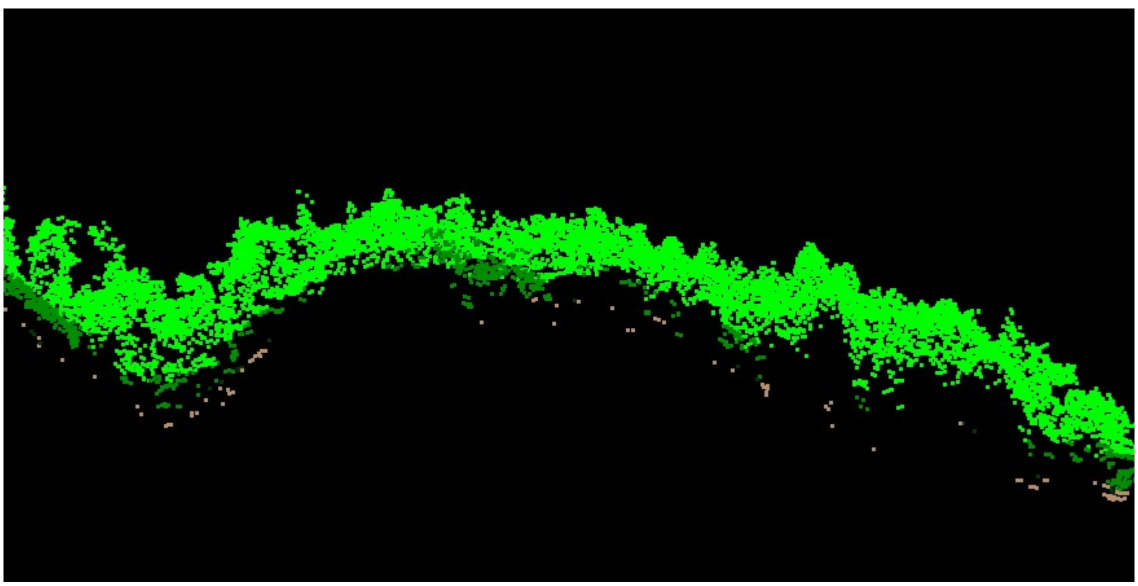

*Figure 17: LAS Point cloud view from previous figure*

## 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 – 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 examples shows the DEM where a bridge has been removed.

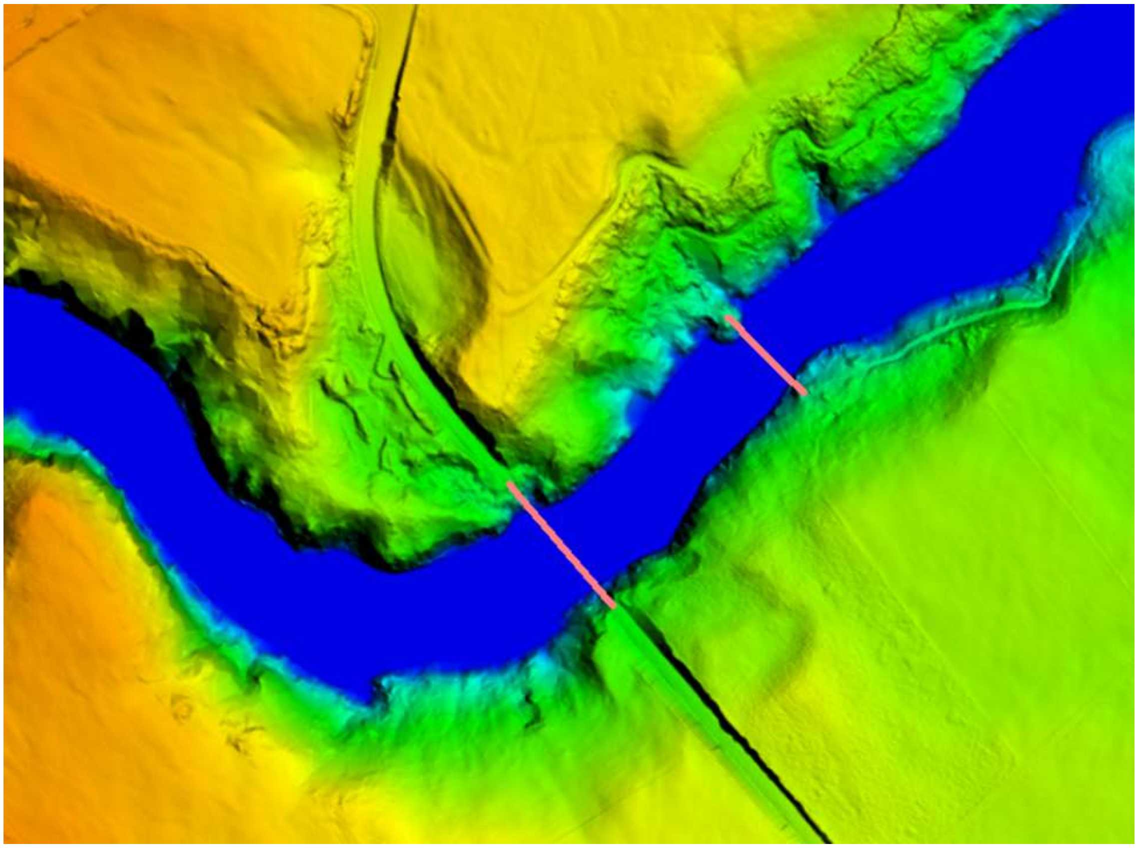

Figure 18: Tile DEM_BF35_2021_1000_2727 with LINZ bridge centreline

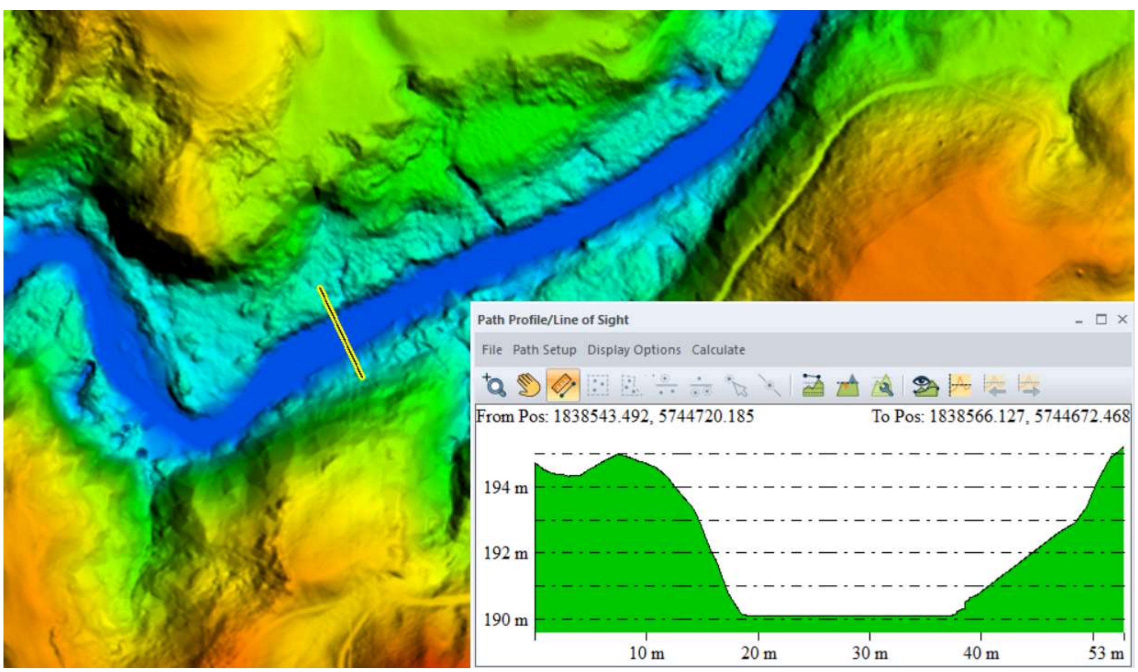


*Figure 19: DEM Tile BF35_2021_1000_3022*

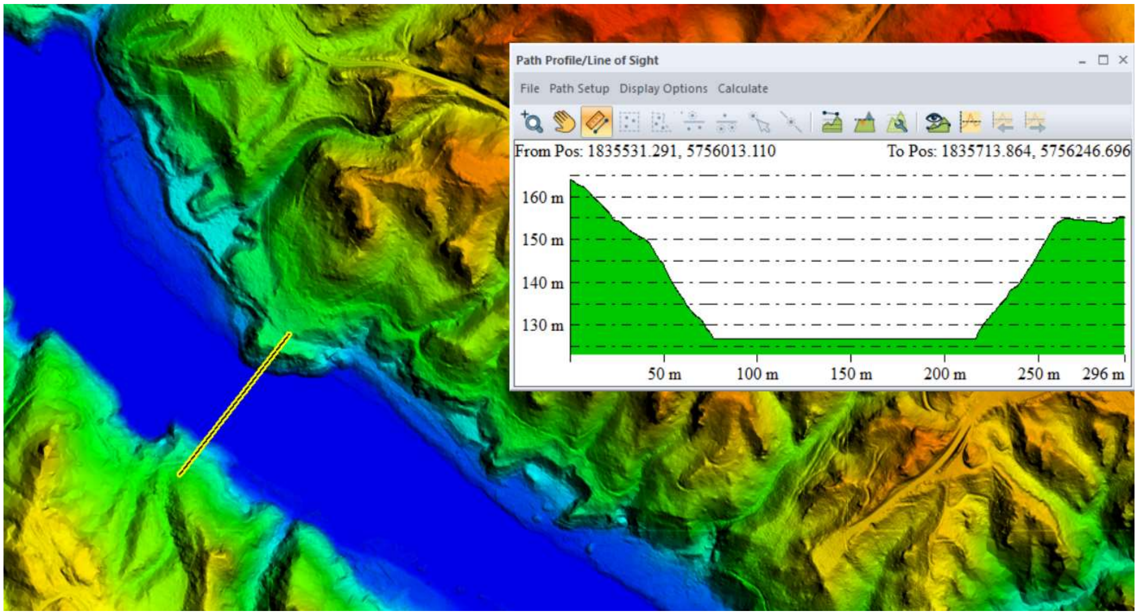


*Figure 20: DEM Tile BH35_2021_1000_1416*

The example below shows a road cut into a slope rather than a bridge.

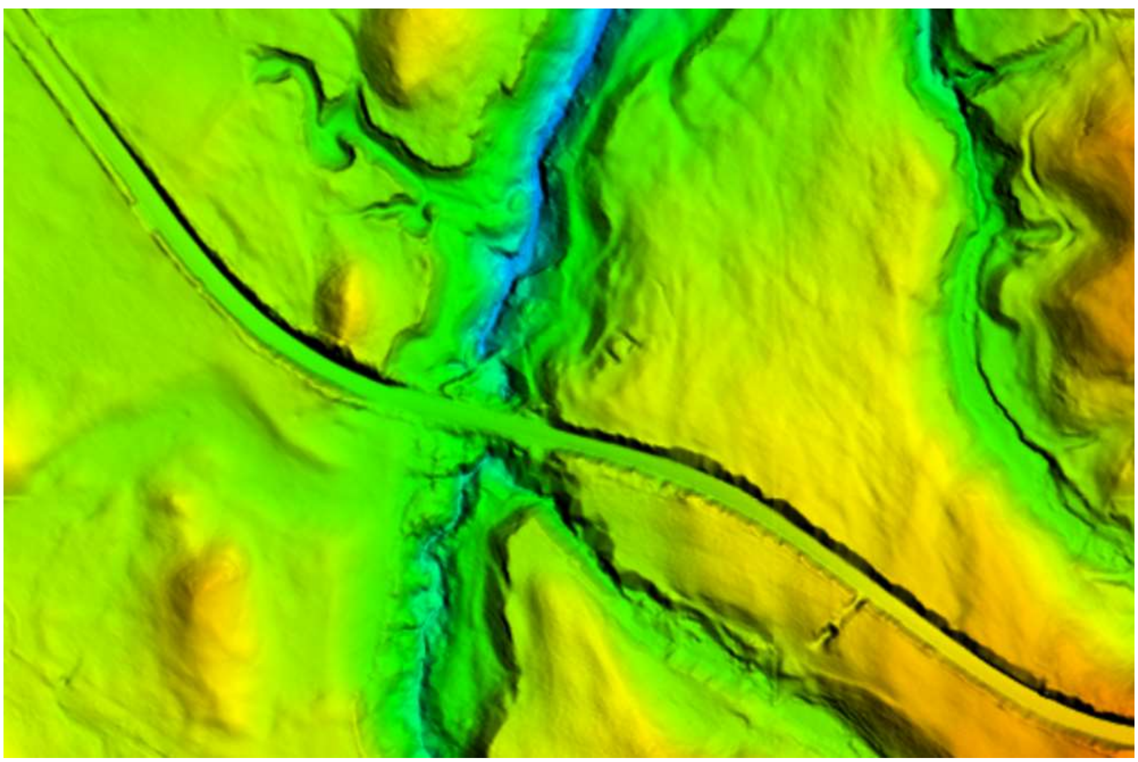

*Figure 21: DEM Tile BF35_2021_1000_4741*

The example below shows a Bridge in the LINZ shapefile that is a culvert and is therefore not edited to class 17.

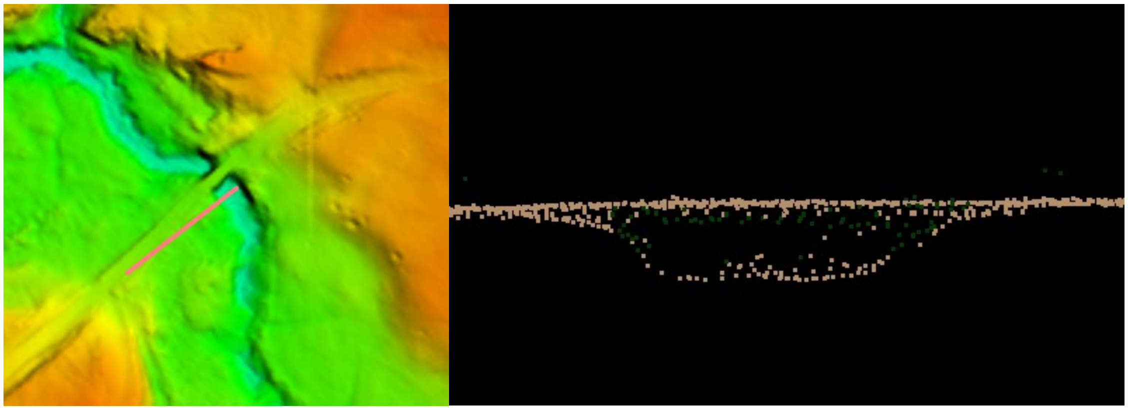

Figure 22: DEM Tile BE34_1000_3627

# 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 000m$^2$ or larger in size.

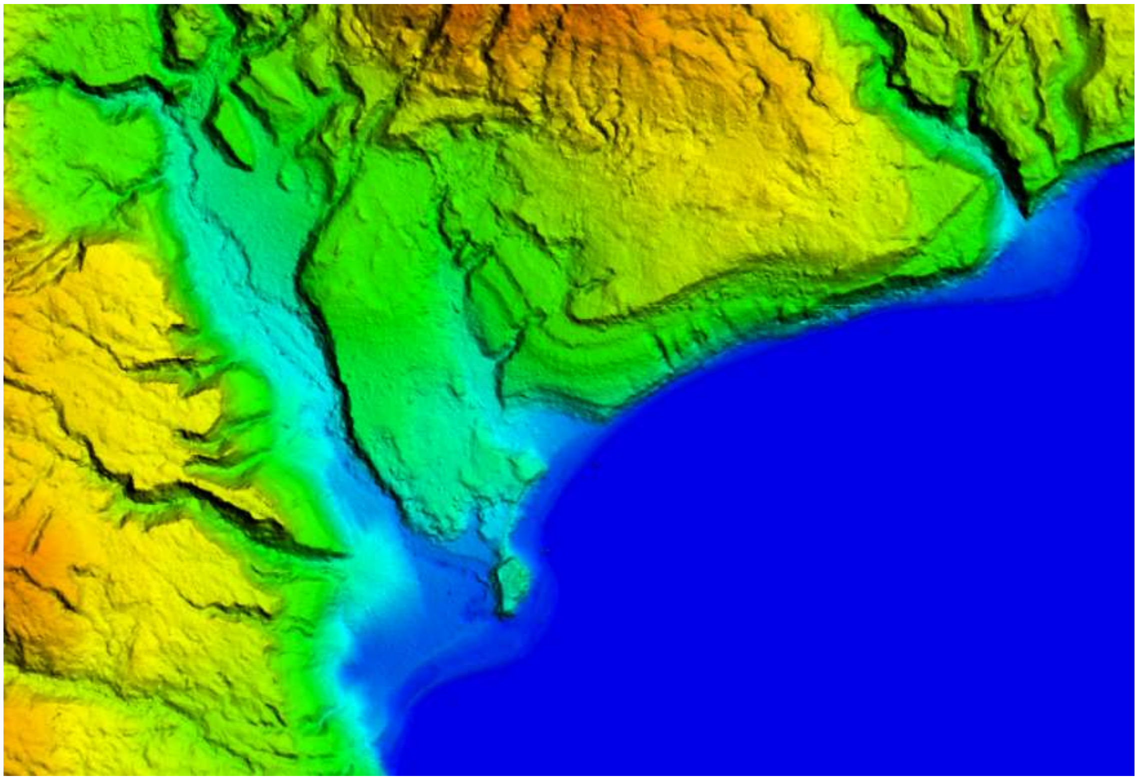

*Figure 23: Example of a hydro-flattened DEM Lake Tile DEM_BG35_2021_1000_2037*

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.

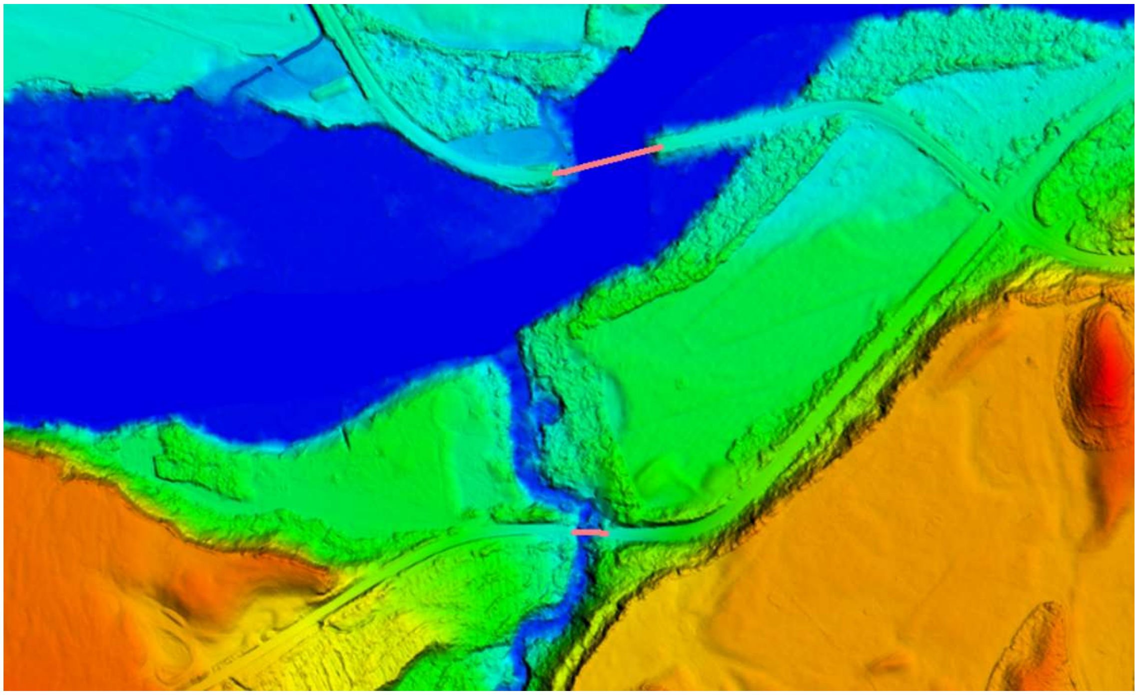

Figure 24: Example of Bridge with LINZ bridge centreline

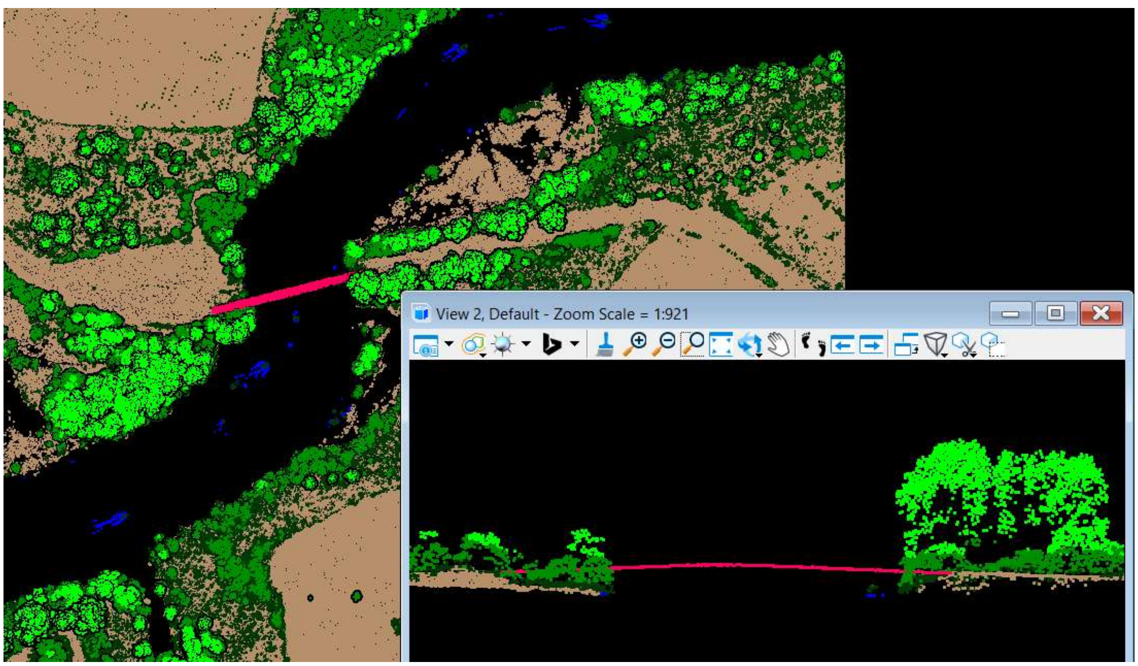


Figure 25: Same location as above DEM.

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.

| | | | |
|---|---|---|---|
| 1 | 1929744.8358 | 5615128.2638 | 7.7096 |
| 2 | 1929746.0769 | 5615130.8498 | 7.6863 |
| 3 | 1929746.4280 | 5615131.5996 | 7.6796 |
| 4 | 1929746.5107 | 5615131.7727 | 7.678 |
| 5 | 1929746.7841 | 5615132.3591 | 7.6728 |
| 6 | 1929748.0794 | 5615135.0799 | 7.6483 |
| 7 | 1929748.5703 | 5615136.1455 | 7.6388 |
| 8 | 1929749.4246 | 5615138.0643 | 7.622 |
| 9 | 1929749.8587 | 5615139.0742 | 7.6132 |
| 10 | 1929750.6288 | 5615140.9327 | 7.5973 |
| 11 | 1929751.0393 | 5615141.7916 | 7.5896 |
| 12 | 1929751.5292 | 5615142.7809 | 7.5805 |
| 13 | 1929754.3861 | 5615148.3485 | 7.529 |
| 14 | 1929754.7868 | 5615149.1041 | 7.5219 |
| 15 | 1929754.7991 | 5615149.1267 | 7.5217 |
| 16 | 1929757.3347 | 5615152.1834 | 7.4808 |
| 17 | 1929757.8445 | 5615152.7752 | 7.4594 |

*Figure 26: Excerpt of river points used to create the centreline*

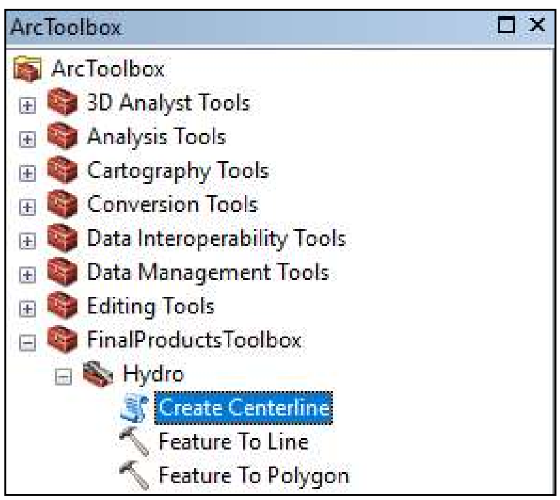


*Figure 27: Centreline for the stream within the project's survey*

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:

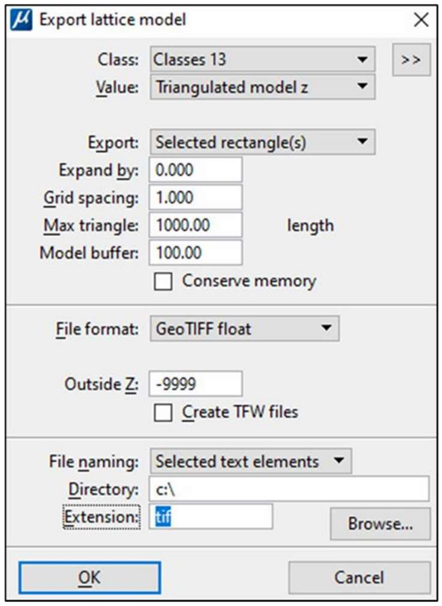


*Figure 28: Settings used to export lattice models.*

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.

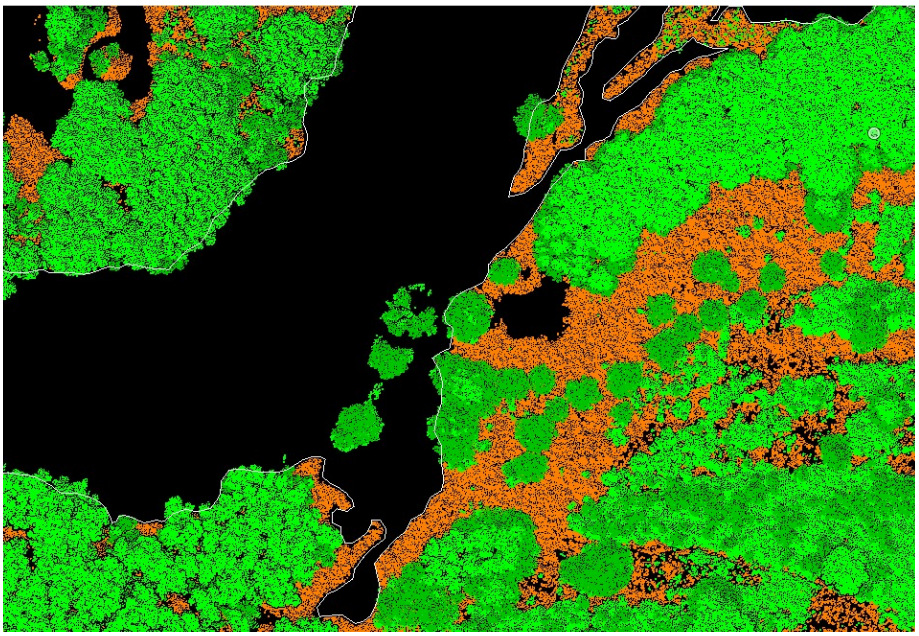

*Figure 29: Pre-filter, overhead view of ground and veg points with hydro lines*

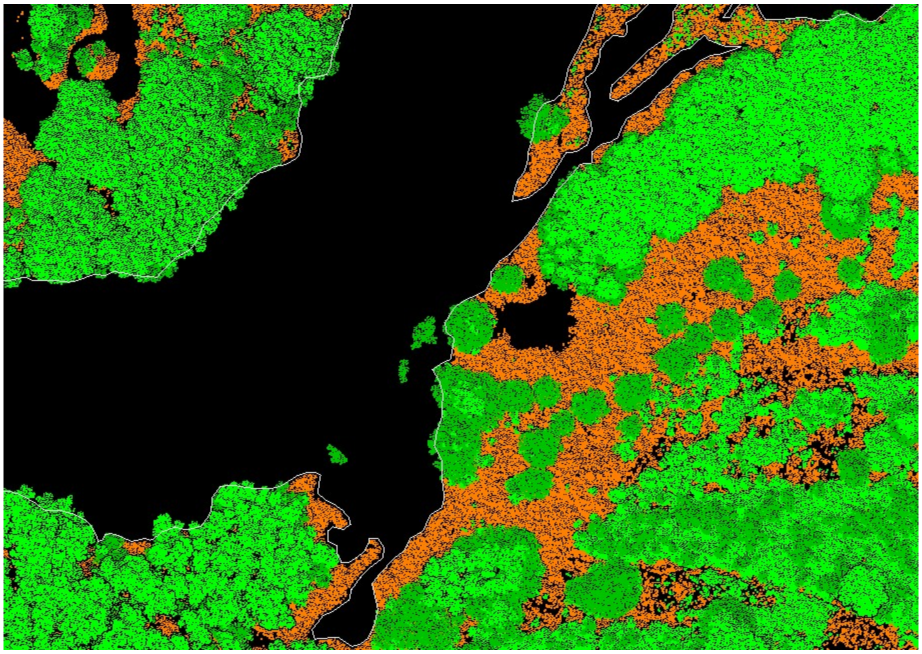

*Figure 30: Post-filter, overhead view of ground and veg points with hydro lines*

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 31: Point cloud – boulder filled stream*


*Figure 32: Imagery – boulder filled stream*

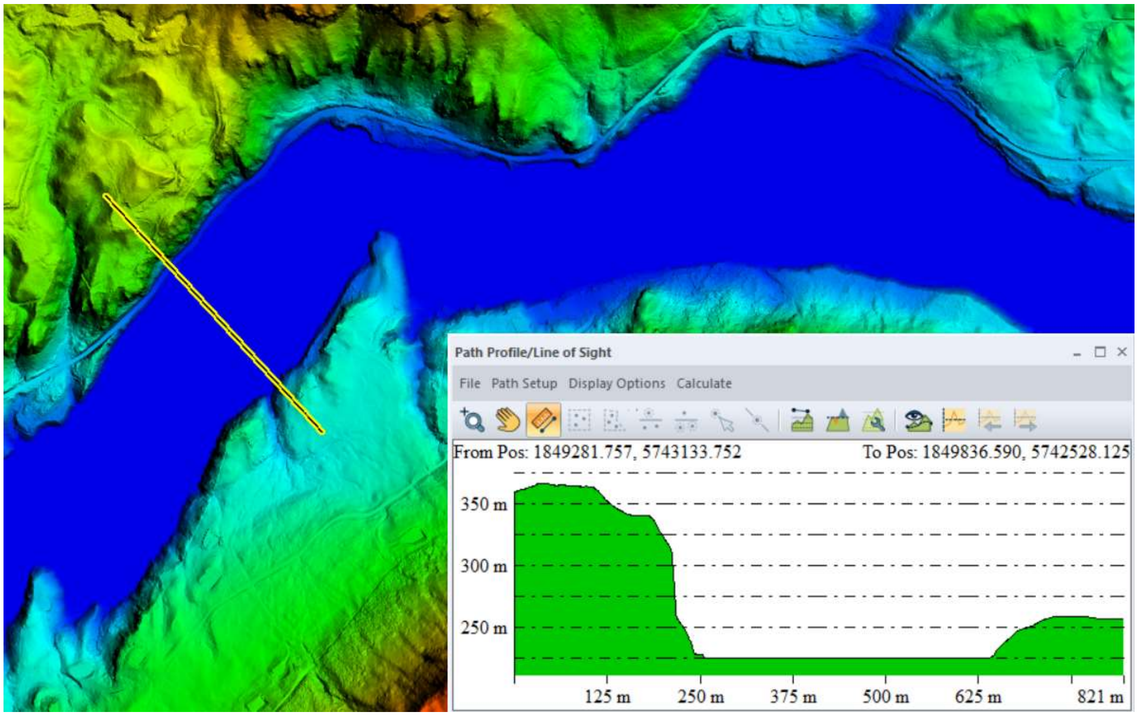


*Figure 33: Example of hydroflattened DEM: DEM_BF35_2021_1000_3345*

# 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 E was captured using Leica TerrainMapper sensor 513 and 559, flown on days 05th, 06th, 10th, 11th, 14th, 15th, 25th, 26th, 29th, 30th, 31st January, 1st, 3rd, 11th, 12th, 16th, 18th, 19th, 20th February, 11th, 13th, 21st, 22nd, 23rd, 24th March 2021.

Please note the dates above refer to all dates flown for the entirety of Block E inclusive of North (1), North (2) and South.

The extent of Block E can be seen in Figure 34. The flight lines relating to the area can be seen in Figure 35.

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 figure 33.

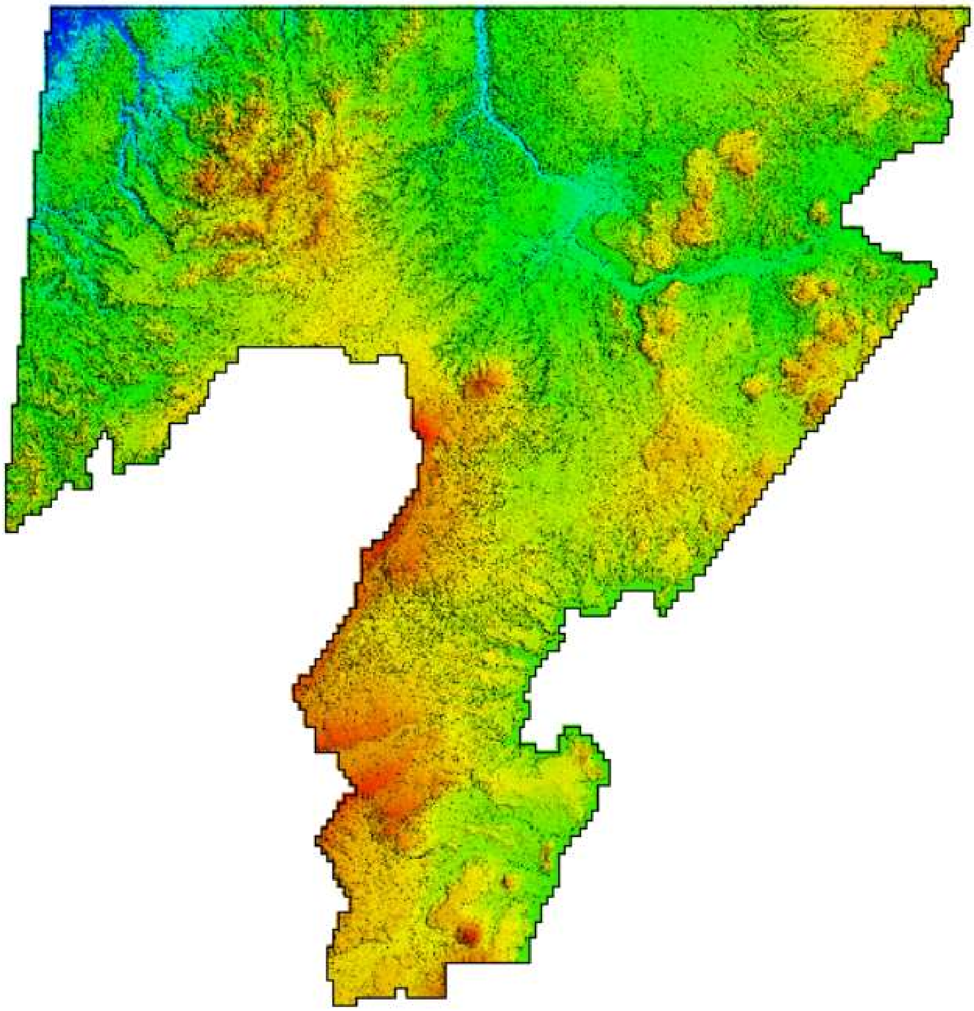

*Figure 34: Extent of deliverable data for Block E North (2)*

### 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. Refer to the purple polygon illustrating Block E North (2).

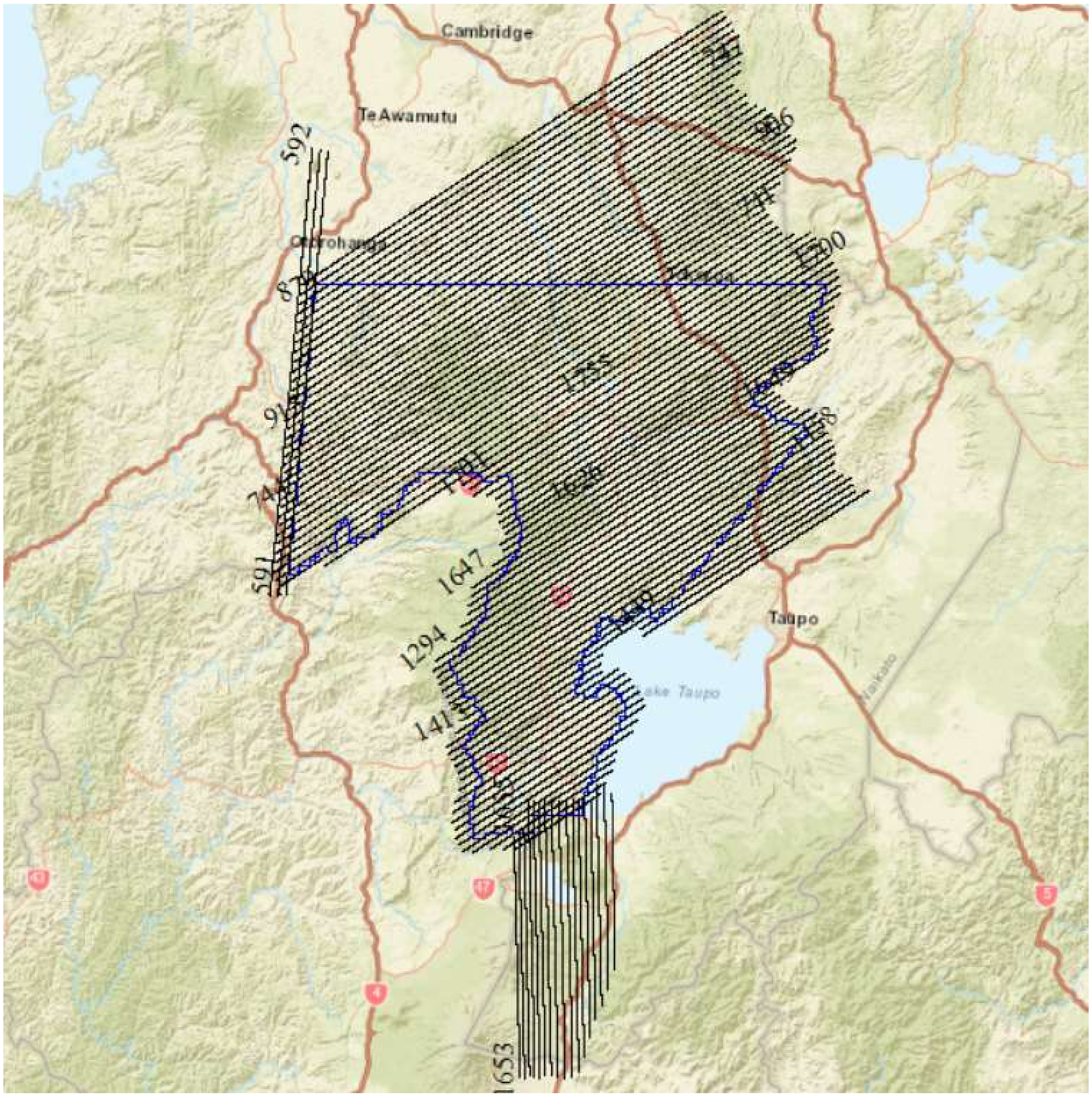


*Figure 35: Flight lines for 4ppm2 data coverage over Block E North (2)*

## 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 36: WKT of a LAS file shown by LASTools.*

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.

| File | Points | Version | File Signature | File Source ID | CRS is WKT | Coordinate System |
|---|---|---|---|---|---|---|
| CL2_BG35_2021_1000_0405.las | 3,030,325 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG35_2021_1000_0406.las | 3,746,394 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG35_2021_1000_0407.las | 4,888,335 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG35_2021_1000_0408.las | 4,717,818 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG35_2021_1000_0418.las | 5,431,876 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG35_2021_1000_0419.las | 4,767,456 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG35_2021_1000_0420.las | 3,401,279 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG35_2021_1000_0422.las | 2,639,543 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG35_2021_1000_0423.las | 3,244,777 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG35_2021_1000_0427.las | 3,780,786 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG35_2021_1000_0428.las | 3,035,123 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG35_2021_1000_0439.las | 2,878,256 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG35_2021_1000_0440.las | 3,293,866 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG35_2021_1000_0446.las | 2,805,652 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG35_2021_1000_0447.las | 3,311,312 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG35_2021_1000_0448.las | 4,731,069 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG35_2021_1000_0449.las | 3,645,816 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG35_2021_1000_0503.las | 2,940,714 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG35_2021_1000_0504.las | 3,886,904 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG35_2021_1000_0505.las | 4,456,422 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |

*Table 2: Representative output from LP360 illustrating LAS file specification compliance (Rev1)*

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 analysist 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.

It is noted for Blocks F & G due to the dense vegetation and steep terrain the penetration of the LiDAR to the ground in some areas is minimal (Figure 18 is a good example). This will show in the DEM as large, triangulated areas or give the impression of pitting where only isolated ground returns have been identified.
For these areas it is recommended to compare any potential DEM discrepancies with the point cloud to confirm the absence of available ground points.

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.

| File | Format | NoData Value | BPB | Bands | Data Type | Pixel Size | Coordinate System |
|---|---|---|---|---|---|---|---|
| DEM_BF35_2021_1000_0314.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BF35_2021_1000_0334.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BF35_2021_1000_0335.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BF35_2021_1000_0336.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BF35_2021_1000_0414.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BF35_2021_1000_0415.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BF35_2021_1000_0432.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BF35_2021_1000_0433.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BF35_2021_1000_0434.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BF35_2021_1000_0435.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BF35_2021_1000_0436.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BF35_2021_1000_0439.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BF35_2021_1000_0440.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BF35_2021_1000_0441.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BF35_2021_1000_0514.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BF35_2021_1000_0515.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BF35_2021_1000_0540.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BF35_2021_1000_0541.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BF35_2021_1000_0614.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BF35_2021_1000_0714.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |

*Table 3: Condensed output from LP360 illustrating DEM file specification compliance (Rev1)*

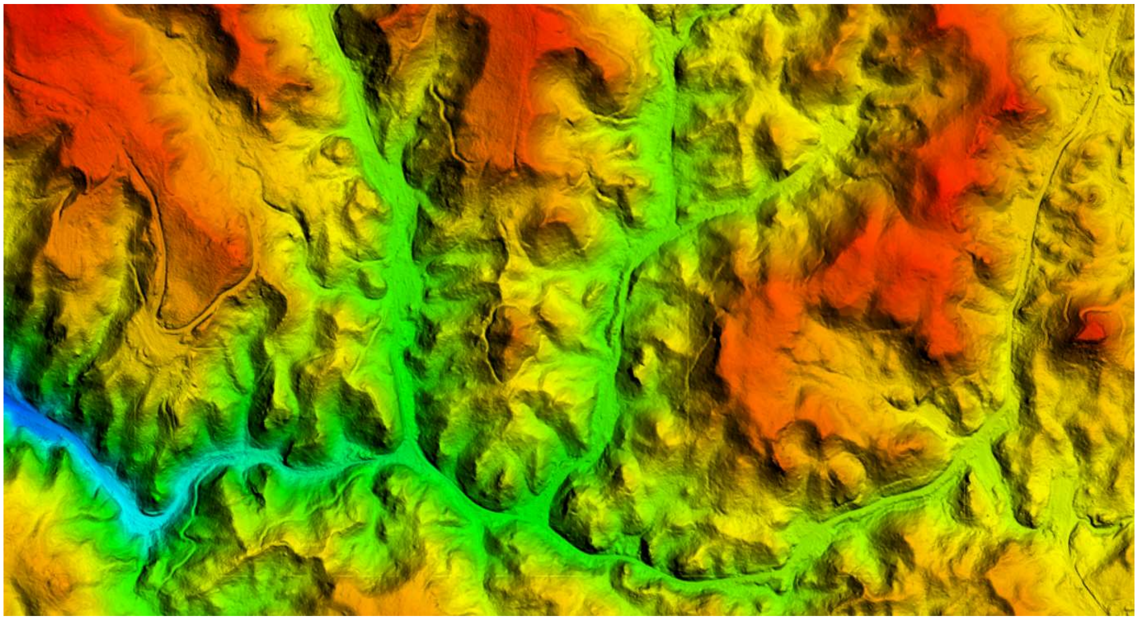

*Figure 37: DEM Example Tiles BF35_1000_0919, BF35_1000_0920 & BF35_1000_0921*

### 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.

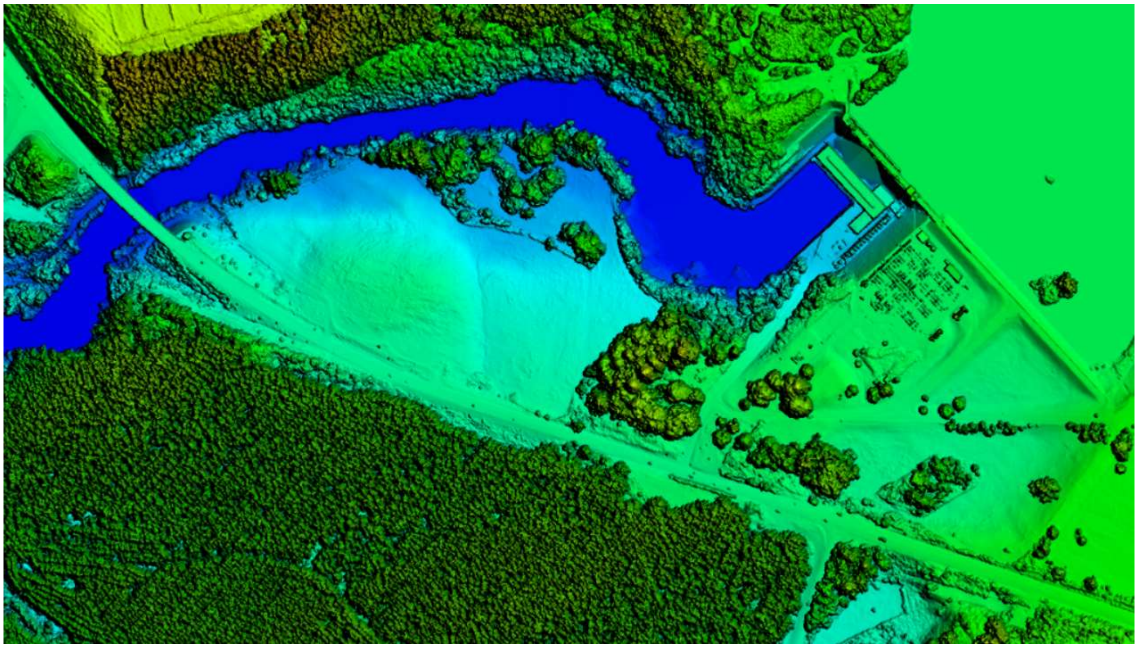

*Figure 38: Excerpt from DSM_BF36_1000_2824_&_BF36_1000_2825*

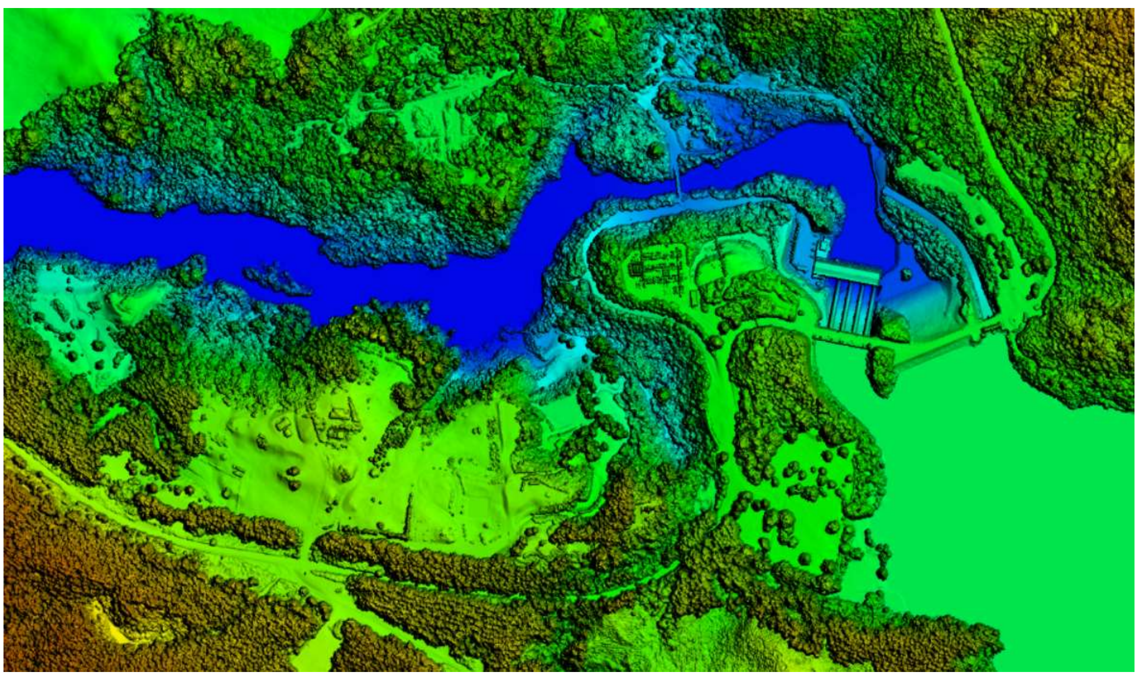

*Figure 39: Excerpt from BF36_1000_3136 & BF36_1000_3137*

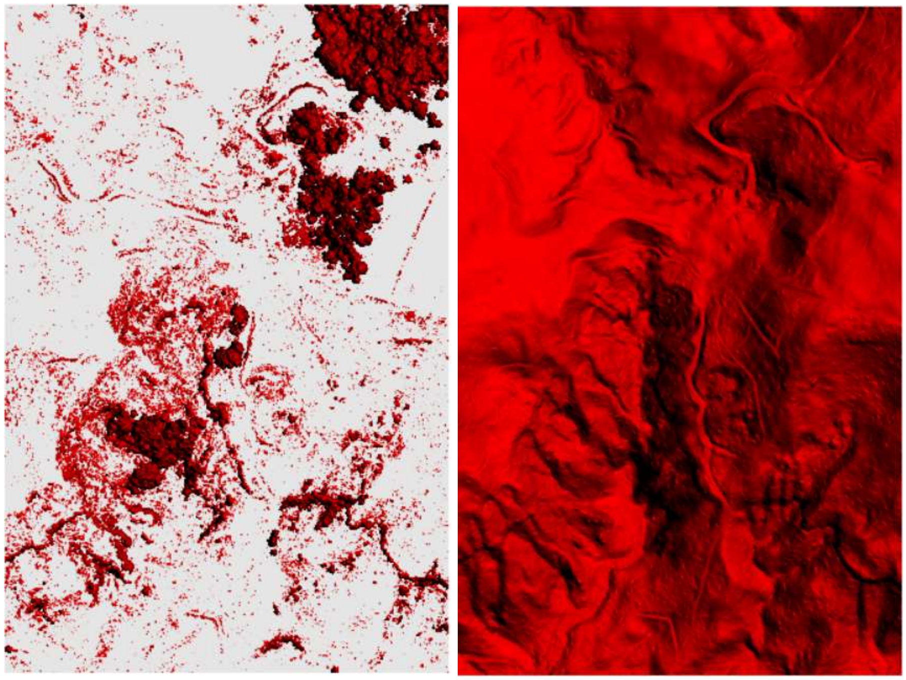

*Figure 40: Difference between DSM and DEM differences in height along cliff lines*

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.

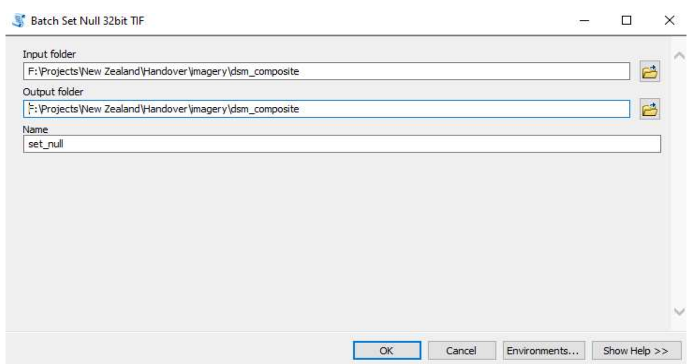


*Figure 41: Script used in ArcMap to achieve a NoData value of -9999.*

| | |
|---|---|
| Format | IMAGINE Image |
| Source Type | Generic |
| Pixel Type | floating point |
| Pixel Depth | 32 Bit |
| NoData Value | -9999 |

*Figure 42: 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.

| File | Format | NoData Value | BPB | Bands | Data Type | Pixel Size | Coordinate System |
|---|---|---|---|---|---|---|---|
| DSM_BF35_2021_1000_1046.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BF35_2021_1000_1047.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BF35_2021_1000_1048.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BF35_2021_1000_1049.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BF35_2021_1000_1050.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BF35_2021_1000_1101.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BF35_2021_1000_1102.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BF35_2021_1000_1103.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BF35_2021_1000_1104.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BF35_2021_1000_1105.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BF35_2021_1000_1106.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BF35_2021_1000_1107.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BF35_2021_1000_1108.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BF35_2021_1000_1109.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BF35_2021_1000_1110.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |

*Table 4: LP360 DSM Results example table (rev1)*

## 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.

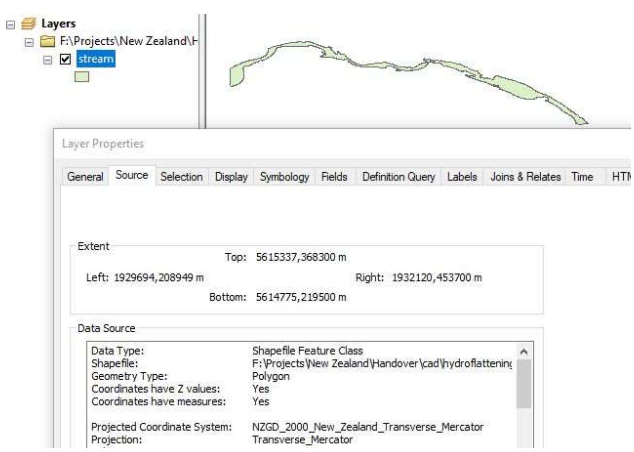


*Figure 43: Stream break line properties in ArcMap.*

## 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 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. Samples have been provide of contours including those that straddle block joins.

Contours will be generated at 1,5 and 10 metre markers. They will adopt a naming convention as per WRC suggestion e.g. *CRT_BB35_2021_1000_1515. CRT refers to Cartographic and opposed to engineering contours.*

# 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_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.

o Check for presence of correct ESPG Codes for geodetic & vertical datums, and map projection

o 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.

| Naming Convention for point clouds, DEMs, and other tiled products<br>*[product]_[sheet]_[year]_[scale]_[tile].[ext]* | | |
|---|---|---|
| **Product** | *DEM* | **CL2-Point Cloud Classification Level 2**<br>**DEM-Bare Earth Digital Elevation Model**<br>**DSM-Digital Surface Model**<br>DTM-Digital Terrain Model<br>UNC-Unclassified Point Cloud<br>INT-Intensity image<br>CHM – Canopy Height Model<br>IMG-Aerial photography<br>etc |
| **Sheet** | *BK34* | LINZ Topo50 identifier (4 characters) |
| **Year** | *2016* | Year of survey commencement |
| **Scale** | *1000* | Nominal scale of NZTopo50 subtiles |
| **Tile** | *4118* | Row number (41), Column number (18) of tile with respect to an upper left origin |
| **ext** | *tif* | File extension according to format conventions<br>las<br>tif<br>shp<br>etc |
| *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-flatting break line bank line strings
│         │ └───stream_islands – Hydro-flatting 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

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 Lessons learned and collaboration

Thanks goes to the team at WRC for providing inputs to previous blocks that has informed decisions on processing for this block and the entirety of Block E. There is some challenging terrain and dense vegetation that hindered penetration is some parts and made for some difficult processing with significant manual editing.

## 6.4 WRC Tracking Spreadsheet

Below is a table showing one of the pages of the tracking spreadsheet which was supplied by WRC and LINZ and reviewed and commented on by Ocean Infinity and/or Woolpert. This was further supplemented by shapefiles, geodatabase files, reference images / snips and other information to support identification, rectification and repair.

*Table 6: WRC Defect tracking Spreadsheet – Populated post rework*

| Date | Item | Product | Raised By | Description | Assigned to | Woolpert Review | Woolpert Comment |
|---|---|---|---|---|---|---|---|
| 23/01/2023 | 1 | All | RossM | All items in "WRC_IssuesPoints Defects" tab ) and WRC_IssuesPoints featureclass | Audi/Zu | Reviewed | In Progress |
| 23/01/2023 | 2 | All | RossM | All items in "WRC_IssuesPolygons Defects" tab ) and WRC_IssuesPolygons featureclass | Audi/Zu | Reviewed | In Progress |
| 23/01/2023 | 3 | All | RossM | All items in "LINZ_defects" tab and LINZ_ feature classes in the main geodatabase WRCReview20240125_EN2_v1.gdb | Audi/Zu | Reviewed | In Progress - LINZ feature class corrupt - shp resupplied |
| 23/01/2023 | 4 | All | RossM | Data processing report hasn't been delivered | Zu/Luke/OI | Supplied | All materials delivered to OI for report configuration |
| Dans additional manifold checks to follow (refer to repsective tabs) | | | | | | | |
| 23/01/2023 | 5 | DEM | DanB | [I110 BRIDGE REMOVAL] - Nine bridges have not been removed from the DEM. See layer [I110 BRIDGE REMOVAL.gpkg] | Zu | Fixed | |
| 23/01/2023 | 6 | DEM | DanB | [I37 DEM VOID DETECTION] / [I73 TILE COVER FULL EXTENT] - 3 tiles with DEM data voids. Two are over water on lake Taupo (but still shouldn't be there and on is overland. See layer [I37 DEM VOID DETECTION.gpkg] | Zu | Fixed | No missing pixels observed in regenerated products |
| 23/01/2023 | 7 | DEM | DanB | [M3 NEGATIVE SUBTRACTION] - Pits and spikes in DEM. See QA layer [LidarQA_templates.gdb]::[IssuesPoints.SHAPE] | Audi/Zu | Fixed | All spikes and misclassification issues have been addressed. |
| 23/01/2023 | 8 | DEM | DanB | [I37 DSM VOID DETECTION] / [I90 DSM TILE COVER FULL EXTENT] - 5 tiles with single pixel voids and one tile with larger void over water in Lake Taupo. See [I37 DSM VOID DETECTION.gpkg] | Zu | Fixed | No missing pixels observed in regenerated products |
| 23/01/2023 | 9 | DEM | DanB | [I65 PC TILE AND CRS] - Single missing tile. In DEM/DSM supply but not in LAS. Overwater in Lake Taupo. See QA layer [LidarQA_templates.gdb]::[IssuesPoints.SHAPE] | Zu | Reviewed | No laser strikes within tile boundary |
| 23/01/2023 | 10 | DEM | DanB | [I54 POINT SOURCE FLIGHLINE] - One tile with missing flightline data. See [I54 POINT SOURCE FLIGHLINE.gpkg] | Luke | Fixed | Tile corruption fixed |
| 23/01/2023 | 11 | DEM | DanB | [I57 PC GPS EXTENDED TIME] - Of the 3% of las points randomly selected 4 tiles are without times in extended format. Please check entire dataset.<br>TILE_IDX<br>BF36_1000_3142<br>BF36_1000_3143<br>BG35_1000_2528<br>BG35_1000_2627 | Luke | Fixed | All tiles reviewed and corrected |

## 6.5 Examples of Corrections after initial supply

The following pages are examples of defects that were identified by WRC and or LINZ and how they were rectified.

### 6.5.1 Aerosol spike in DEM

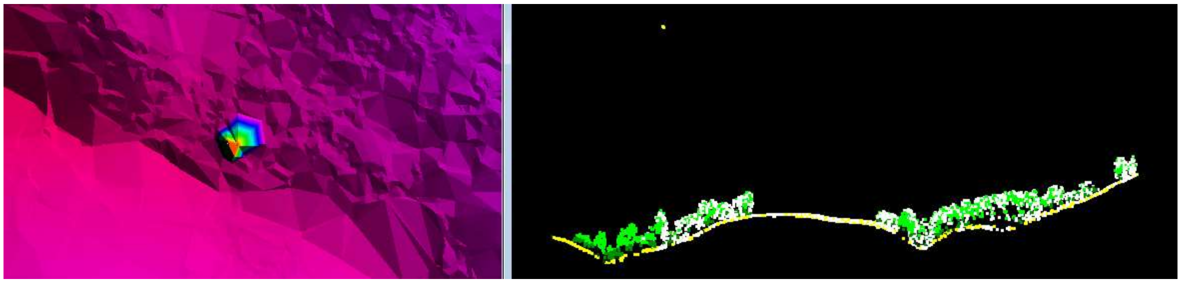

Figure 44: BF33_1000_1142 Before

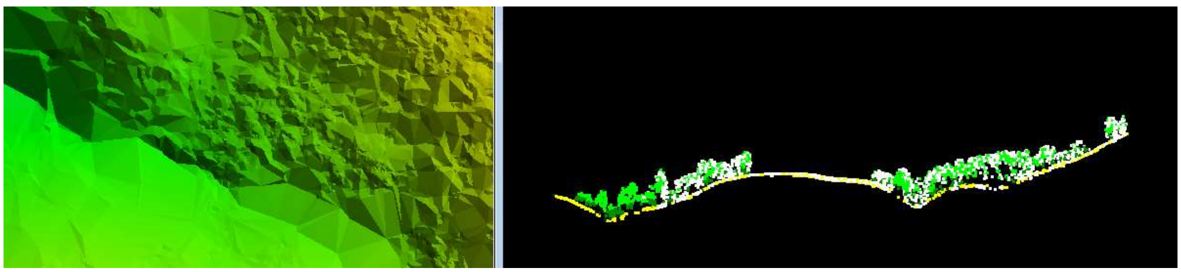

Figure 45: BF33_1000_1142 After

### 6.5.2 Pit in DEM

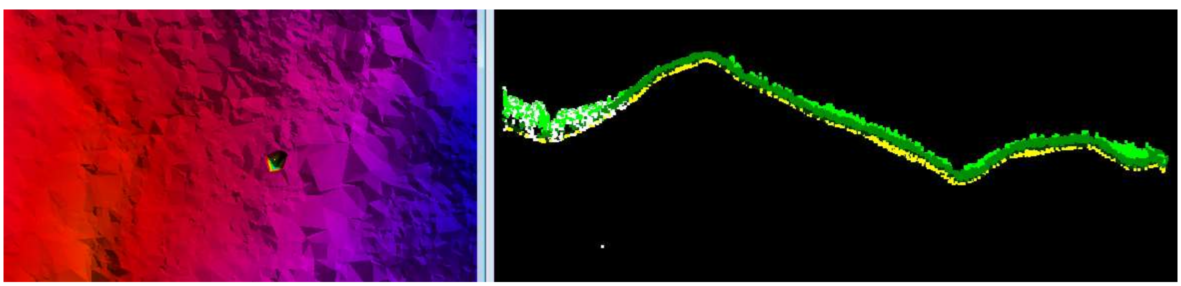

Figure 46: BF34_1000_4119 Before

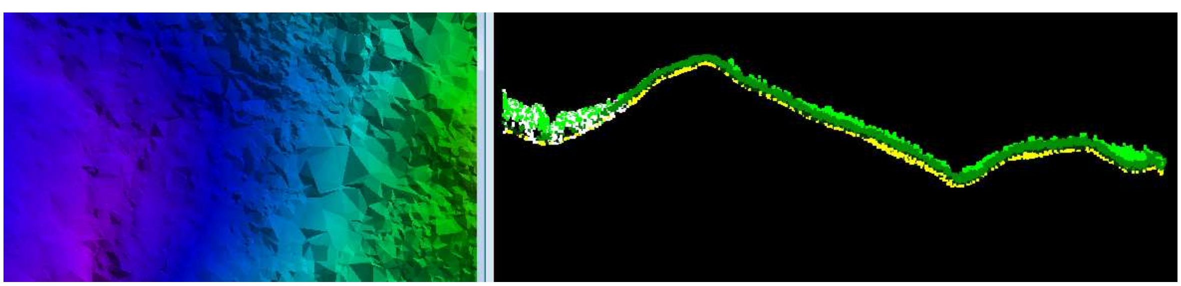

Figure 47: BF34_1000_4119 After

### 6.5.3 DEM texture issue - Canopy points classified as ground

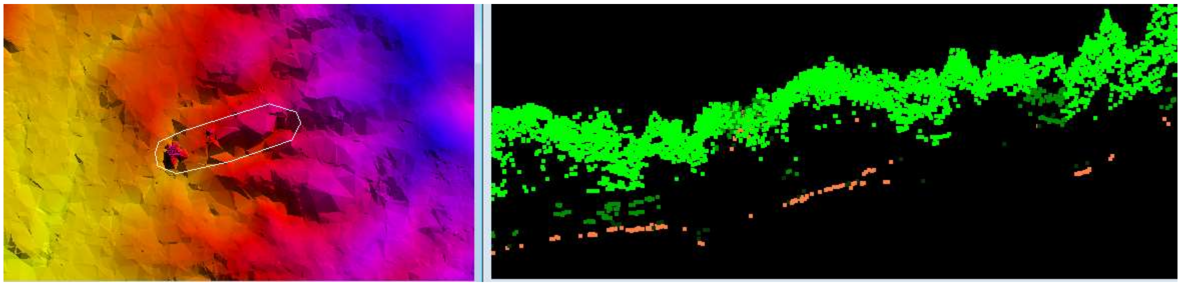

Figure 48: BF34_1000_1846 Before

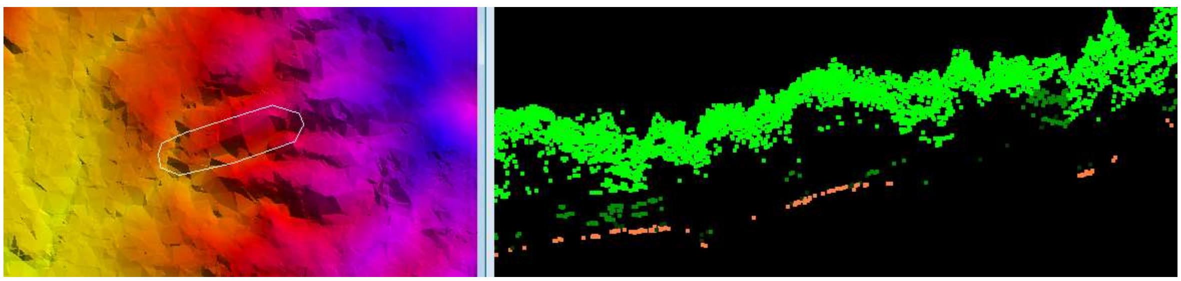

Figure 49: BF34_1000_1846 After

### 6.5.4 Patch of low density last & only points

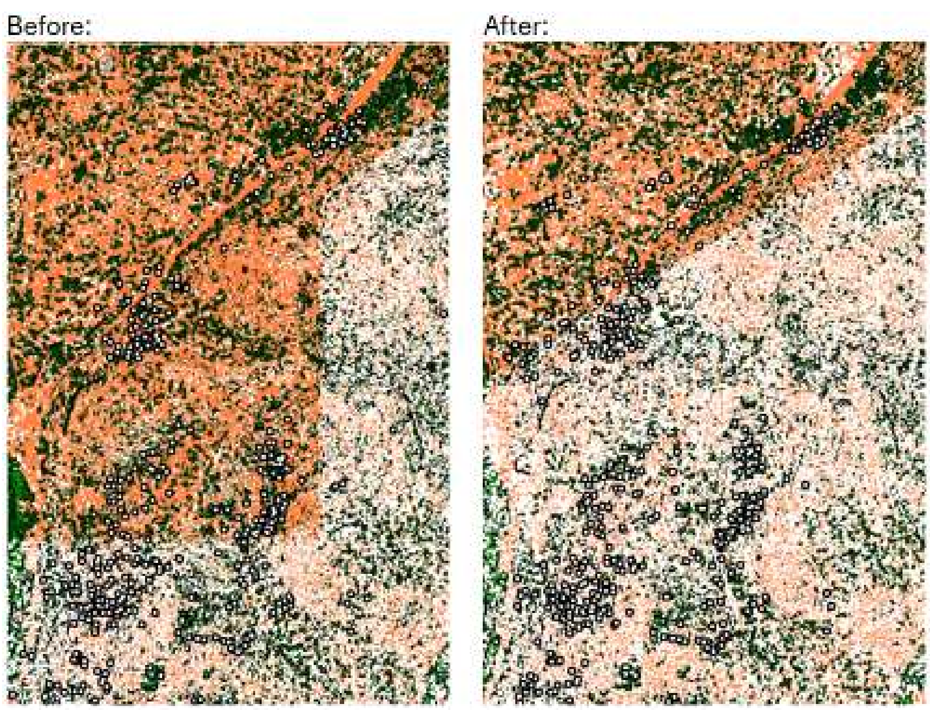


Figure 50: Tile BF36_1000_1918

### 6.5.5 Texture issue from vegetation in DEM (A)

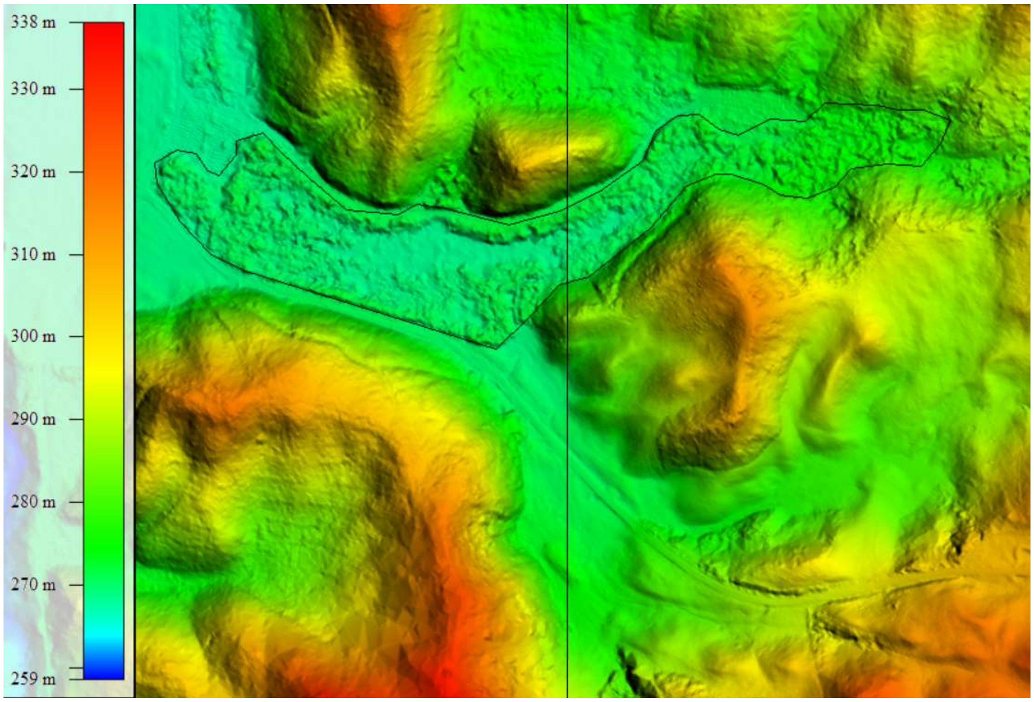


Figure 51: BF36_1000_3713 & BF36_1000_3714 Before

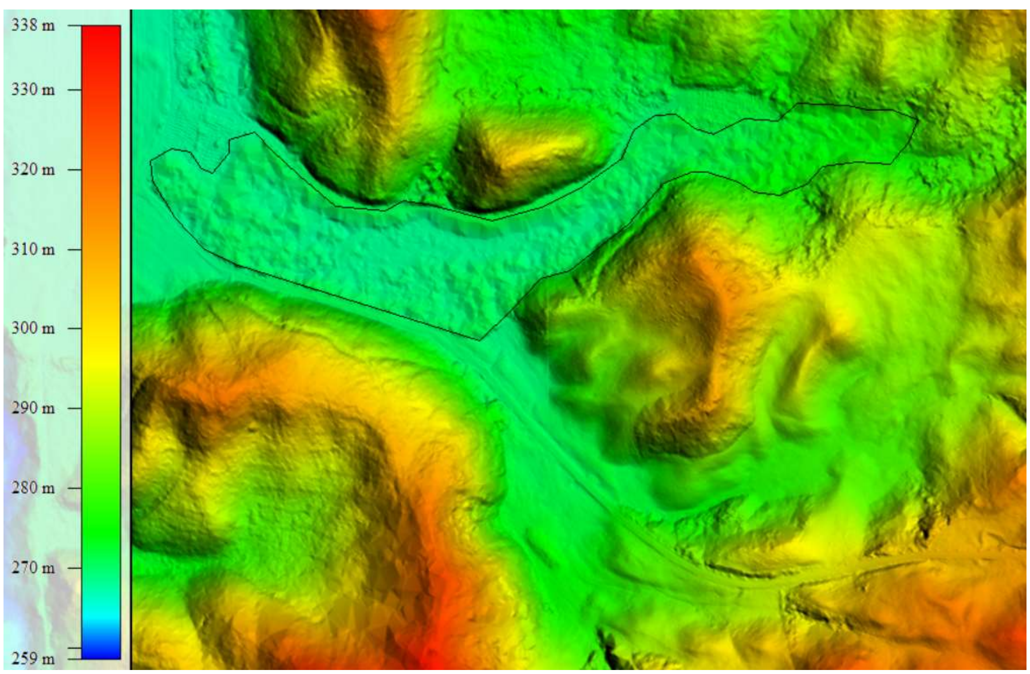


Figure 52: BF36_1000_3713 & BF36_1000_3714 After

### 6.5.6 Texture issue from vegetation in DEM (B)

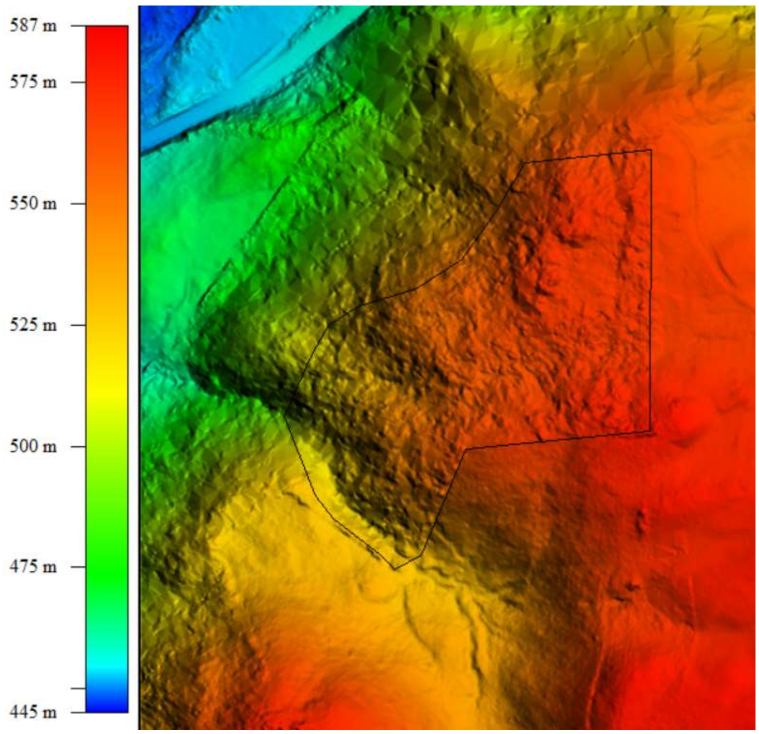


Figure 53: BH35_1000_0211 Before

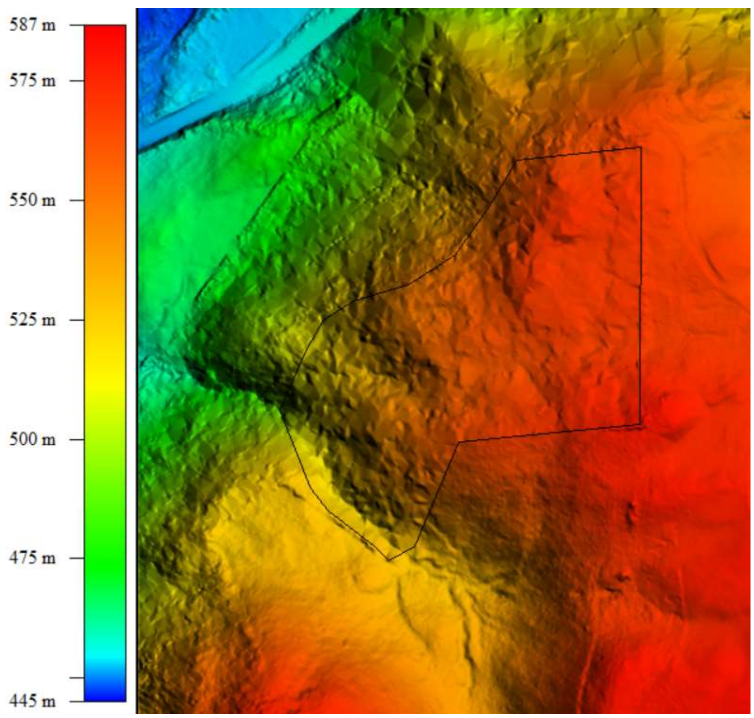


Figure 54: BH35_1000_0211 After

### 6.5.7 Intensity anomalous low values

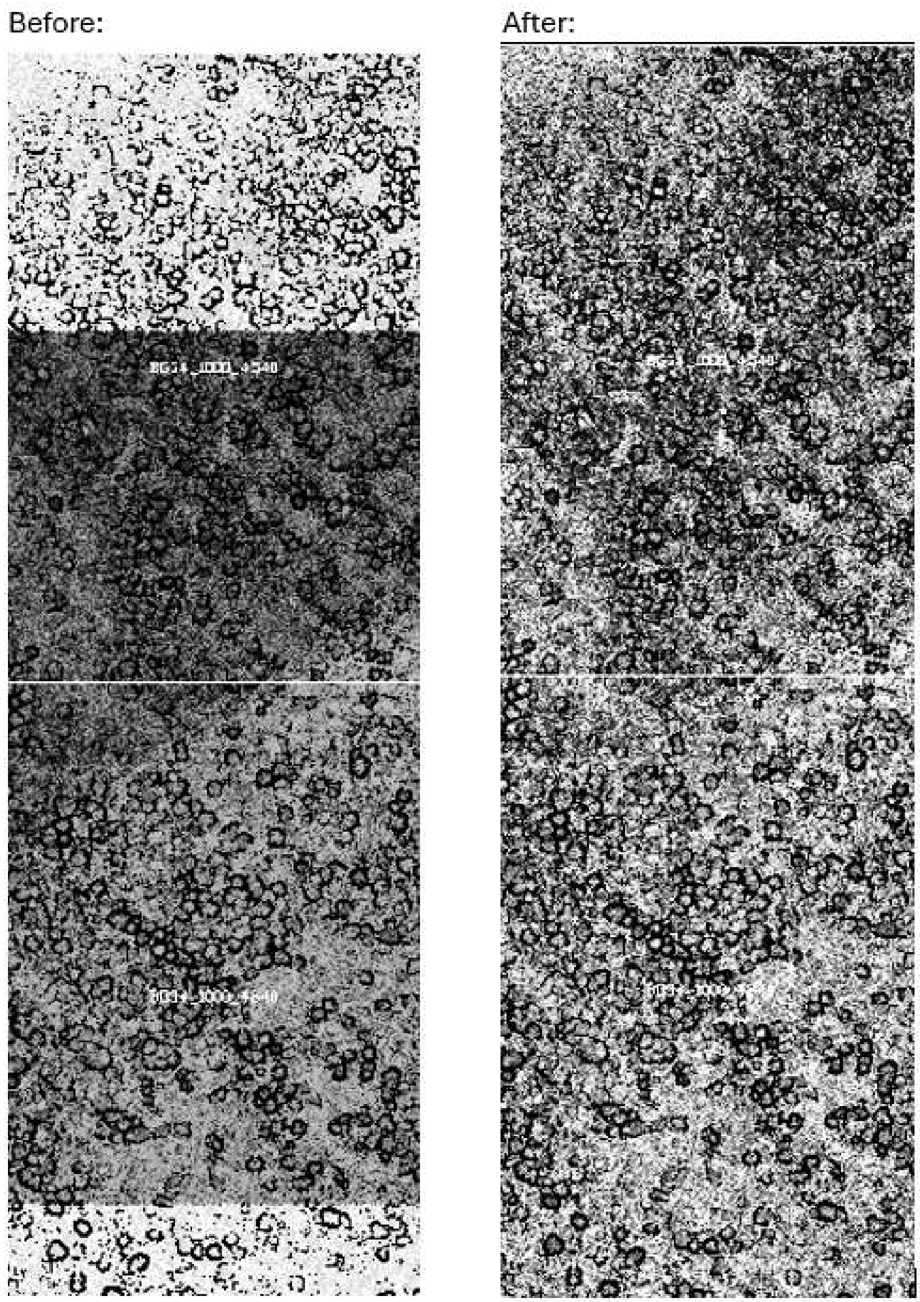


Figure 55: Tiles BG34_1000_4540 & BG34_1000_4640

### 6.5.8 Null pixel in DSM

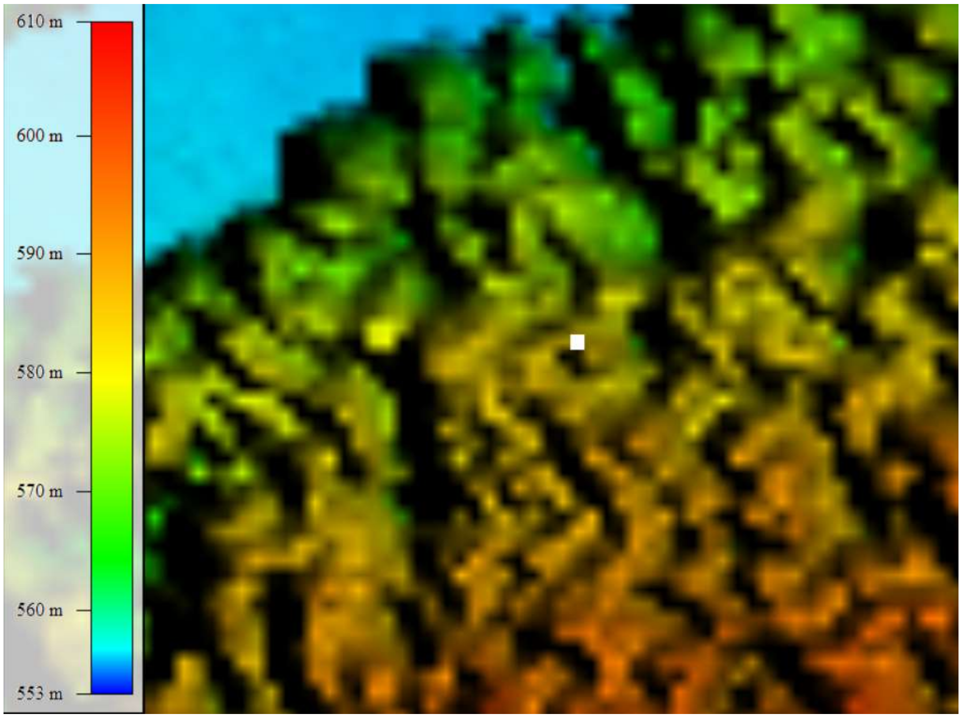


Figure 56: BG35_1000_2805 Before

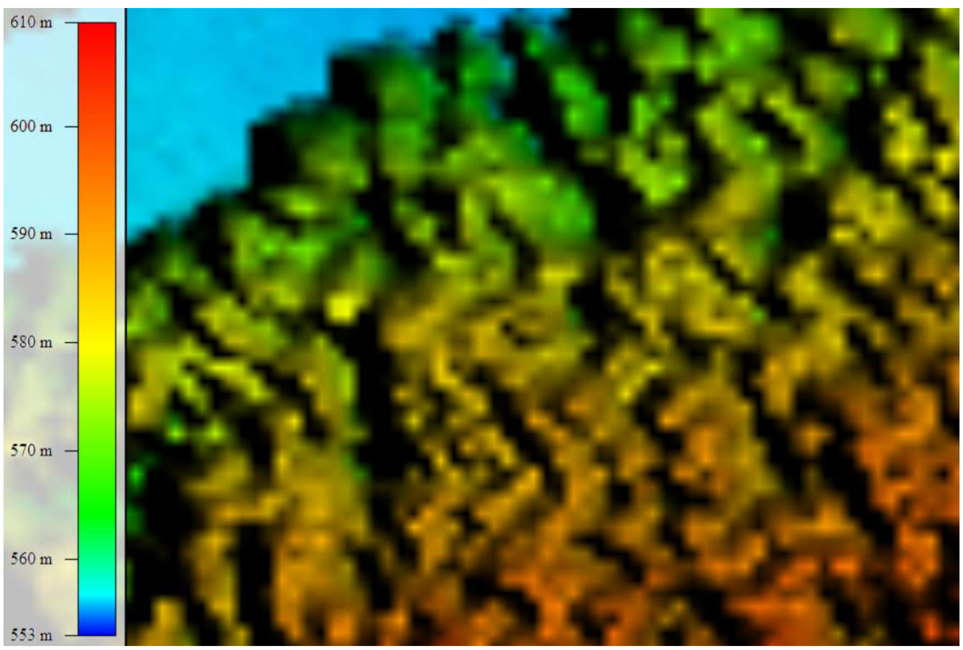


Figure 57: BG35_1000_2805 After

## 6.6 Examples of Corrections after rework and resupply

The following pages are examples of defects that were identified by WRC and or LINZ and how they were rectified. This was following the resupply in May 2024.

### 6.6.1 Bridge partially removed

No correction made to Classified LAS as LiDAR points are correctly classified, only hanging part (red dots as shown below) is bridge. However, synthetic points have been added in DEM creation to force triangulation to stop at bridge area.

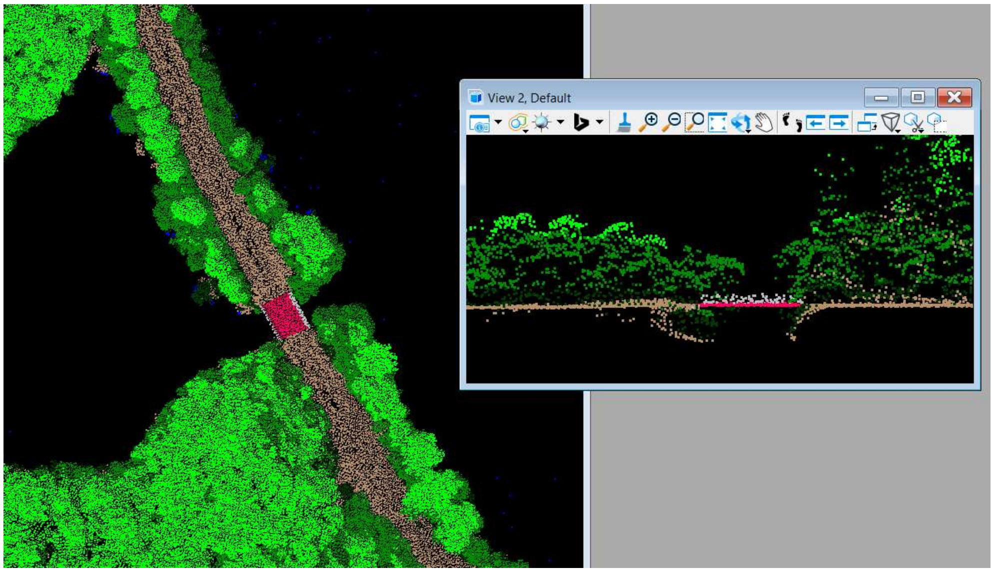


Figure 58: BF35_1000_1214 & BF35_1000_1314 Classified LAS

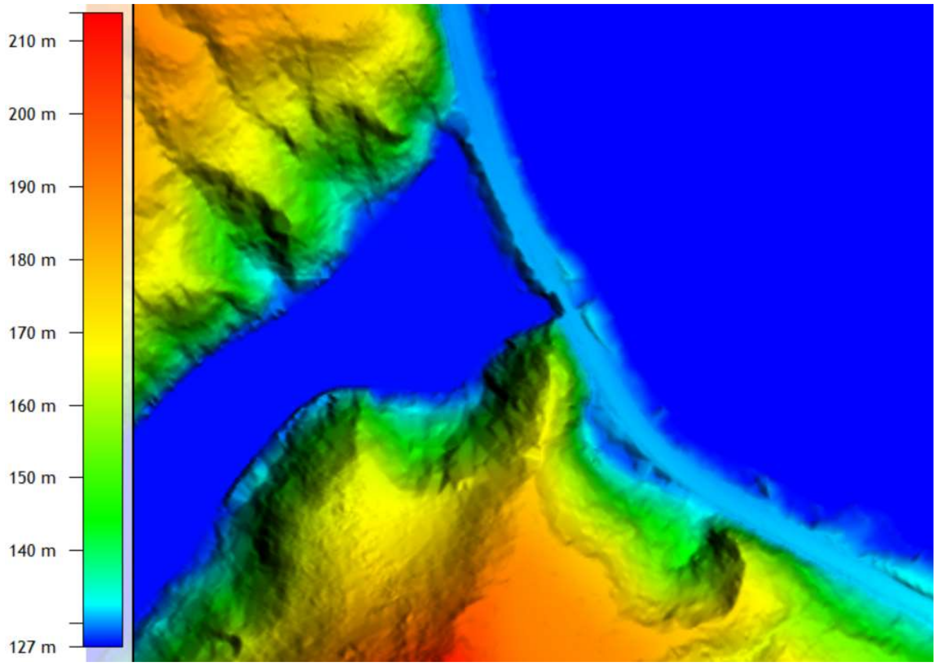


Figure 59: BF35_1000_1214 & BF35_1000_1314 DEM before correction

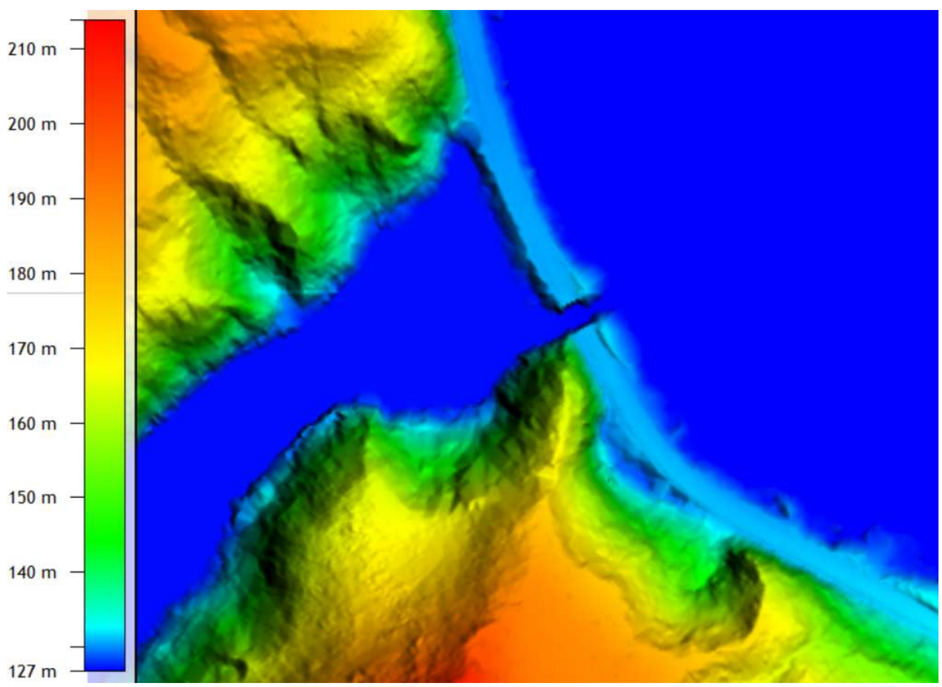


Figure 60: BF35_1000_1214 & BF35_1000_1314 DEM after correction

### 6.6.2 Unnecessary fix for DEM under forestry

Dense under-brush / borage / slash was judged to be out of scope. Low Vegetation reclassified back to ground and all products resupplied.

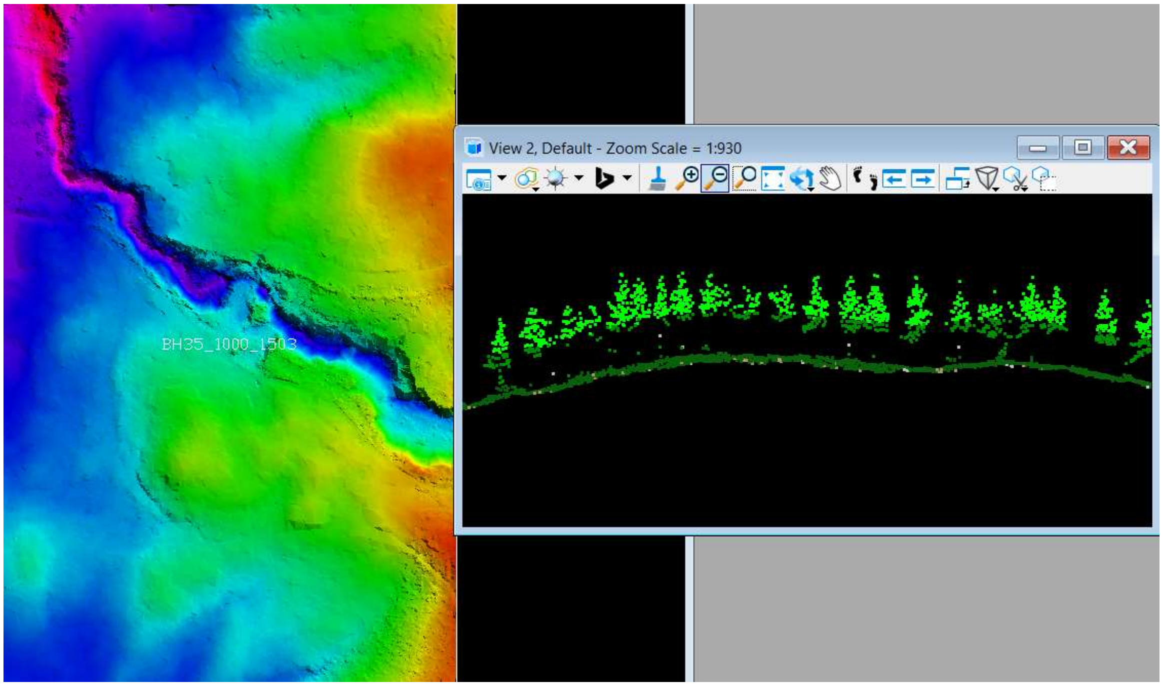


Figure 61: BH35_1000_1503 Classified LAS before correction

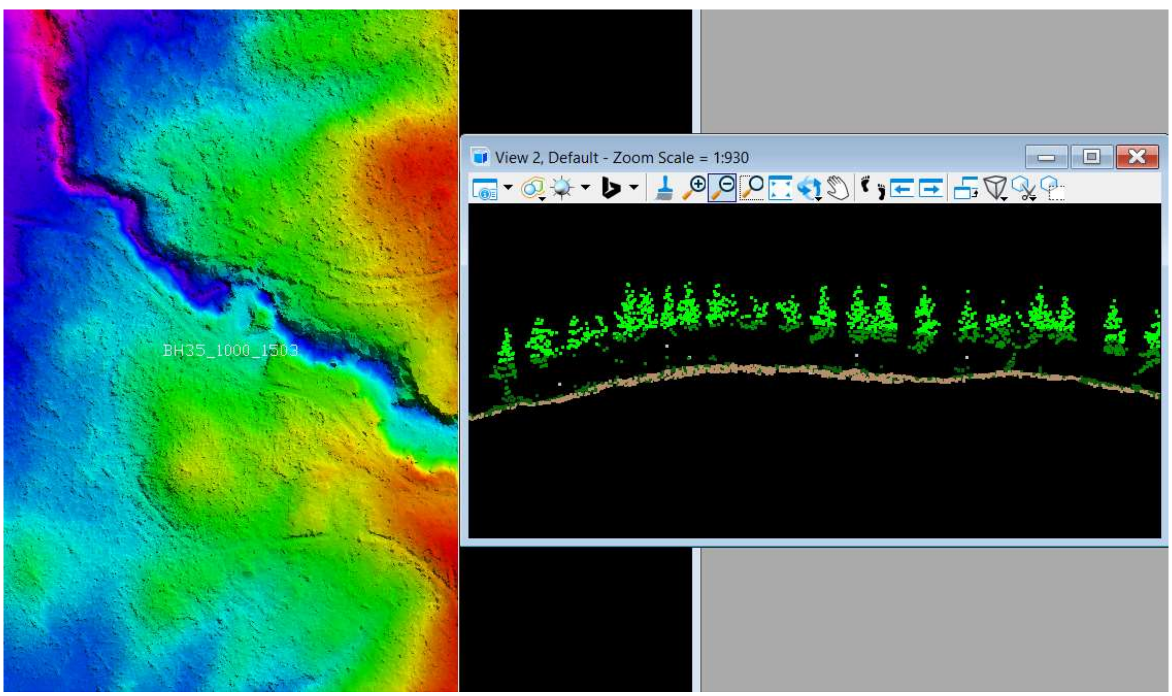


Figure 62: BH35_1000_1503 Classified LAS after correction

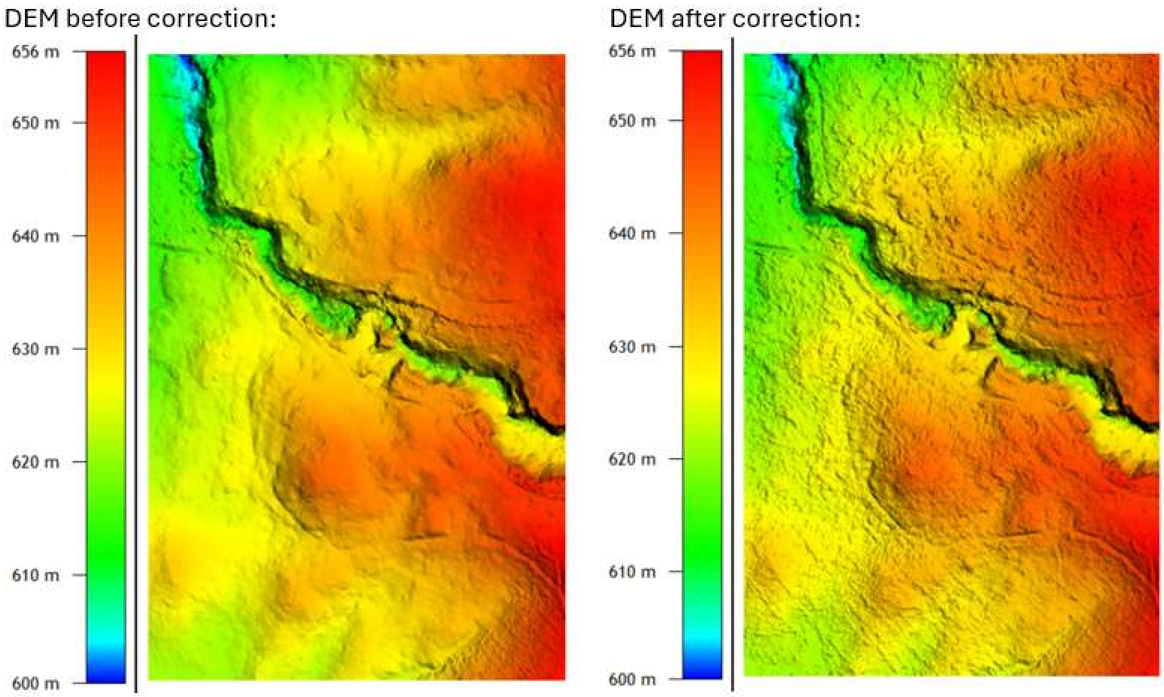


Figure 63: BH35_1000_1503 DEM

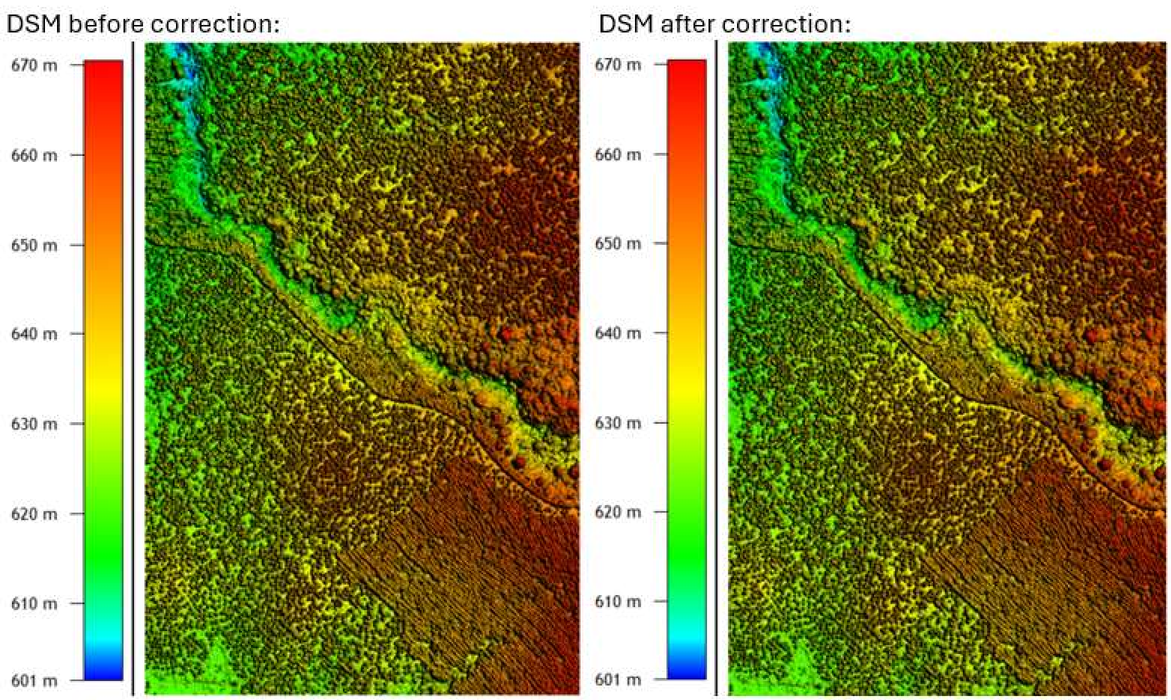


Figure 64: BH35_1000_1503 DSM

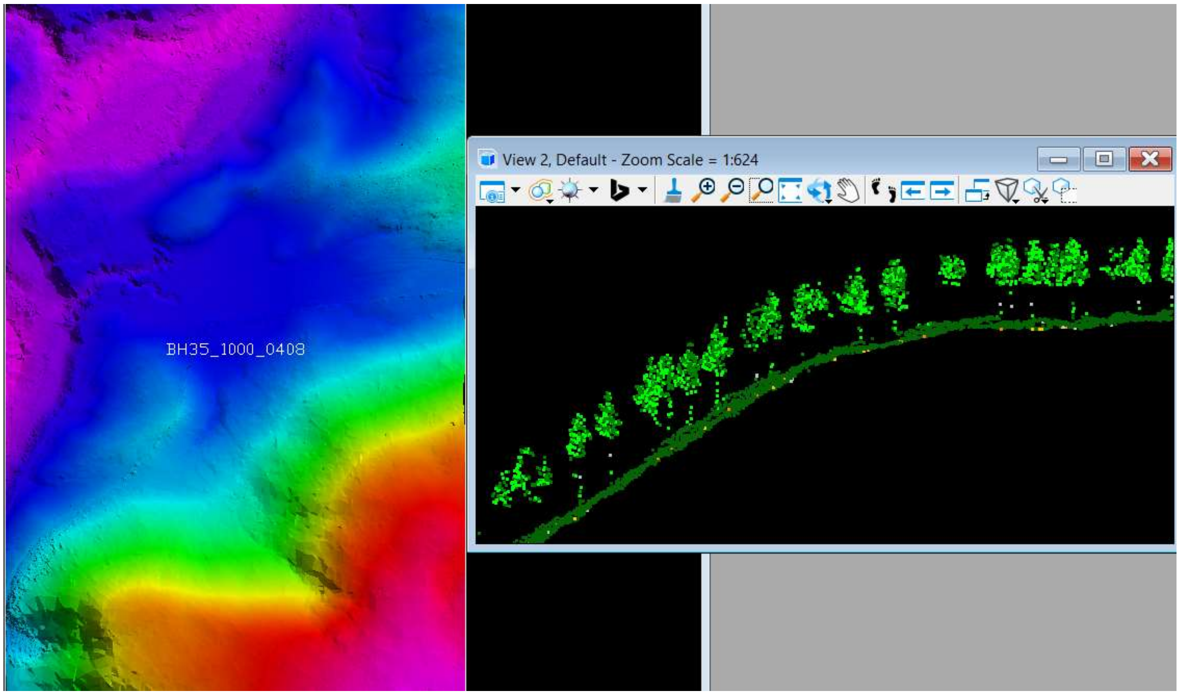


Figure 65: BH35_1000_0408 Classified LAS before correction

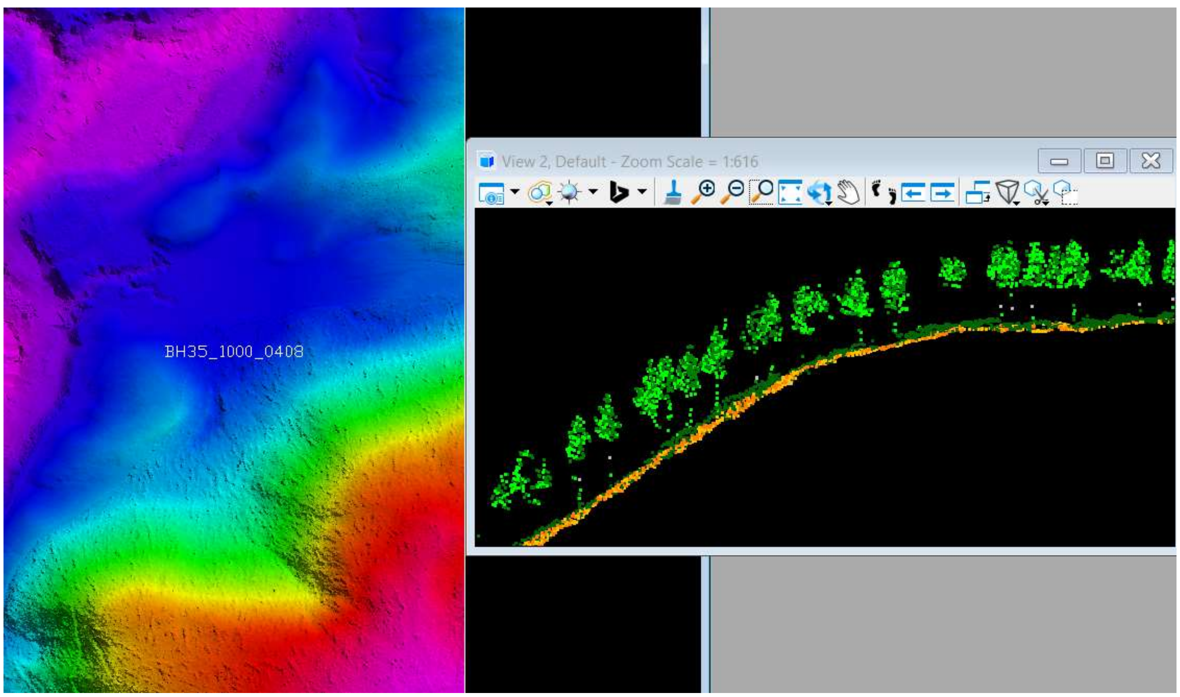


Figure 66: BH35_1000_0408 Classified LAS after correction

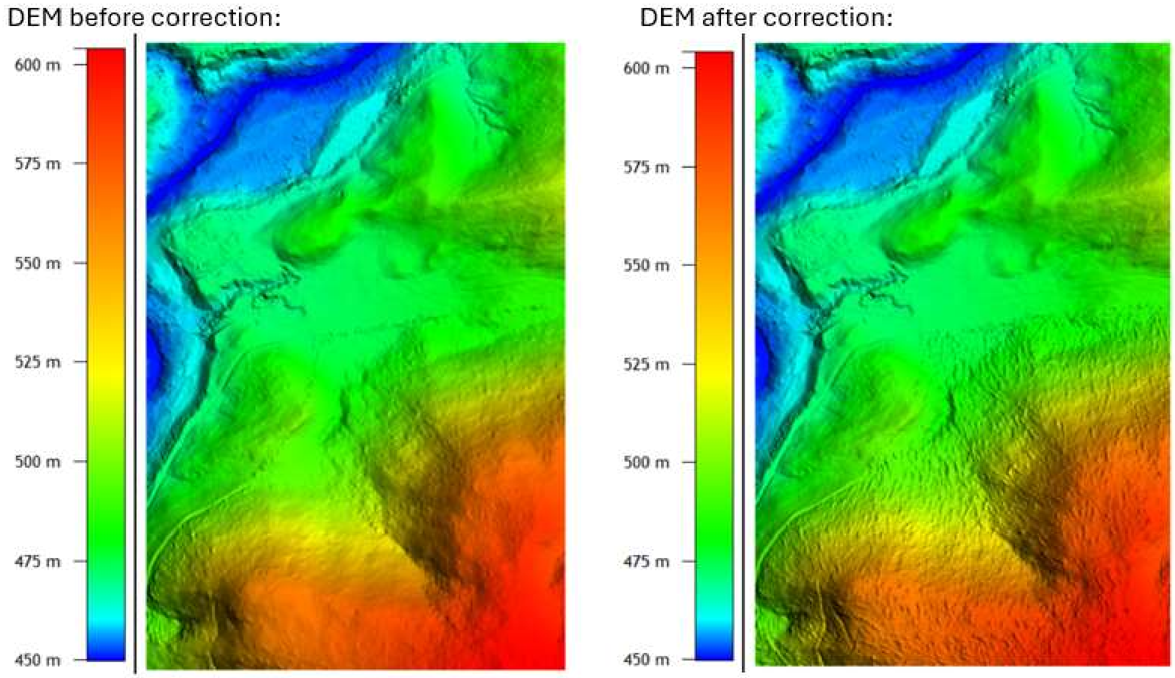


Figure 67: BH35_1000_0408 DEM

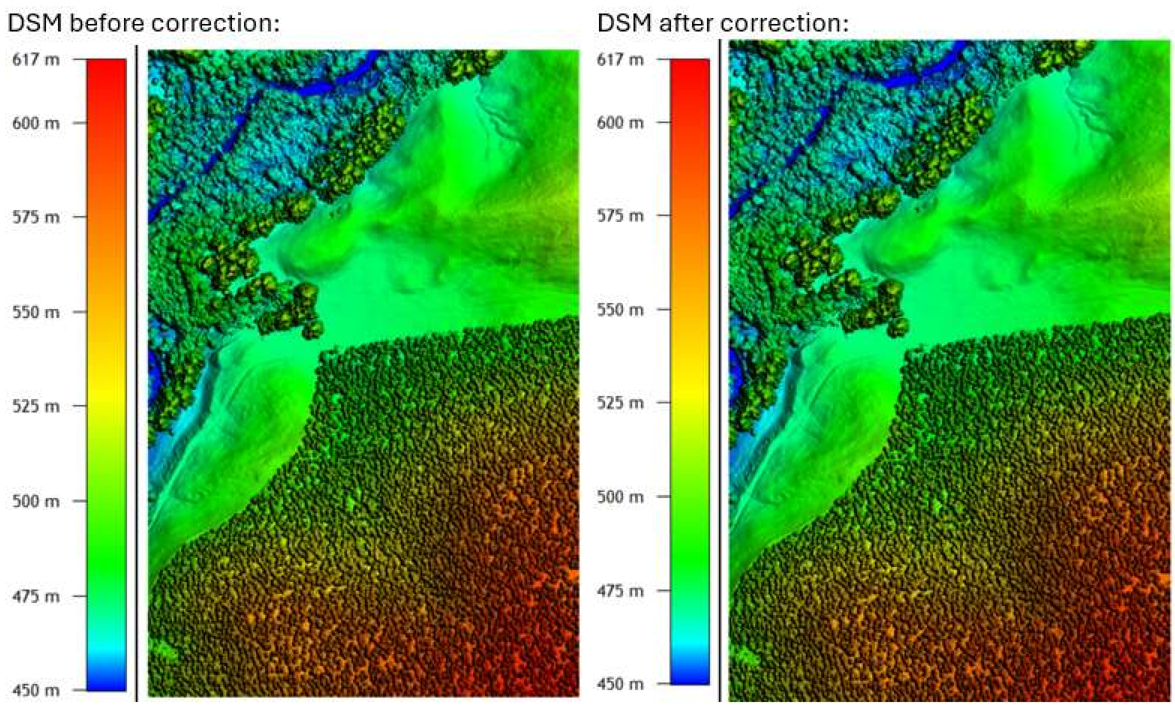


Figure 68: BH35_1000_0408 DSM

### 6.6.3 DEM artefact – Hydro Flattening

Hydro grids added in DEM creation.

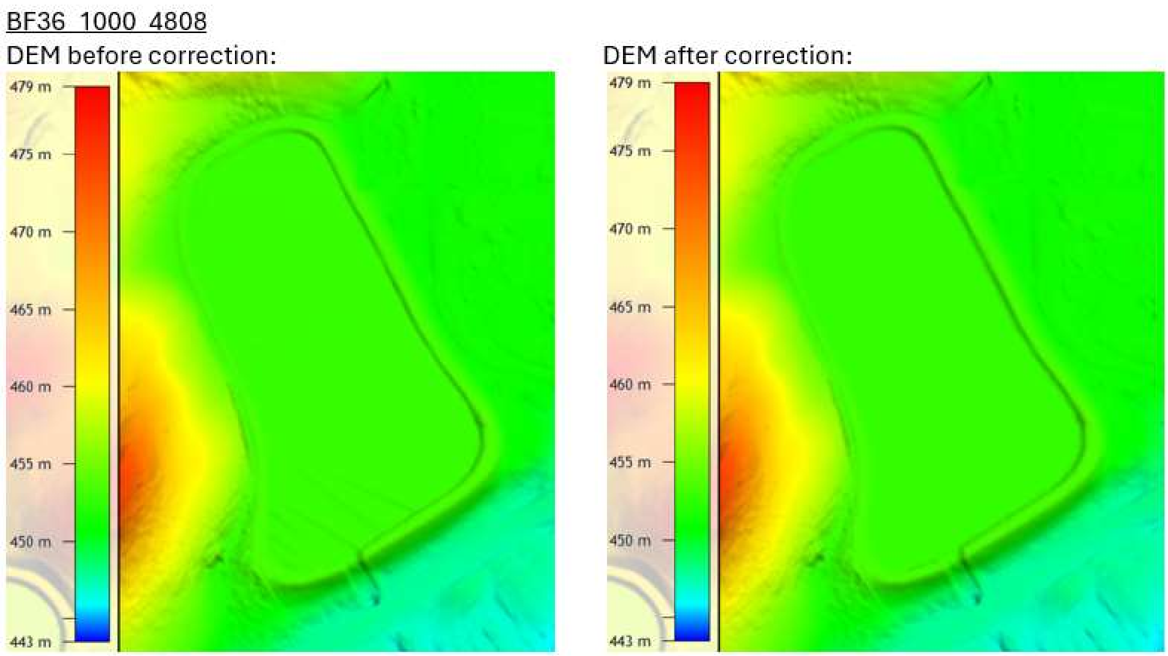


Figure 69: BF36_1000_4808 DEM

### 6.6.4 Hydro Flattening

Hydroflatten DEM to bank edge.

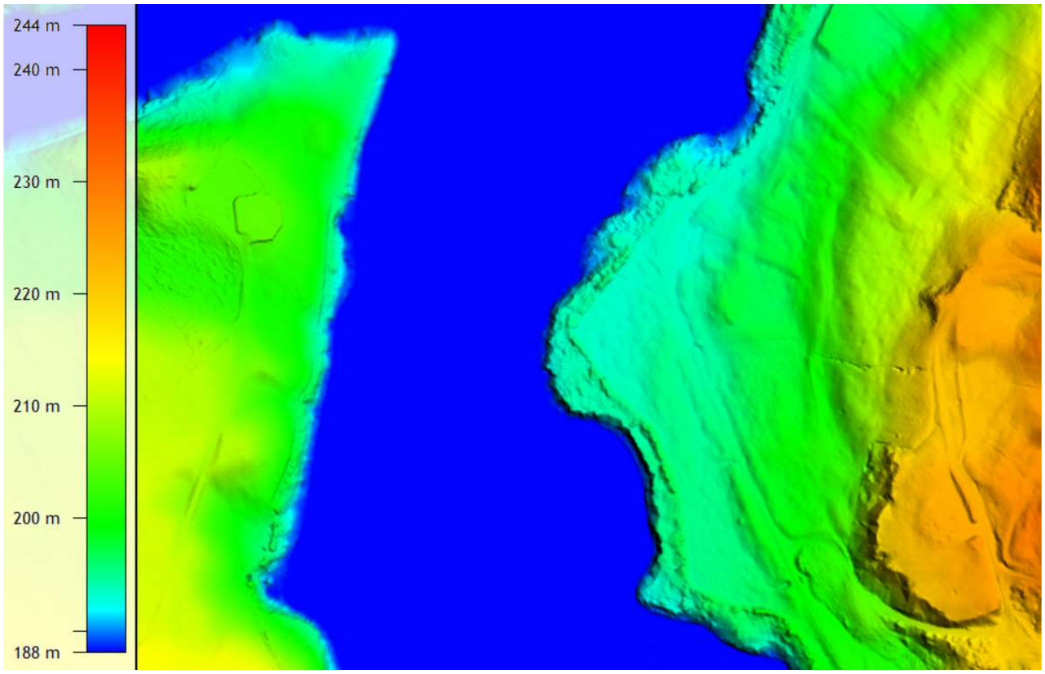


Figure 70: BF35_1000_2729 & BF35_1000_2730 DEM before correction

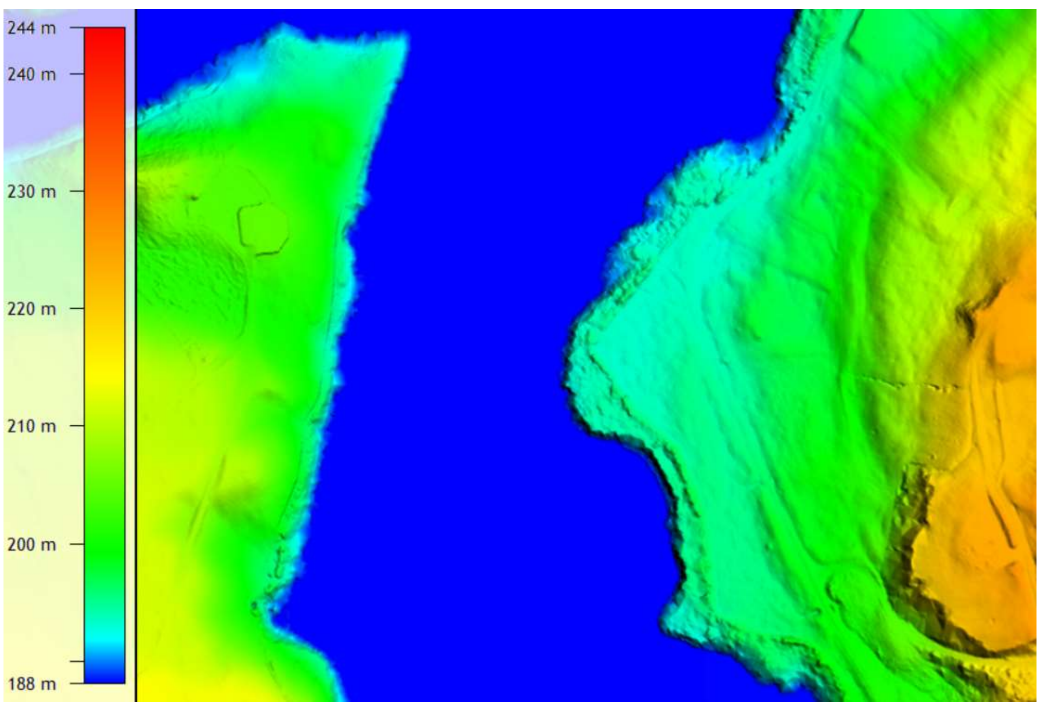


Figure 71: BF35_1000_2729 & BF35_1000_2730 DEM after correction

### 6.6.5 DEM artefact - vegetation/croppage

Low vegetation removed from ground class as best as possible.

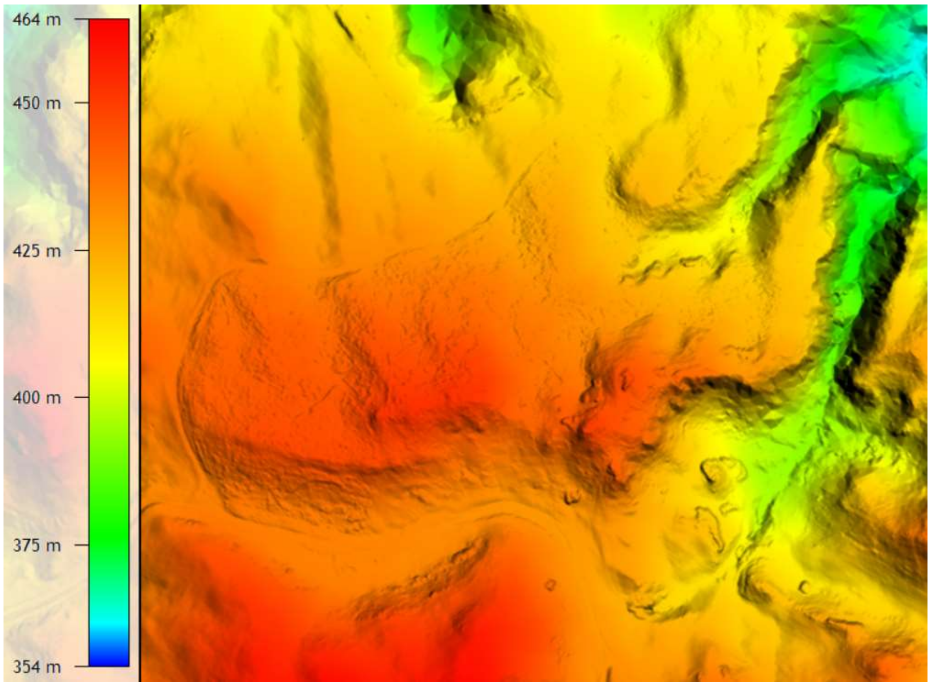


Figure 72: BF35_1000_4120 & BF35_1000_4121 DEM before correction

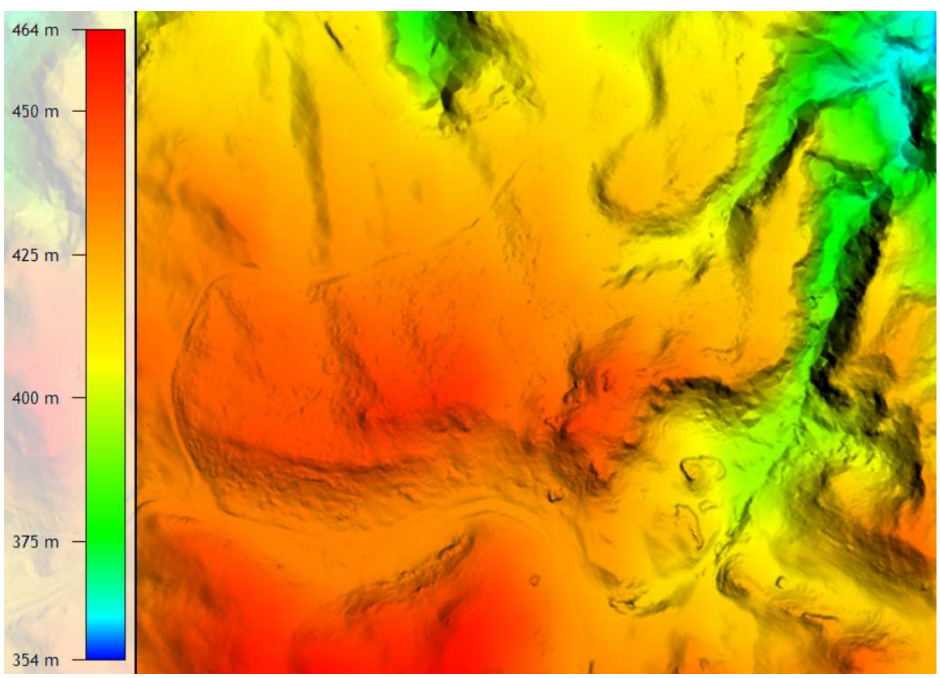


Figure 73: BF35_1000_4120 & BF35_1000_4121 DEM after correction

### 6.6.6 DSM artefact - tinned where PC shows building classification

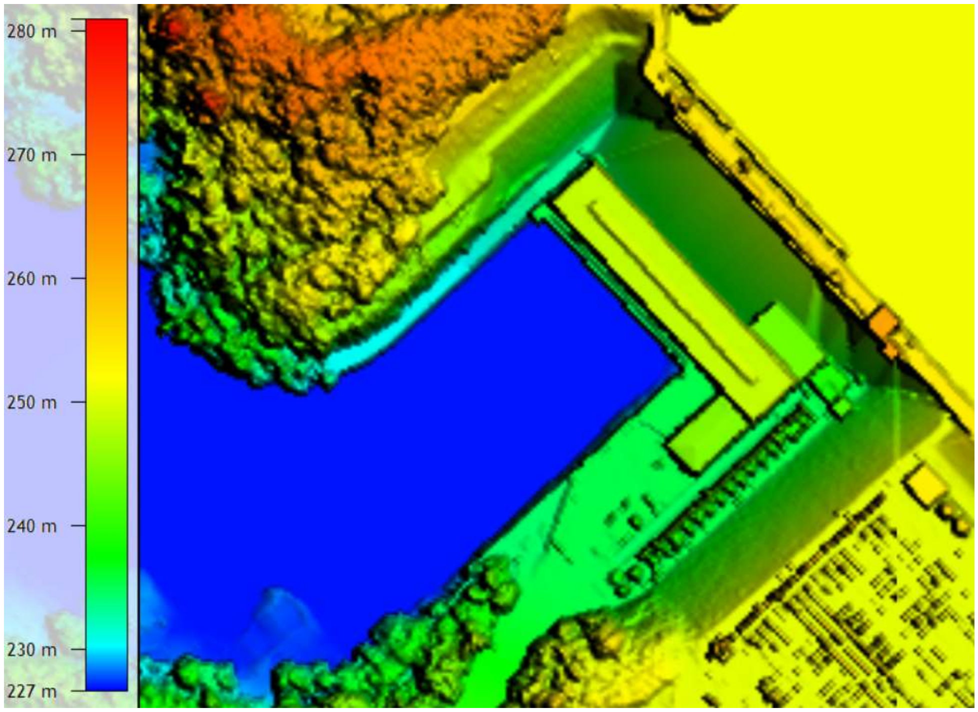


Figure 74: BF36_1000_2825 & BF36_1000_2826 DSM before correction

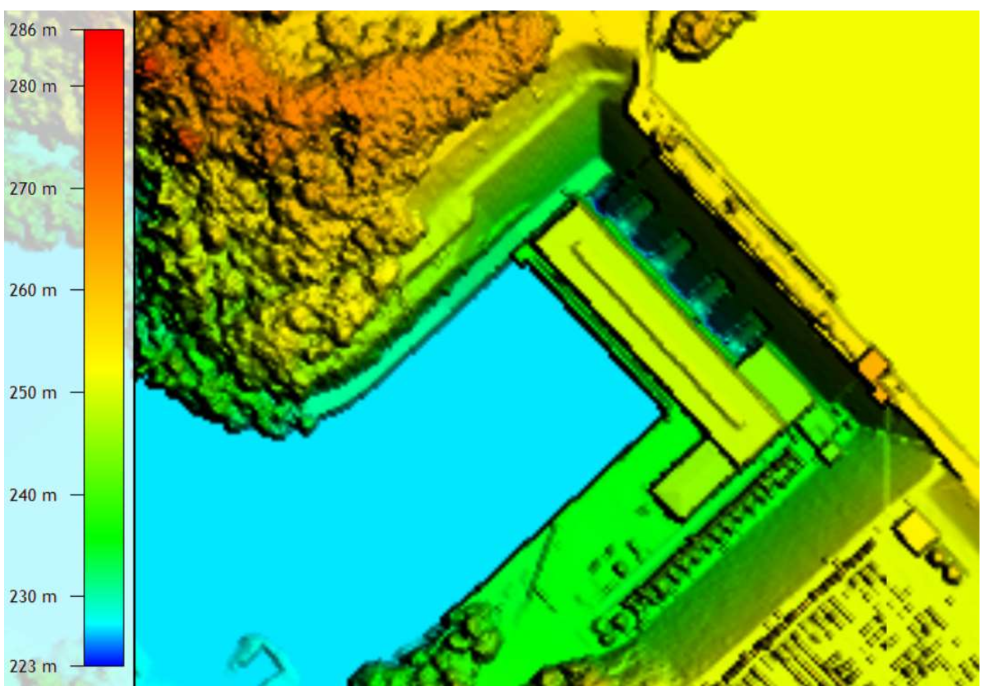


Figure 75: BF36_1000_2825 & BF36_1000_2826 DSM after correction

### 6.6.7 DSM artefacts - vegetation triangulation where void exist

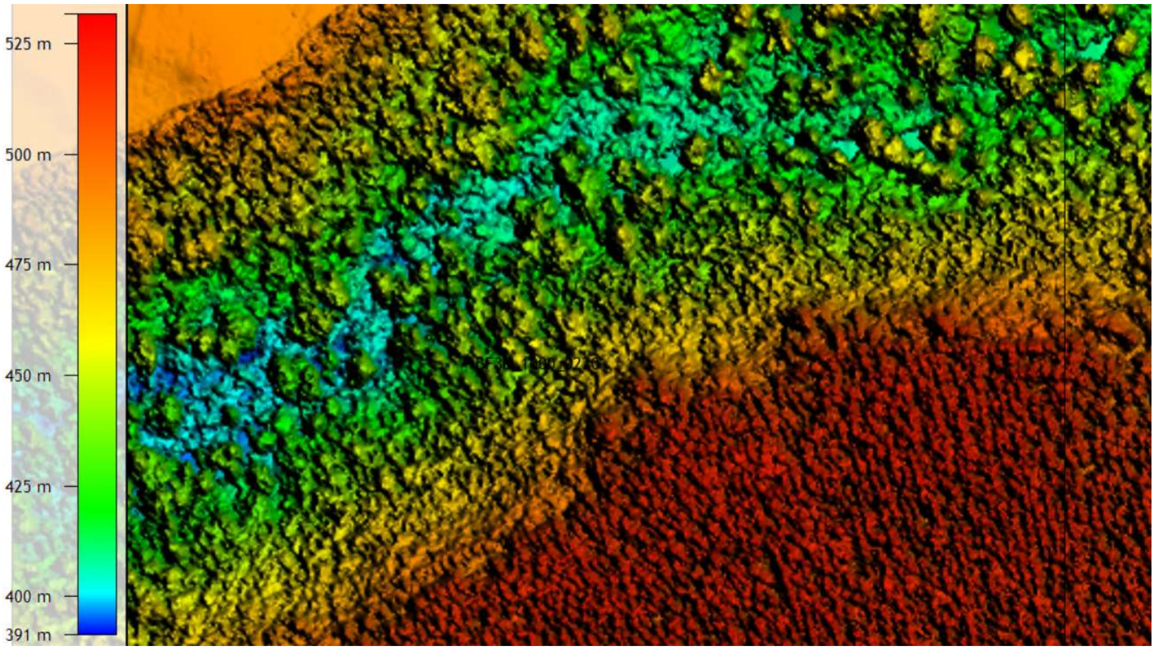


Figure 76: BF36_1000_0220 & BF36_1000_0221 DSM before correction

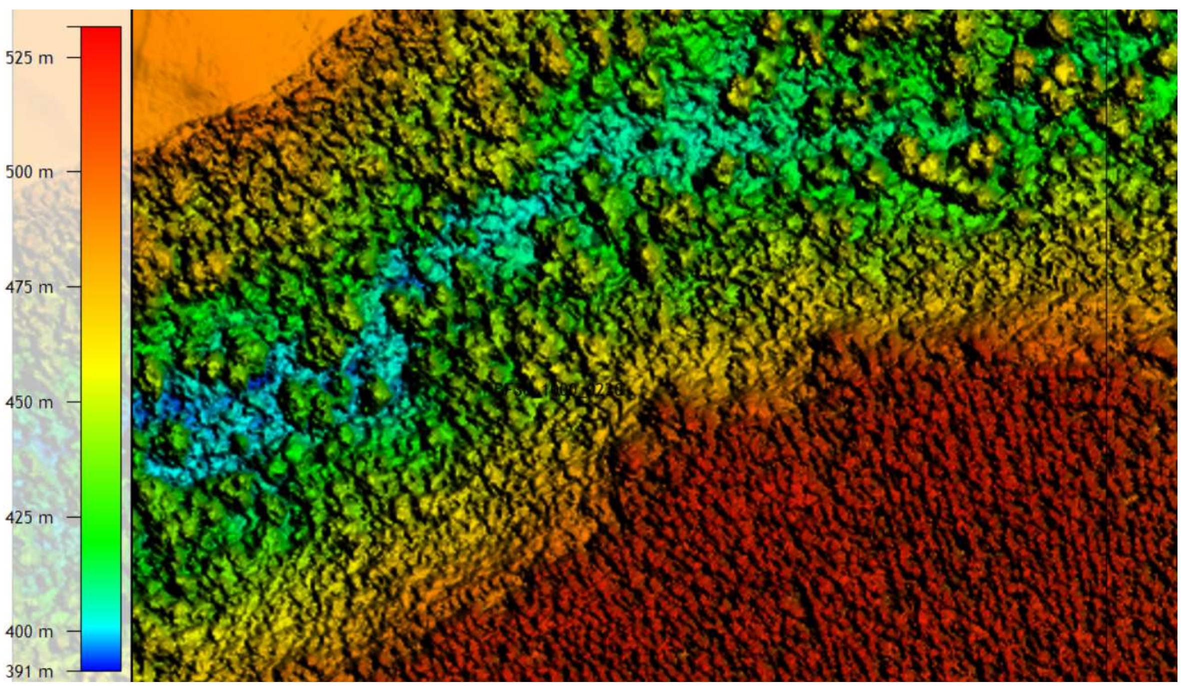


Figure 77: BF36_1000_0220 & BF36_1000_0221 DSM after correction

# 7 Results Acceptance & Signoff

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

| Result Acceptance | | | |
|---|---|---|---|
| Assessment Criteria | Status | Completed By | Date |
| Point cloud classification accuracy | Complete | Woolpert/ AAM | 12 March 2024 |
| Point cloud classification consistency | Complete | Woolpert/ AAM | 12 March 2024 |
| Point Cloud LAS tiled deliverables | Complete | Woolpert/ AAM | 12 March 2024 |
| Hydro-flattened Digital Elevation Models | Complete | Woolpert/ AAM | 12 March 2024 |
| Digital Survey Models | Complete | Woolpert/ AAM | 12 March 2024 |
| Contours | Complete | Woolpert/ AAM | 12 March 2024 |
| Extents, Flight Lines, Break lines, Tile Index | Complete | Woolpert/ AAM | 12 March 2024 |
| | | | |
| Project Manager / Supervisor Signoff | Complete | Luke Graham | 12 March 2024 |
| Ocean Infinity Review | Complete | Luke Leydon | 07 April 2024 |

*Table 7: Processing Results Acceptable Signoff*

| Result Acceptance | | | |
|---|---|---|---|
| Assessment Criteria | Status | Completed By | Date |
| Point cloud classification accuracy | Complete | Woolpert/ AAM | 15 May 2024 |
| Point cloud classification consistency | Complete | Woolpert/ AAM | 15 May 2024 |
| Point Cloud LAS tiled deliverables | Complete | Woolpert/ AAM | 15 May 2024 |
| Hydro-flattened Digital Elevation Models | Complete | Woolpert/ AAM | 15 May 2024 |
| Digital Survey Models | Complete | Woolpert/ AAM | 15 May 2024 |
| Contours | Complete | Woolpert/ AAM | 15 May 2024 |
| Extents, Flight Lines, Break lines, Tile Index | Complete | Woolpert/ AAM | 15 May 2024 |
| | | | |
| Project Manager / Supervisor Signoff | Complete | Luke Graham | 15 May 2024 |
| Ocean Infinity Review | Complete | Luke Leydon | 01 June 2024 |

*Table 8: Processing Results Acceptable Signoff (Rev 1)*

# Appendix A: Lidar Quality Assurance Results

Provided as separate Documents in Appendix A upload

# Waikato Local Authority Shared Services (WLASS) / CoLAB LiDAR Data Capture Services

# LiDAR Processing Report Block E South

Contract Number: AU411

Surveyed By: iXblue Pty Ltd / Ocean Infinity

Processing Completed By: Woolpert USA and Woolpert Australia

Prepared For: Colab (formerly WLASS)

Document Date: 6 June 2024

Ocean Infinity (Australia) Pty Ltd
ABN 61 128 811 978
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## Document Revision

| Revision No | Issue Purpose | Prepared | Checked | Approved |
|---|---|---|---|---|
| 0 | Issue LiDAR Processing Report | L Leydon | L Graham | D Field |
| | | | | |
| | | | | |
| | | | | |

## Approval for Issue

| Name | Signature | Date |
|---|---|---|
| Luke Leydon |  | 06 June 2024 |

# Revision History

| Item | Description of change | Section | Revision |
|---|---|---|---|
| 1 | New Introduction | 1.1 | 1 |
| 1 | Las stats for revision included | Figure 11 | 1 |
| 1 | New LP360 tables added | 4 | 1 |
| 1 | Contours methodology updated | 4.7 | 1 |
| 1 | New sections added to setbacks and solutions | 6.4 | 1 |
| 1 | New results signoff table added | 7 | 1 |

# Contents

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# Figures

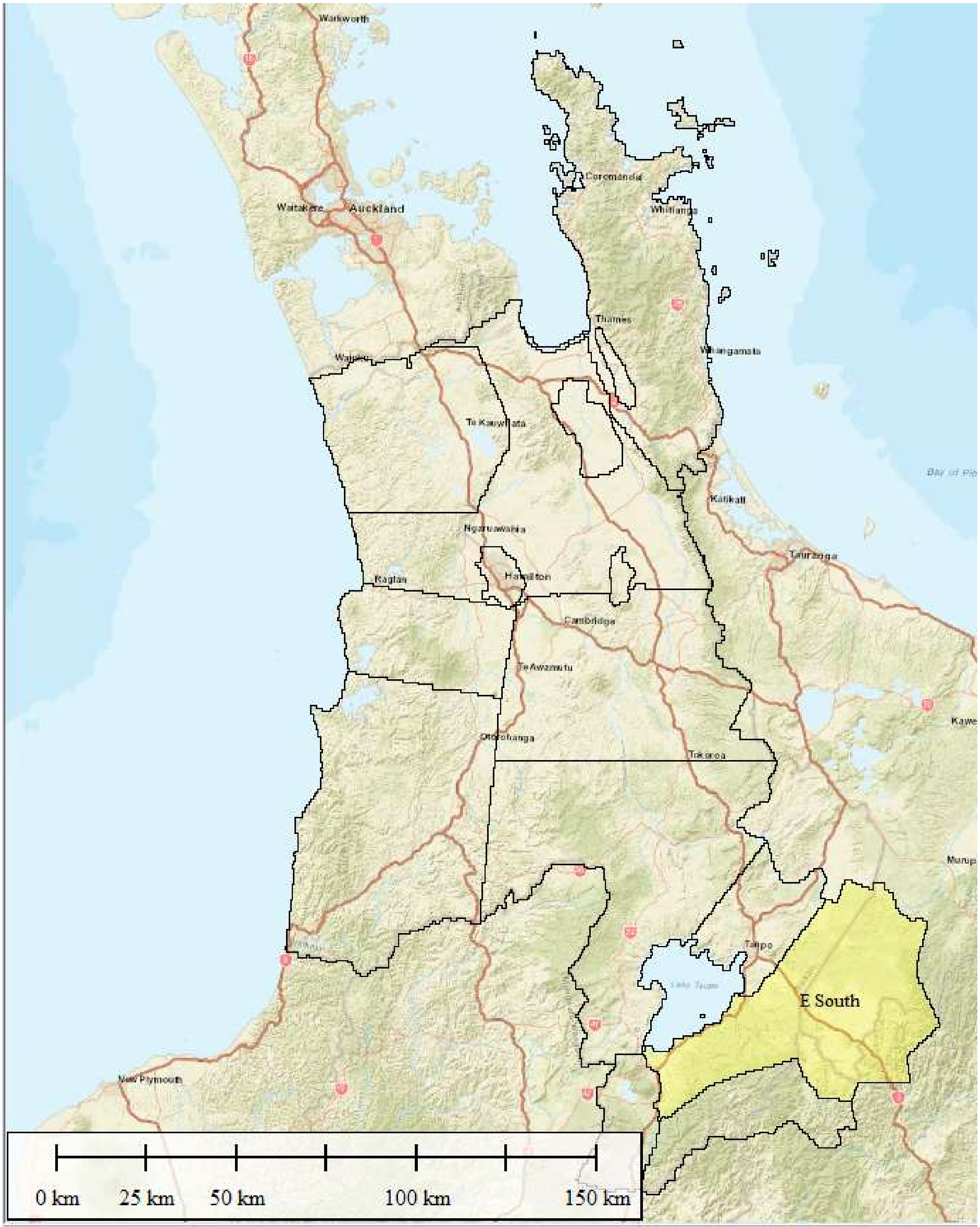



*Figure 1: Waikato Survey Area*

# 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

- AU411_WLASS-Collection_Report-10052021.pdf.

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 E South, as illustrated in yellow in Figure 1 - Waikato Survey. Block E was split into three during processing due to the size, 10,180km$^2$. Block E North (1), Block E North (2) and Block E South are the splits.

This dataset was uploaded by Woolpert Australia in parts completing Friday 10 November 2023. This was transferred to Waikato Regional Council (WRC) Monday 13 November 2023.

## 1.1 Revision 1 Introduction

E south was subject to two further resupplies on Wednesday 20 March and a final resupply post rework on Friday 17$^{th}$ of May.

The failure and subsequent resupply were accompanied by a spreadsheet and returned with comments. 'LINZ_QC_Block_E_South_180424'.

This listed the failures and improvements required. It was supported by Geospatial files which showed the areas of failures.

Thanks go to Emory Beck at LINZ for assistance with corrections to this dataset allowing publication.

# 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).

https://www.linz.govt.nz/system/files_force/media/doc/pgf_version_new_zealand_national_aerial_lidar_base_specification.pdf?download=1

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:

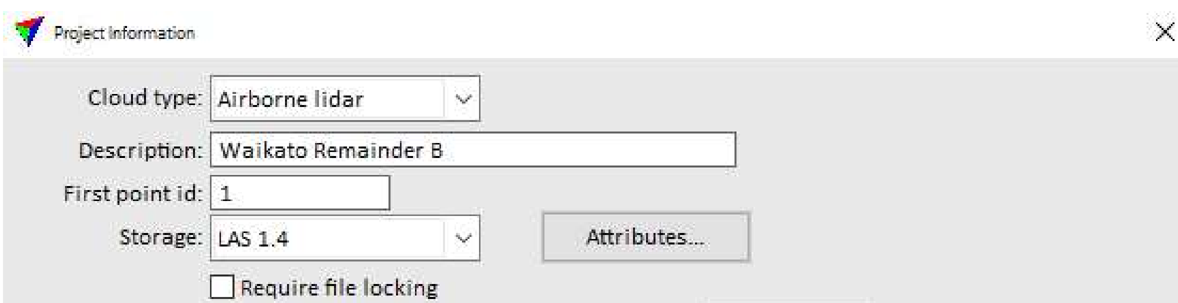



*Figure 2: LAS 1.4 being specified during project – example*

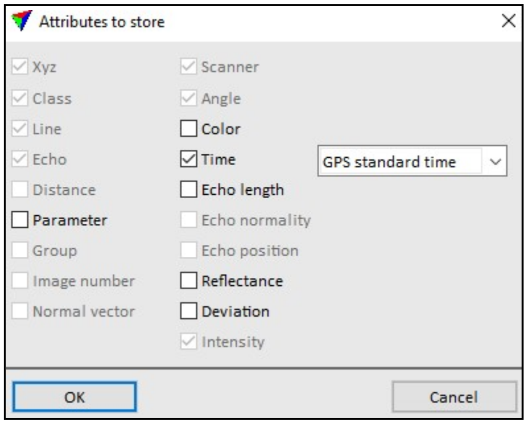
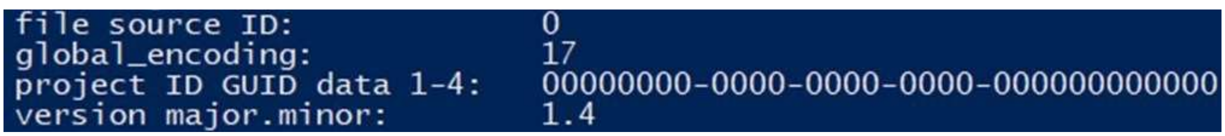



*Figure 3: Project settings used in TerraScan project when importing points into the project.*

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.



```
file source ID:              0
global_encoding:             17
project ID GUID data 1-4:    00000000-0000-0000-0000-000000000000
version major.minor:         1.4
```

*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)

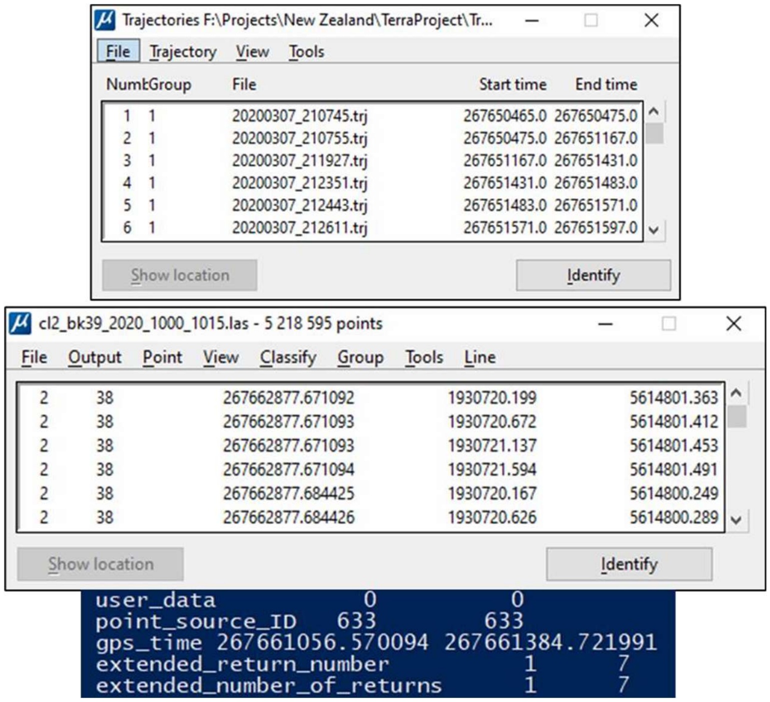



*Figure 5: Representative examples of LAS point attributes*

## 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.

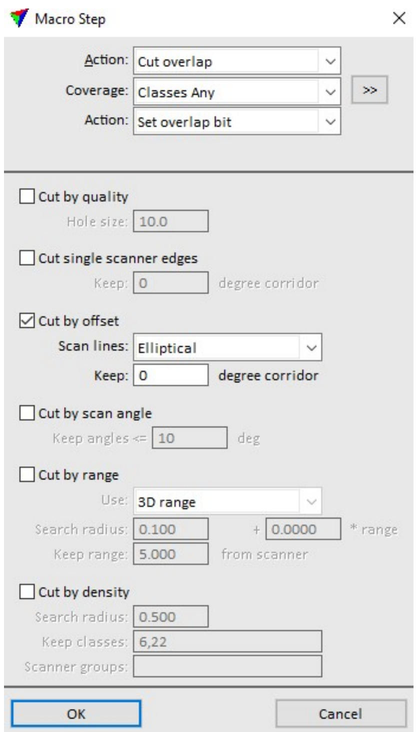



*Figure 6: Settings used when cutting overlap in Microstation.*

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:

| Code | Description |
|---|---|
| 1 | Processed, but unclassified |
| 2 | Ground |
| 3 | Low vegetation <2m |
| 4 | Medium vegetation |
| 5 | High vegetation >8m |
| 6 | Building |
| 7 | Low noise |
| 9 | Water |
| 17 | Bridge deck |
| 18 | High noise |

*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.

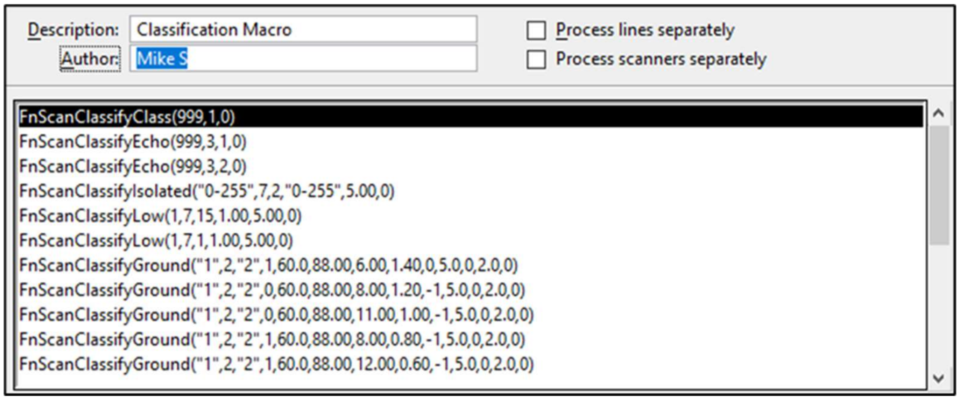



*Figure 7: Automatic classification macro developed for the project area.*

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.

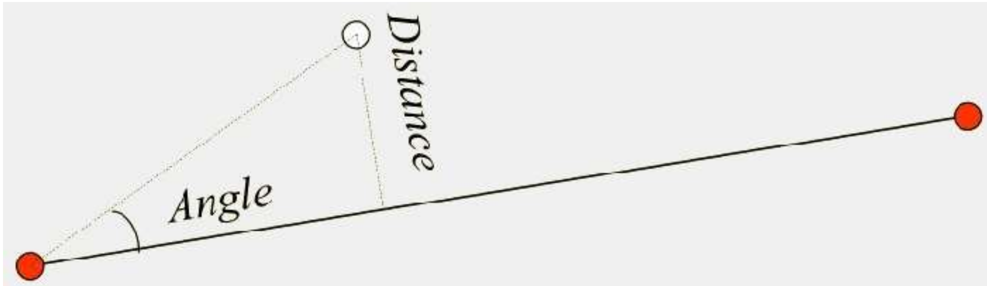



*Figure 8: Illustration of iteration angle and iteration distance parameters in the ground routine.*

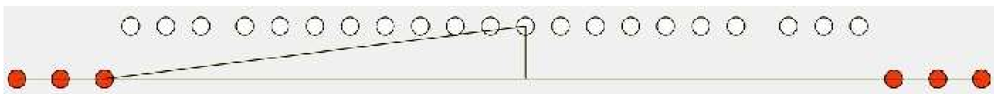


*Figure 9: A smaller iteration distance value avoids classification of ground points on low objects.*

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 or LASTools as illustrated in the figure below.

```
histogram of classification of points:
       1262740  unclassified (1)
    7735746866  ground (2)
    3740813907  low vegetation (3)
    5679900409  medium vegetation (4)
   13090498621  high vegetation (5)
       9115015  building (6)
    1343067849  noise (7)
       1645643  water (9)
         97494  bridge deck (17)
     143428238  Reserved for ASPRS Definition (18)
 +-> flagged as withheld:  1486496087
  +--->      1343067849 of those are noise (7)
  +--->       143428238 of those are Reserved for ASPRS Definition (18)
 +-> flagged as extended overlap: 12378112493
  +--->          440650 of those are unclassified (1)
  +--->      2811890214 of those are ground (2)
  +--->      1519516029 of those are low vegetation (3)
  +--->      2149944632 of those are medium vegetation (4)
  +--->      5170533888 of those are high vegetation (5)
  +--->         5037746 of those are building (6)
  +--->       701176954 of those are noise (7)
  +--->          598173 of those are water (9)
  +--->           51474 of those are bridge deck (17)
  +--->        18922733 of those are Reserved for ASPRS Definition (18)
```

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

```
        973344  unclassified (1)
    3861231281  ground (2)
     844526449  low vegetation (3)
    1141496319  medium vegetation (4)
    1838800569  high vegetation (5)
       7952009  building (6)
     621962604  noise (7)
        779013  water (9)
         58211  bridge deck (17)
      70532880  Reserved for ASPRS Definition (18)
 +-> flagged as withheld:  692495484
  +--->       621962604 of those are noise (7)
  +--->        70532880 of those are Reserved for ASPRS Definition (18)
 +-> flagged as extended overlap: 3413247520
  +--->          480493 of those are unclassified (1)
  +--->      1478494786 of those are ground (2)
  +--->       365467871 of those are low vegetation (3)
  +--->       459292791 of those are medium vegetation (4)
  +--->       758797611 of those are high vegetation (5)
  +--->         4632322 of those are building (6)
  +--->       328578972 of those are noise (7)
  +--->          289701 of those are water (9)
  +--->           34541 of those are bridge deck (17)
  +--->        17178432 of those are Reserved for ASPRS Definition (18)
```

*Figure 11: Statistics showing the classes of all the LAS points within the project area (Rev 1)*

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.

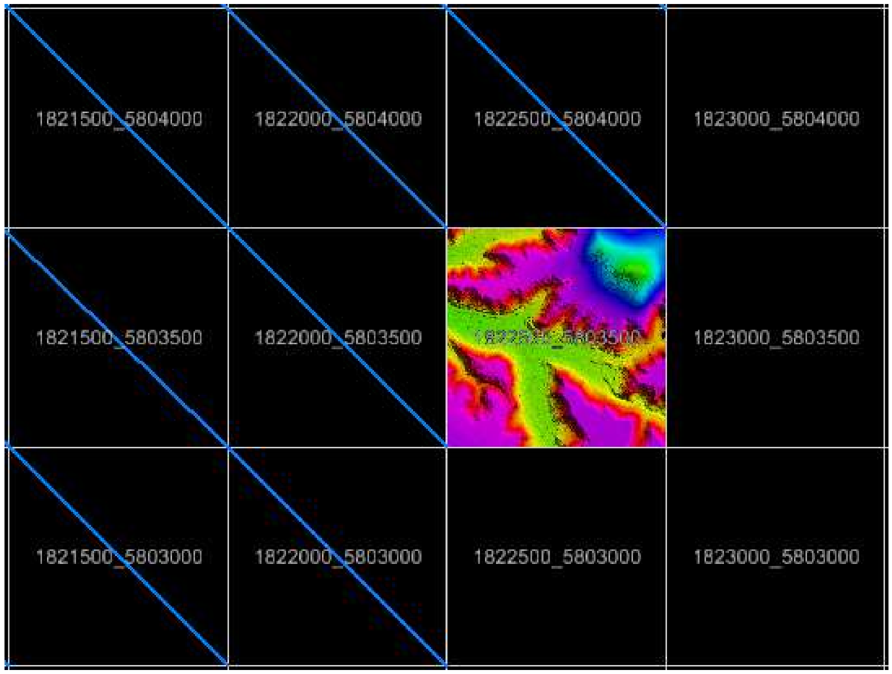



*Figure 12: The diagonal hatching seen above shows how the progress was tracked (example)*

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.

### 2.8.1 Building Classification

The classification of building points has been undertaken by utilizing the TerraScan *buildings* routine. This routine classifies points on buildings which form a planar surface, several rules can be set to fine tune these results including the minimum building size/footprint, z tolerance of the point alignment along the roof line and use of echo information.

The use of echo information can further support the classification as points on roofs mostly belong to the echo type ‘only echo’ whereas vegetation usually contains a lot of ‘first of many’ and ‘intermediate’ echoes.

Additionally, the LINZ building footprint was also integrated into the building classification workflow to further constrain the classification and improve the overall output.

### 2.8.2 Vegetation & Low-Level Noise Classification:

In agreeance with all parties, Woolpert have classified the lower 0 – 0.3m of the low vegetation class to class 7 (low noise).

This was done to effectively remove the lower noise stratification points and unused ground points from class 3 over areas which do not represent vegetation e.g. man-made surfaces and structures (sealed roads).

The remaining vegetation points were classified using TerraScan's classify *by height from ground* which uses the ground surface to calculate the distance of each point above and below ground. All identified vegetation points were classified to the nominated classes using the height ranges specified in the *New Zealand Nation Aerial LiDAR Base Specification* (See below).

**Table 4 Minimum LAS point cloud classification scheme**

| Code | Description |
|---|---|
| 1 | Processed, but unclassified |
| 2 | Ground |
| 3 | Low vegetation <2m |
| 4 | Medium vegetation |
| 5 | High vegetation >8m |
| 6 | Building |
| 7 | Low noise |
| 9 | Water |
| 18 | High noise |

## 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.

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 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.

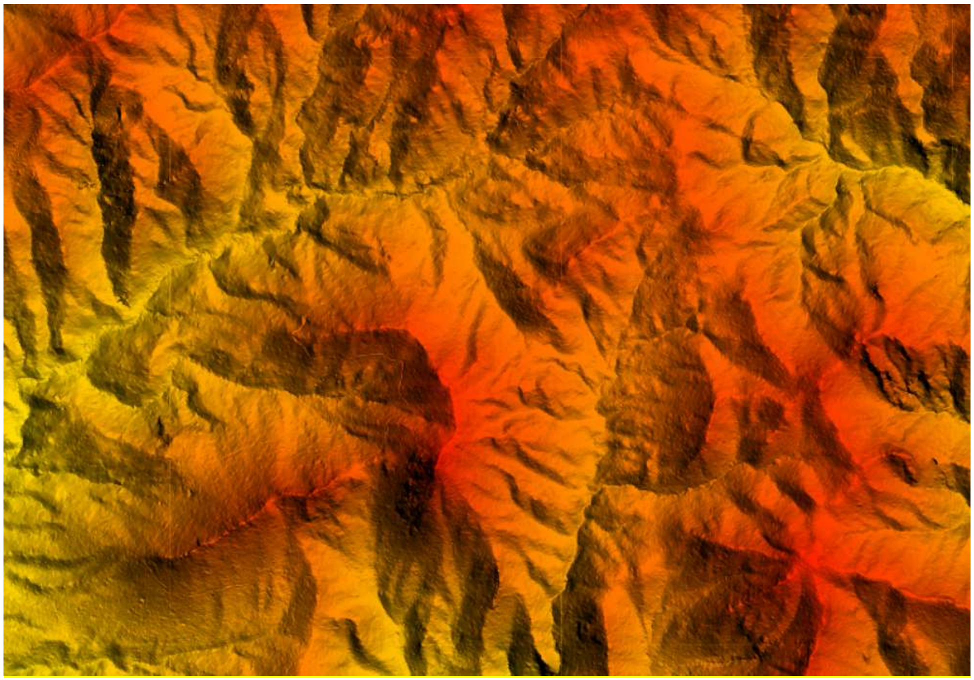


*Figure 13: Example overhead image of DEM over cliffs*

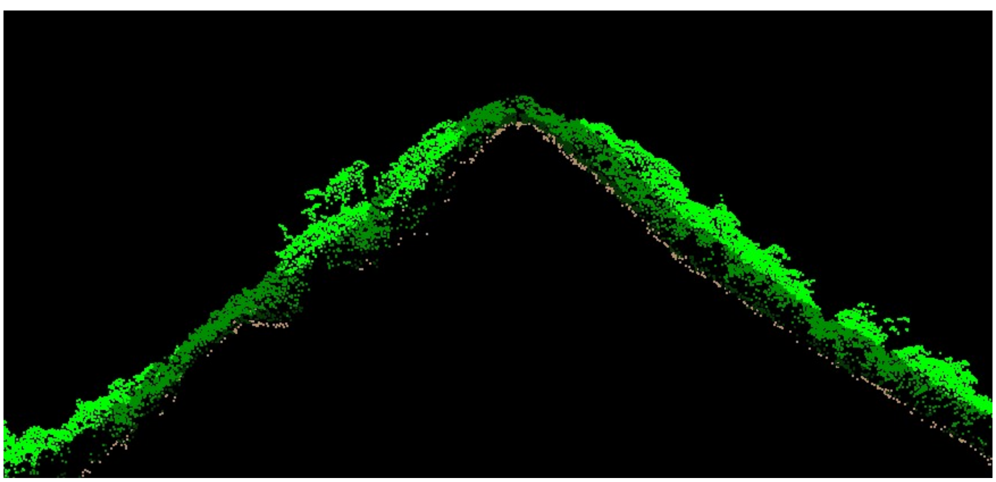


*Figure 14: LAS point cloud profile view from previous figure*

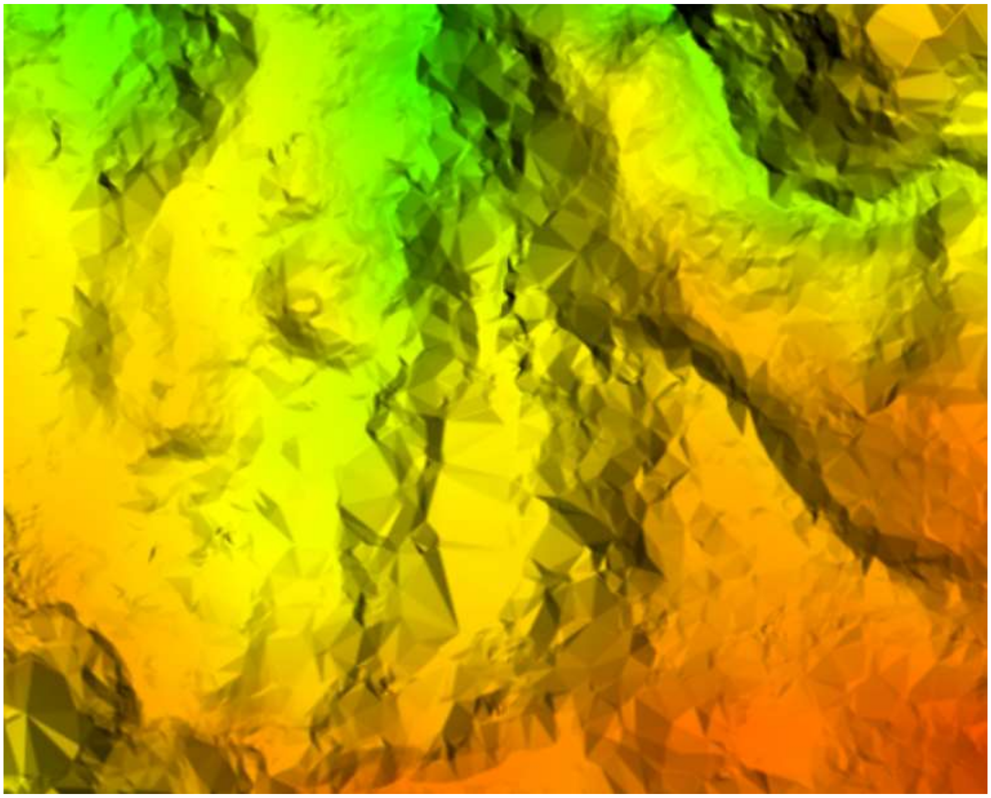


*Figure 15: Example overhead image of DEM interpolation*

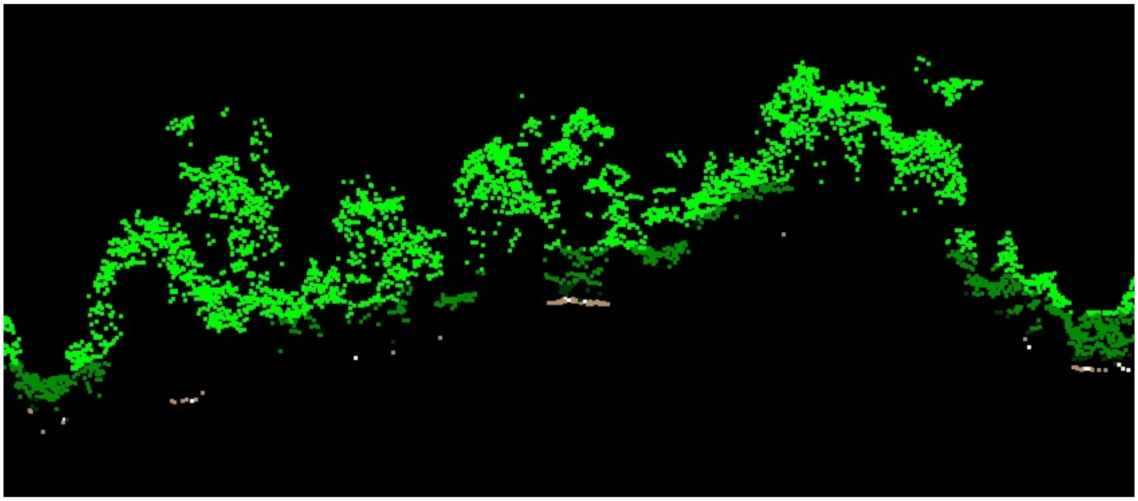


*Figure 16: LAS Point cloud view from previous figure*

## 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 – 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 examples shows the DEM where a bridge has been removed.

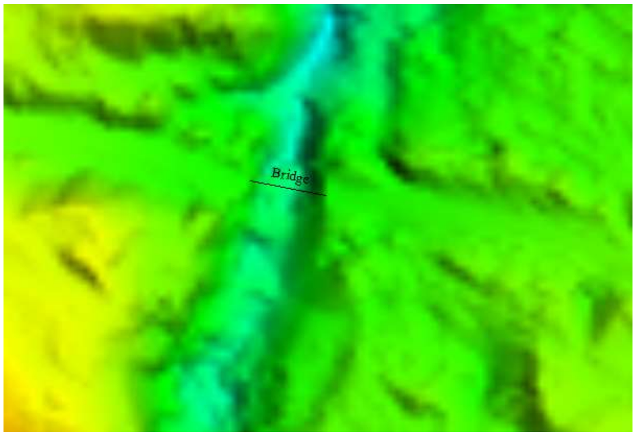



Figure 17: Tile DEM_BH36_2021_1000_1531 with LINZ bridge centreline

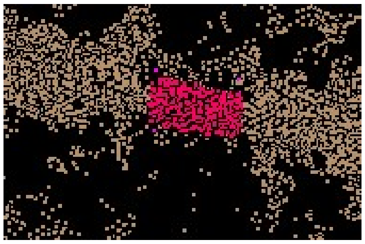


Figure 18: BH36_2021_1000_1531 – Top down

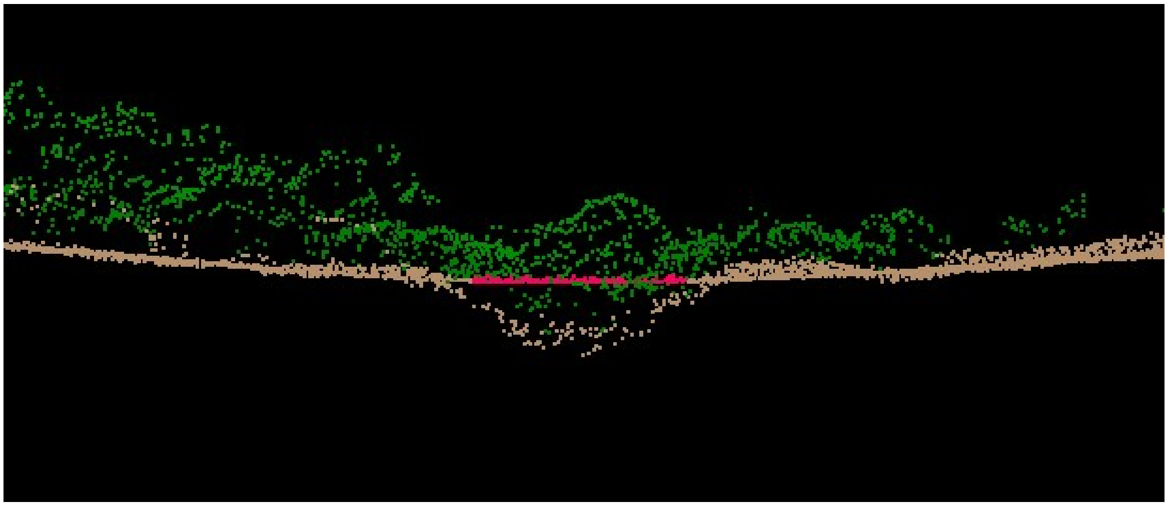


Figure 19: BH36_2021_1000_1531 – Side profile

The examples below shows no visible bridge at LINZ location: tile BG38_4840

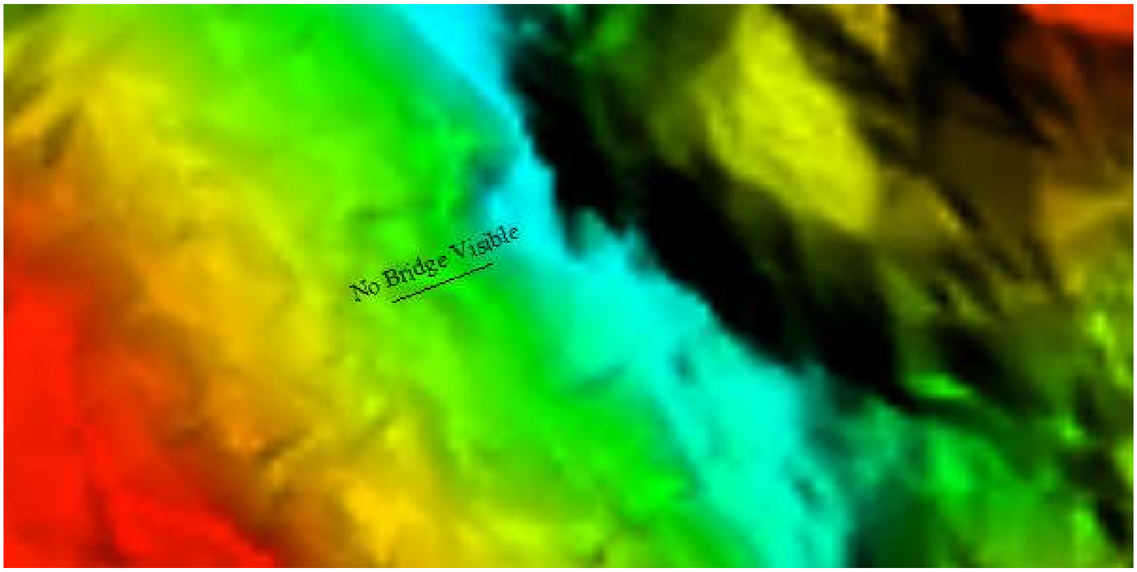



Figure 20: DEM Tile BG38_2021_1000_4840

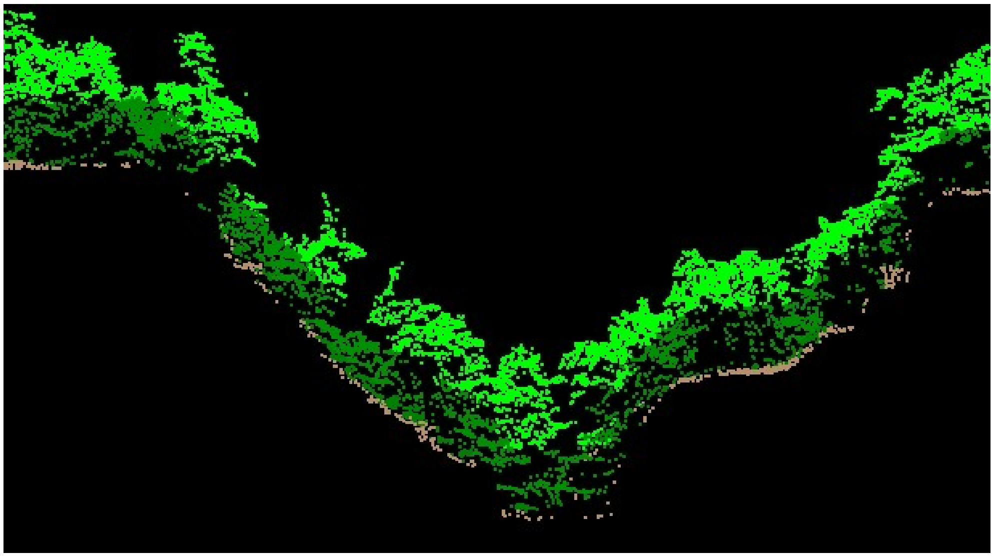


*Figure 21: Pointcloud BG38_2021_1000_4840*

The example below shows a Bridge in the LINZ shapefile that is a culvert and is therefore not edited to class 17.

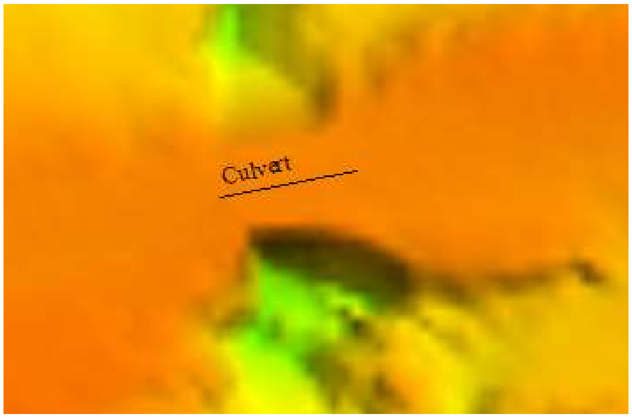



Figure 22: DEM Tile BH35_1826

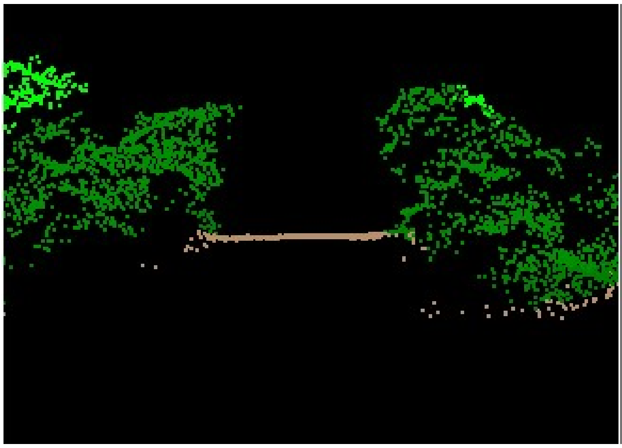


Figure 23: Pointcloud Tile BH35_1826

# 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.

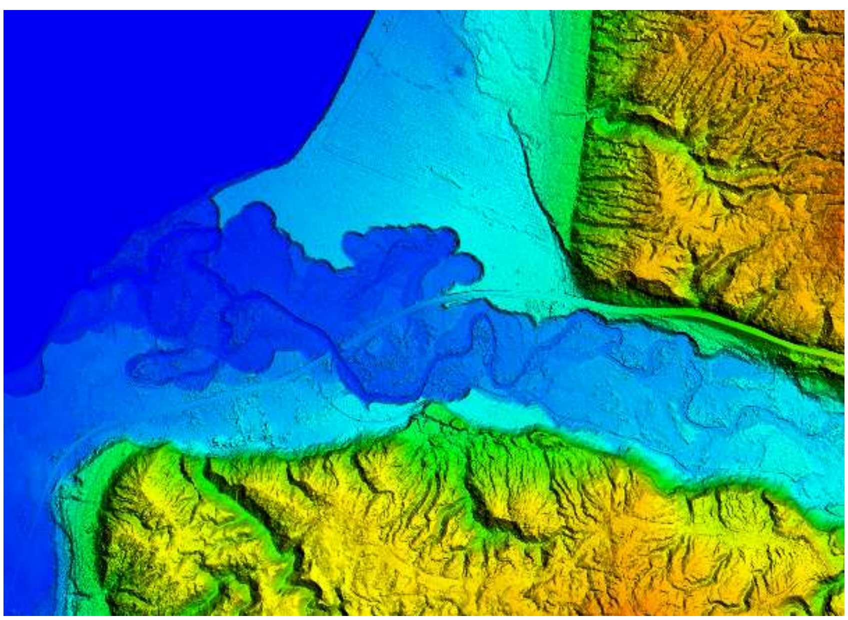


*Figure 24: Example of a hydro-flattened DEM Lake and river mouth*

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.

| | | | |
|---|---|---|---|
| 1 | 1929744.8358 | 5615128.2638 | 7.7096 |
| 2 | 1929746.0769 | 5615130.8498 | 7.6863 |
| 3 | 1929746.4280 | 5615131.5996 | 7.6796 |
| 4 | 1929746.5107 | 5615131.7727 | 7.678 |
| 5 | 1929746.7841 | 5615132.3591 | 7.6728 |
| 6 | 1929748.0794 | 5615135.0799 | 7.6483 |
| 7 | 1929748.5703 | 5615136.1455 | 7.6388 |
| 8 | 1929749.4246 | 5615138.0643 | 7.622 |
| 9 | 1929749.8587 | 5615139.0742 | 7.6132 |
| 10 | 1929750.6288 | 5615140.9327 | 7.5973 |
| 11 | 1929751.0393 | 5615141.7916 | 7.5896 |
| 12 | 1929751.5292 | 5615142.7809 | 7.5805 |
| 13 | 1929754.3861 | 5615148.3485 | 7.529 |
| 14 | 1929754.7868 | 5615149.1041 | 7.5219 |
| 15 | 1929754.7991 | 5615149.1267 | 7.5217 |
| 16 | 1929757.3347 | 5615152.1834 | 7.4808 |
| 17 | 1929757.8445 | 5615152.7752 | 7.4594 |

*Figure 25: Excerpt of river points used to create the centreline*

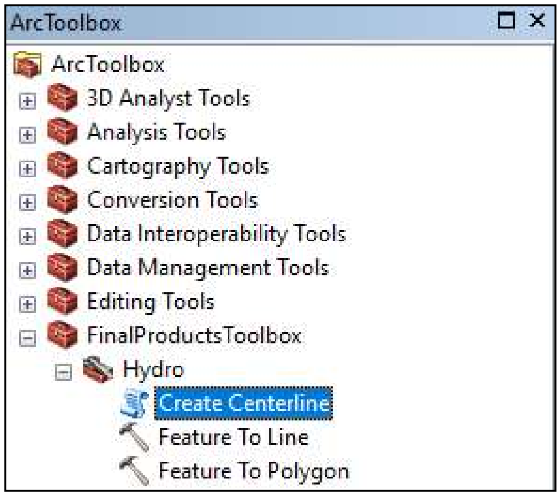



*Figure 26: Centreline for the stream within the project's survey*

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:

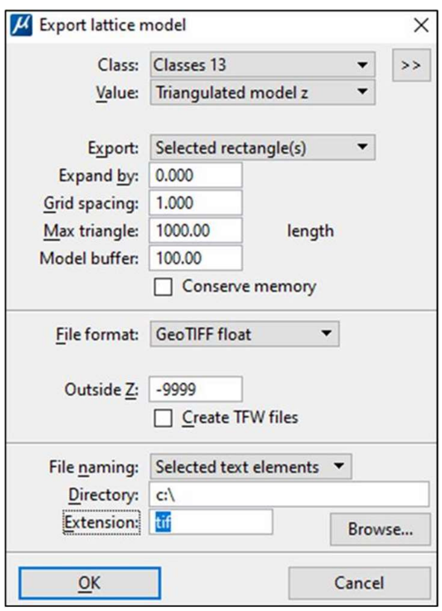



*Figure 27: Settings used to export lattice models.*

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.

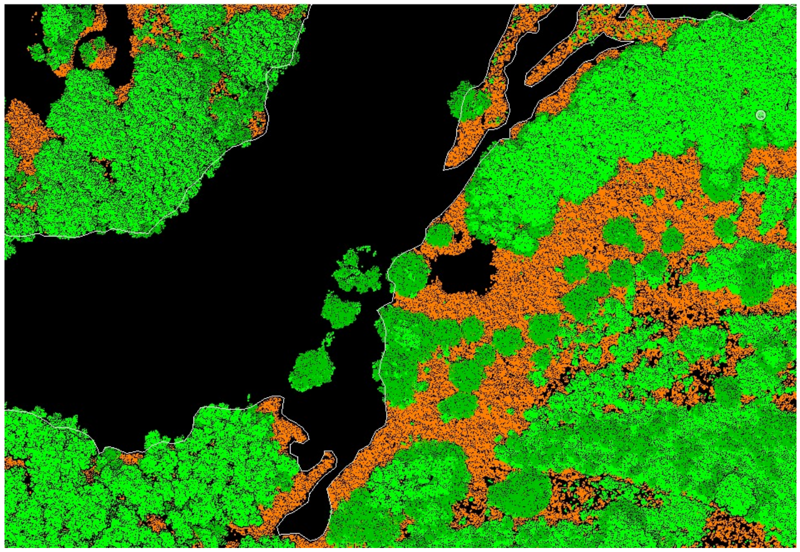


*Figure 28: Pre-filter, overhead view of ground and veg points with hydro lines*

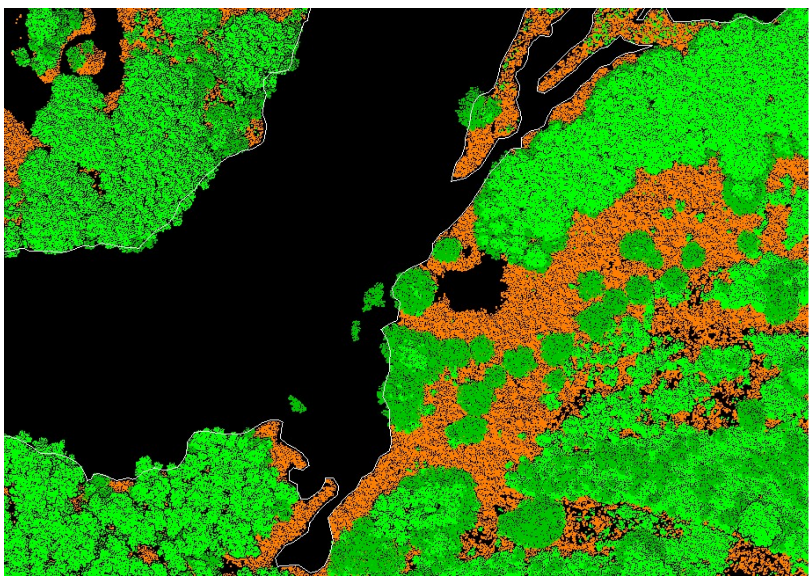


*Figure 29: Post-filter, overhead view of ground and veg points with hydro lines*

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 30: Point cloud – boulder filled stream*


*Figure 31: Imagery – boulder filled stream*

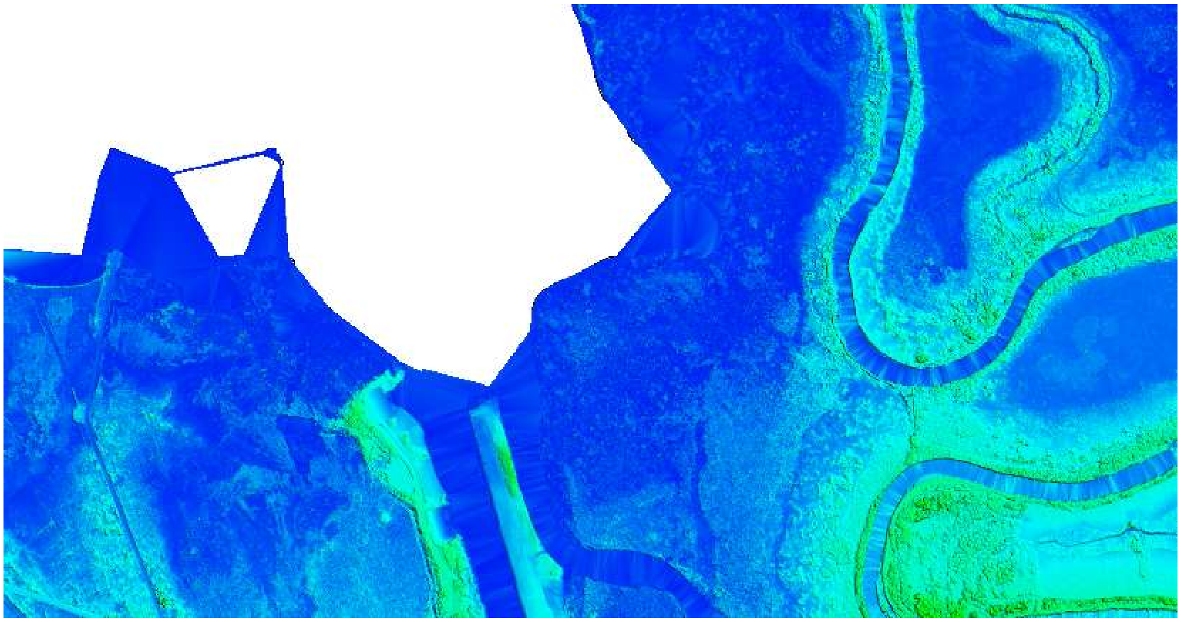


*Figure 32: Example of DEM tile prior to hydroflattening: BH35_1000_1426 and neighbours*

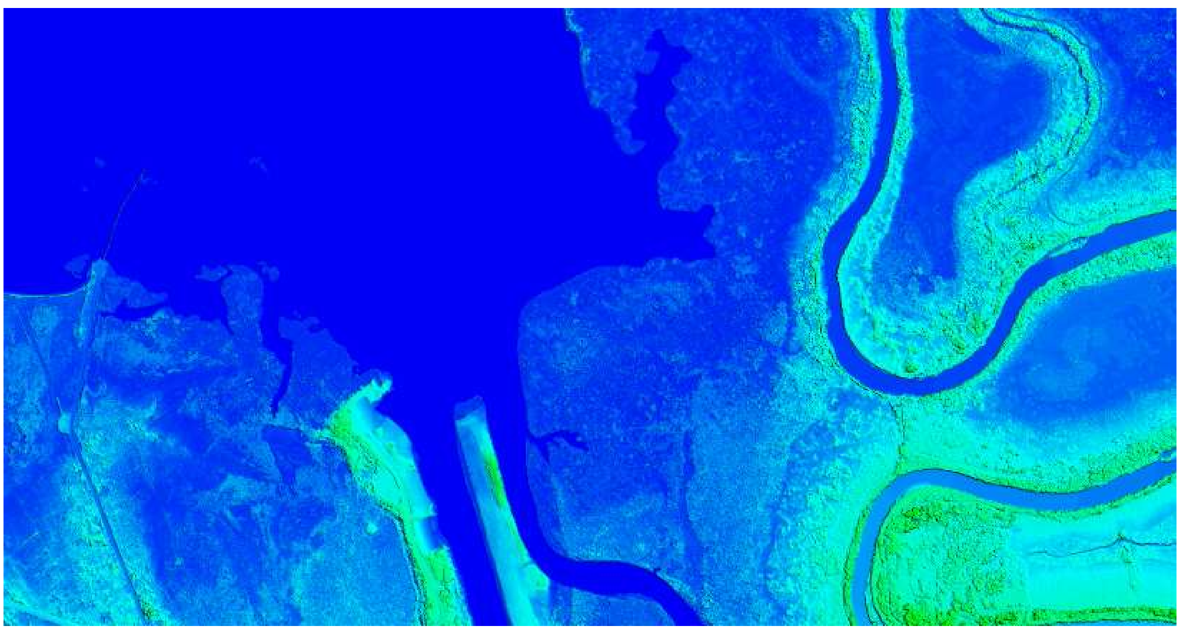


*Figure 33: Example of DEM tile post hydroflattening: BH35_1000_1426 and neighbours*

# 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 E was captured using Leica TerrainMapper sensor 513 and 559, flown on days 05th, 06th, 10th, 11th, 14th, 15th, 25th, 26th, 29th, 30th, 31st January, 1st, 3rd, 11th, 12th, 16th, 18th, 19th, 20th February, 11th, 13th, 21st, 22nd, 23rd, 24th March 2021.

Please note the dates above refer to all dates flown for the entirety of Block E inclusive of North (1), North (2) and South.

The extent of Block E can be seen in Figure 34. The flight lines relating to the area can be seen in Figure 35.

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 figure 41.

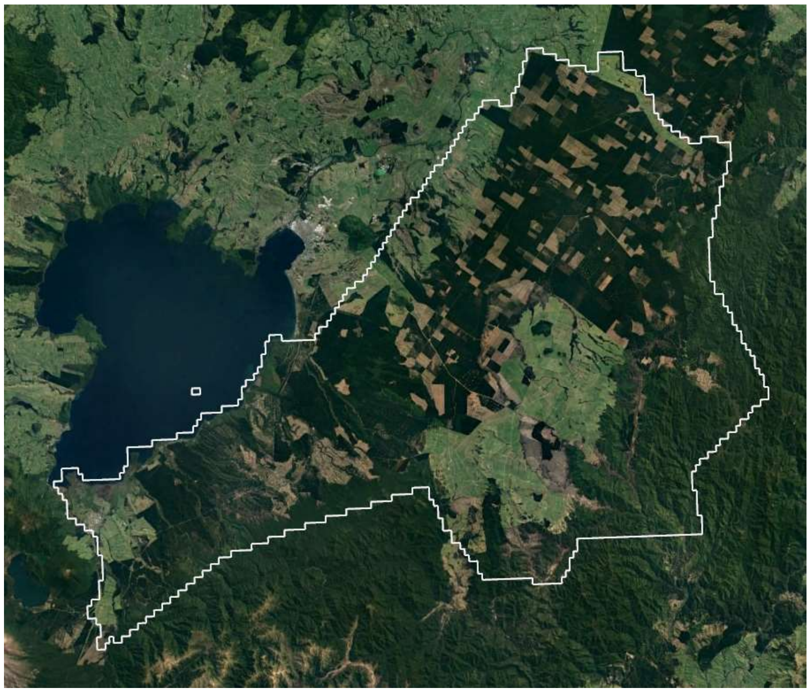


*Figure 34: Extent of deliverable data for Block E South*

### 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. Refer to the purple polygon illustrating Block E South.

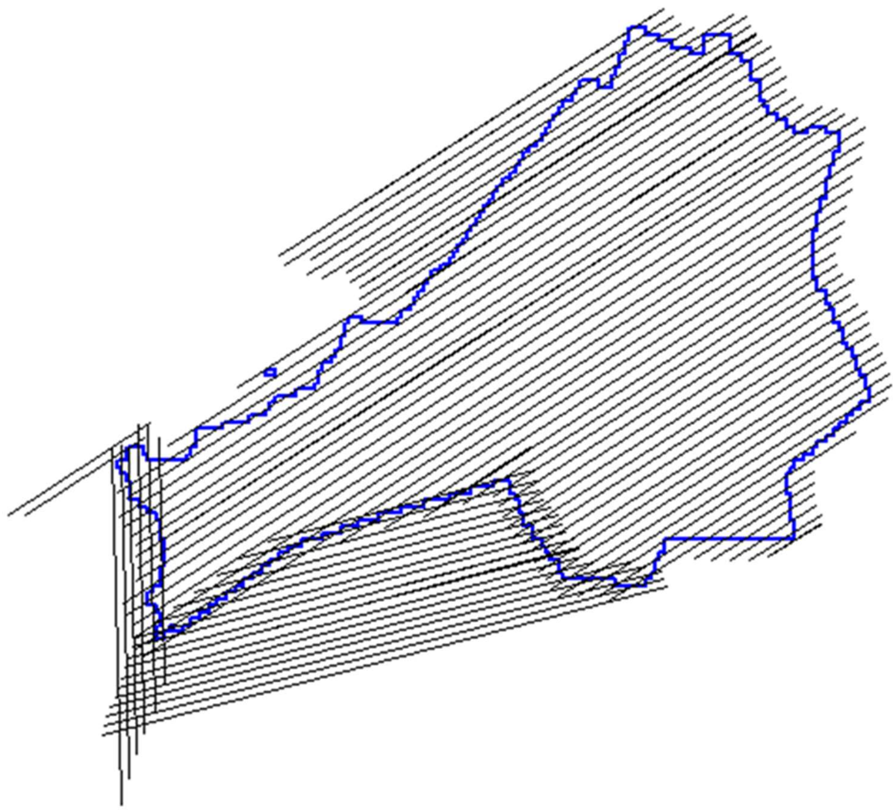


*Figure 35: Flight lines for 4ppm2 data coverage over Block E South*

## 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 36: WKT of a LAS file shown by LASTools.*

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.

| File | Points | Version | File Signature | File Source ID | CRS is WKT | Coordinate System |
|---|---|---|---|---|---|---|
| CL2_BG38_2021_1000_4104.las | 2,374,402 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG38_2021_1000_4105.las | 3,279,058 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG38_2021_1000_4106.las | 2,668,226 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG38_2021_1000_4107.las | 2,115,573 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG38_2021_1000_4201.las | 2,014,442 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG38_2021_1000_4202.las | 3,628,374 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG38_2021_1000_4203.las | 2,957,649 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG38_2021_1000_4204.las | 2,431,375 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG38_2021_1000_4205.las | 1,837,787 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG38_2021_1000_4206.las | 2,157,424 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG38_2021_1000_4207.las | 4,565,389 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG38_2021_1000_4208.las | 4,728,640 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG38_2021_1000_4209.las | 3,351,275 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG38_2021_1000_4301.las | 2,878,970 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG38_2021_1000_4302.las | 2,290,613 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG38_2021_1000_4303.las | 2,788,100 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG38_2021_1000_4304.las | 3,168,250 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG38_2021_1000_4305.las | 4,252,550 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG38_2021_1000_4306.las | 2,791,845 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BG38_2021_1000_4307.las | 2,300,920 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |

*Table 2: Representative output from LP360 illustrating LAS file specification compliance (Rev1)*

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 analysist 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.

It is noted for Blocks F & G due to the dense vegetation and steep terrain the penetration of the LiDAR to the ground in some areas is minimal (Figure 18 is a good example). This will show in the DEM as large, triangulated areas or give the impression of pitting where only isolated ground returns have been identified.
For these areas it is recommended to compare any potential DEM discrepancies with the point cloud to confirm the absence of available ground points.

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.

| File | Format | NoData Value | BPB | Bands | Data Type | Pixel Size | Coordinate System |
|---|---|---|---|---|---|---|---|
| DEM_BG37_2021_1000_4444.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BG37_2021_1000_4445.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BG37_2021_1000_4446.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BG37_2021_1000_4447.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BG37_2021_1000_4448.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BG37_2021_1000_4449.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BG37_2021_1000_4450.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BG37_2021_1000_4530.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BG37_2021_1000_4531.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BG37_2021_1000_4532.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BG37_2021_1000_4533.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BG37_2021_1000_4534.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BG37_2021_1000_4535.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BG37_2021_1000_4536.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BG37_2021_1000_4537.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BG37_2021_1000_4538.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BG37_2021_1000_4539.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |

*Table 3: Condensed output from LP360 illustrating DEM file specification compliance (Rev 1)*

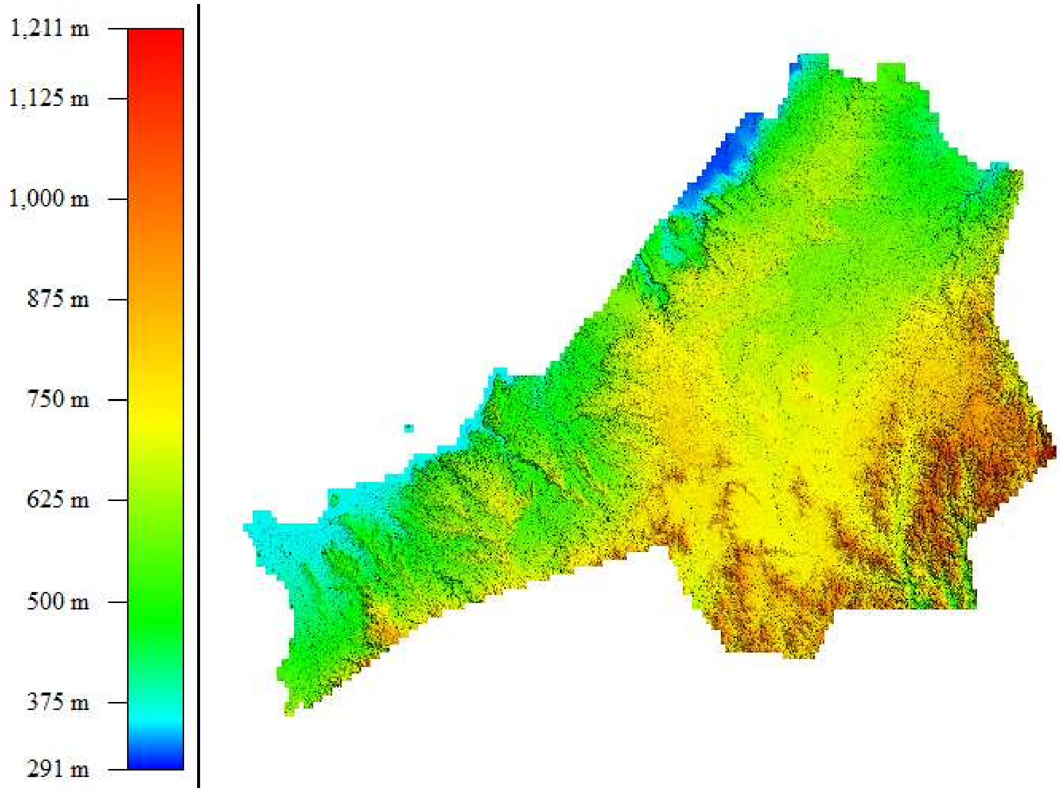



*Figure 37: 1 Metre DEM*

### 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.

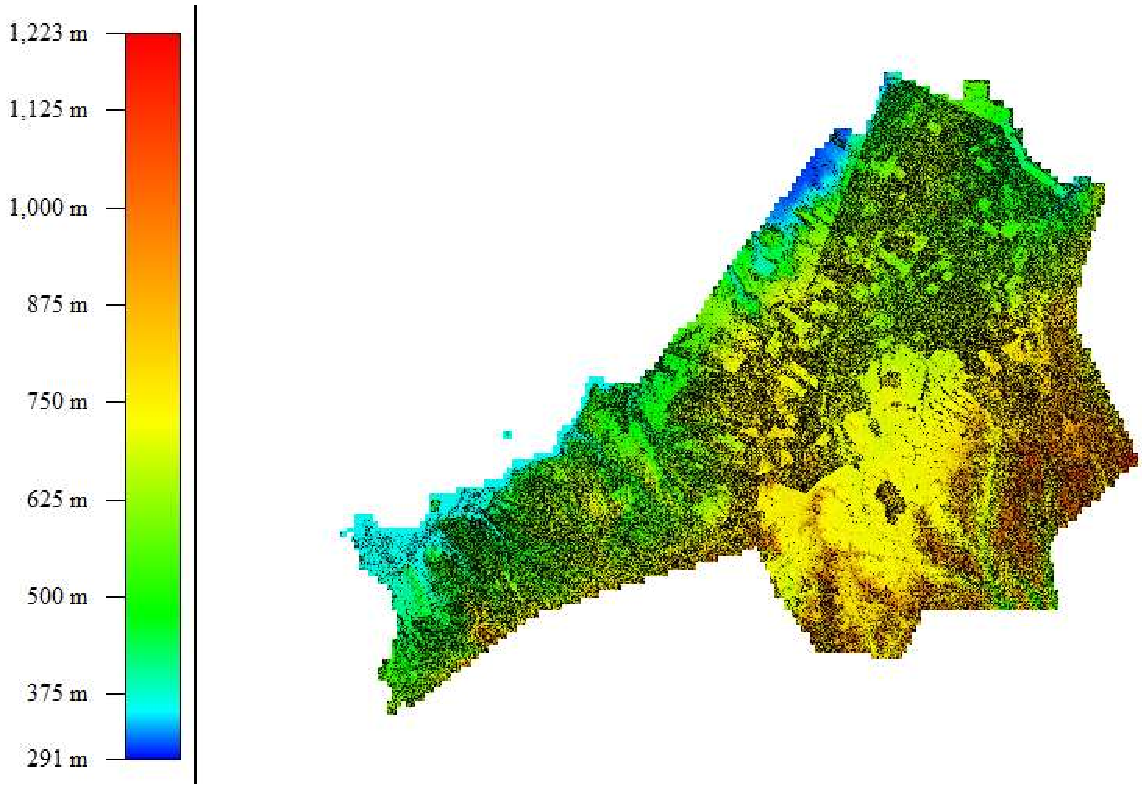



*Figure 38: 1 Metre DSM*

The figures below show a DEM and DSM Comparison:

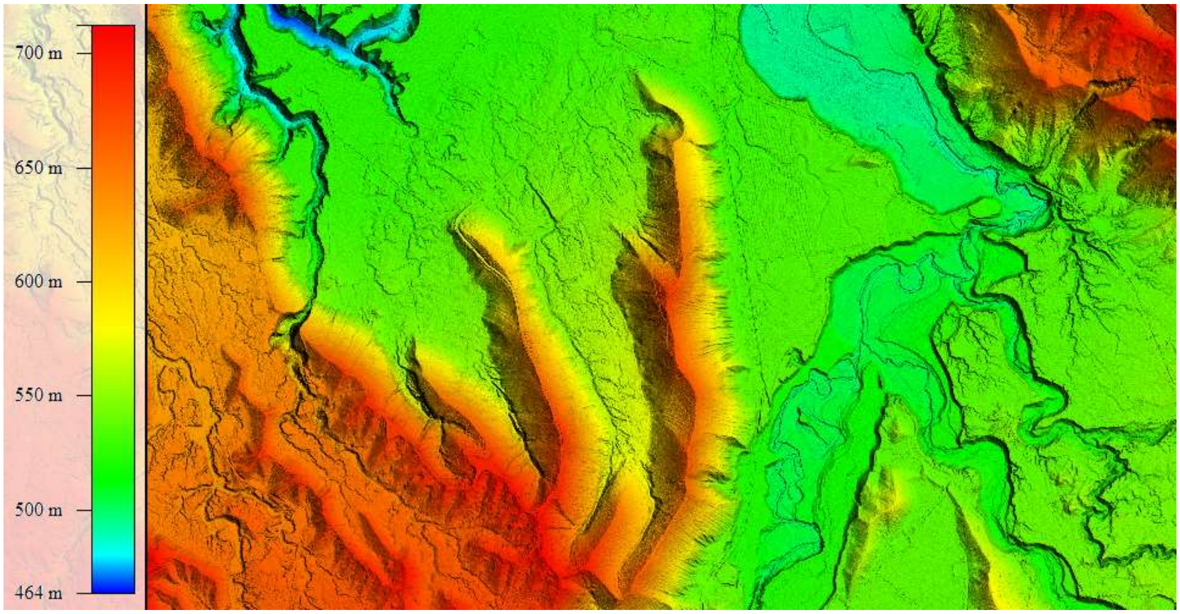



*Figure 39: DEM Comparison*

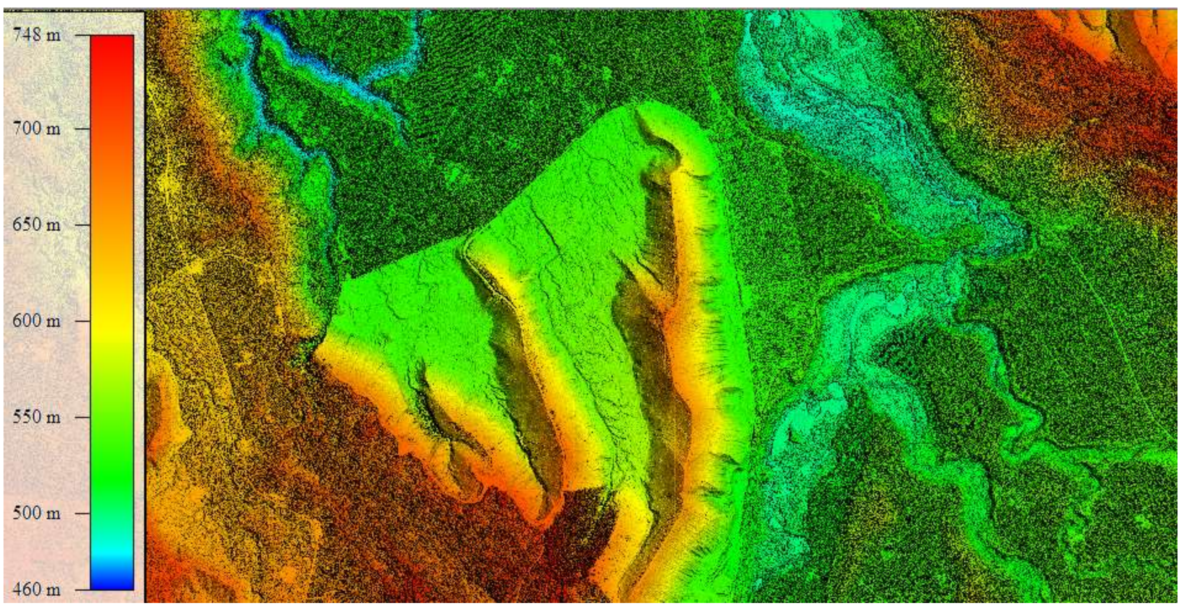
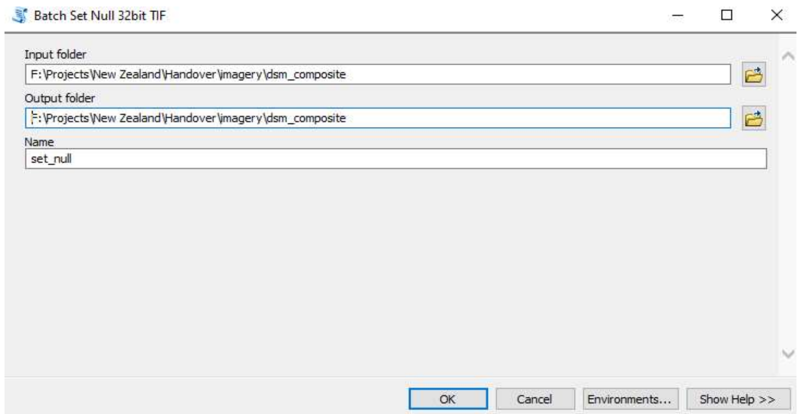



*Figure 40: DSM Comparison*

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.




| | |
|---|---|
| Format | IMAGINE Image |
| Source Type | Generic |
| Pixel Type | floating point |
| Pixel Depth | 32 Bit |
| NoData Value | -9999 |

*Figure 42: 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.

| File | Format | NoData Value | BPB | Bands | Data Type | Pixel Size | Coordinate System |
|---|---|---|---|---|---|---|---|
| DSM_BH35_2021_1000_2233.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BH35_2021_1000_2234.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BH35_2021_1000_2235.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BH35_2021_1000_2236.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BH35_2021_1000_2237.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BH35_2021_1000_2238.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BH35_2021_1000_2239.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BH35_2021_1000_2240.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BH35_2021_1000_2241.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BH35_2021_1000_2242.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BH35_2021_1000_2243.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BH35_2021_1000_2244.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BH35_2021_1000_2333.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BH35_2021_1000_2334.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BH35_2021_1000_2335.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |

*Table 4: Condensed output from LP360 illustrating DSM file specification compliance (Rev 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.

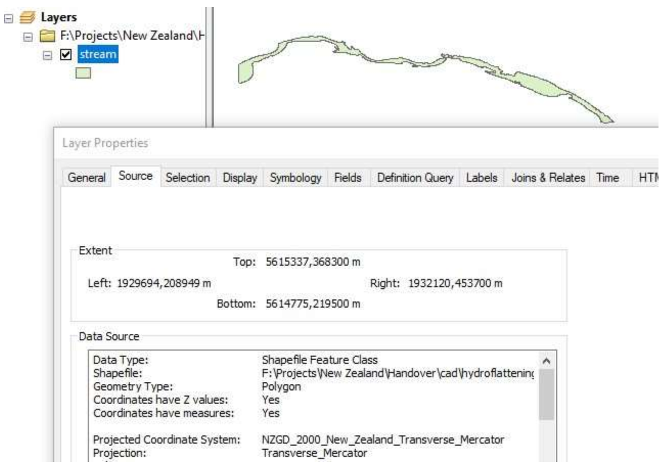



*Figure 43: Stream break line properties in ArcMap.*

## 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

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

Contours will be generated from the DEM. Samples have been provide of contours including those that straddle block joins.

Contours will be generated at 1,5 and 10 metre markers. They will adopt a naming convention as per WRC suggestion e.g. *CRT_BB35_2021_1000_1515. CRT refers to Cartographic and opposed to engineering contours.*

# 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_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.

o Check for presence of correct ESPG Codes for geodetic & vertical datums, and map projection

o 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.

| Naming Convention for point clouds, DEMs, and other tiled products<br>*[product]_[sheet]_[year]_[scale]_[tile].[ext]* | | |
|---|---|---|
| **Product** | *DEM* | **CL2-Point Cloud Classification Level 2**<br>**DEM-Bare Earth Digital Elevation Model**<br>**DSM-Digital Surface Model**<br>DTM-Digital Terrain Model<br>UNC-Unclassified Point Cloud<br>INT-Intensity image<br>CHM – Canopy Height Model<br>IMG-Aerial photography<br>etc |
| **Sheet** | *BK34* | LINZ Topo50 identifier (4 characters) |
| **Year** | *2016* | Year of survey commencement |
| **Scale** | *1000* | Nominal scale of NZTopo50 subtiles |
| **Tile** | *4118* | Row number (41), Column number (18) of tile with respect to an upper left origin |
| **ext** | *tif* | File extension according to format conventions<br>las<br>tif<br>shp<br>etc |
| *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-flatting break line bank line strings
│      │ └──stream_islands – Hydro-flatting 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

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.

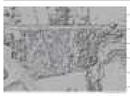
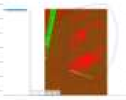
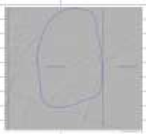
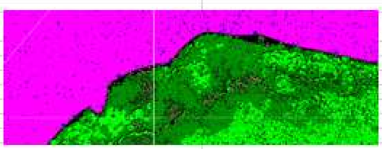
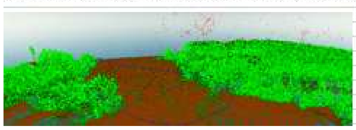
## 6.3 Lessons learned and collaboration

Thanks goes to the team at WRC for providing inputs to previous blocks that has informed decisions on processing for this block and the entirety of Block E. There is some challenging terrain and dense vegetation that hindered penetration is some parts and made for some difficult processing with significant manual editing.

## 6.4 WRC / LINZ Tracking Spreadsheet

Below is a table showing one of the pages of the tracking spreadsheet which was supplied by WRC and LINZ and reviewed and commented on by Ocean Infinity and/or Woolpert. This was further supplemented by shapefiles, geodatabase files, reference images / snips and other information to support identification, rectification and repair.

**Failed Items**

| *Issue* | *Tile* | *Information* | *Woolpert Comment* |
|---|---|---|---|
| **1. Speckling/corduroying in DEM and DSM from low vegeta** | Widespread. Almost every area of clear open ground. See **issues_review.shp** for broad extent of sites to review and fix, PC, DSM and DEM. | Reclassify PC so these occurrences are noise/unclassified and ensure DEM and DSM in areas identified by issues_review.shp are free of these artefacts. DEM subtle, DSM and PC quite obvious. Has partially been addressed by resupply, however not actioned entirely for the DEM, and there are remaining sites that show subtle expressions of this issue. PC and DSM has not been reviewed and fixed and are heavily impacted. Appears to be very prevalent in this block over clear open ground. Other QC'd and published blocks do not appear to have this issue to the extent that is in this block. For consistency across all blocks, fix for all products and resupply. Example sites provided in issues_review.shp. Review and fix all sites within big polygons covering clear open ground areas. Focus on artefacts that follow trajectory, mirror flightline - obvious processing artefacts that are clearly not related to on-the-ground features. | Clean up run to remove most of the near surface artefacts. |
|  |  |  | |
| **2. Voids in vegetation canopy from Noise classification an** | Please fix all sites in **issues_review.shp** | Same as previous blocks. Additional sites identified by QC of resupply. Other sites over clear open ground. Fix all affected products and resupply. | Edited tiles in Issues.shp |
|   |   | | |
| **3. Hydroflattening** | Please fix all sites in **issues_review.shp** | Same as previous blocks. Hydroflatten to bank edge. Lake Taupo sites show artificial beach in DEM. Focus on Lake Taupo. Ignore for non-major bodies of water. Resupply DEM | |
|   | | | Have made the hydro surface closer to the coast where possible (within provided mark-ups). |
| **4. Point source ID, Intensity, GPS time, etc... - 0** | CL2_BG38_2021_1000_2205<br>CL2_BH36_2021_1000_1531 | Fix and resupply PC - minor issue. | Deleted 5 (break line) points in 2 LAS tiles |
| **5. Spikes in DSM (one general location) from high vegetat** | Please fix for polygon in **issues_review.shp** | Reviewing PC, high vegetation classification mirrors what high noise looks like (linear strikes trending near vertically) | Edited tiles in Issues.shp |
|  | | | |

# 7 Results Acceptance & Signoff

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

| Result Acceptance | | | |
|---|---|---|---|
| Assessment Criteria | Status | Completed By | Date |
| Point cloud classification accuracy | Complete | Woolpert/ AAM | 13 November 2023 |
| Point cloud classification consistency | Complete | Woolpert/ AAM | 13 November 2023 |
| Point Cloud LAS tiled deliverables | Complete | Woolpert/ AAM | 13 November 2023 |
| Hydro-flattened Digital Elevation Models | Complete | Woolpert/ AAM | 13 November 2023 |
| Digital Survey Models | Complete | Woolpert/ AAM | 13 November 2023 |
| Contours | Complete | Woolpert/ AAM | 13 November 2023 |
| Extents, Flight Lines, Break lines, Tile Index | Complete | Woolpert/ AAM | 13 November 2023 |
| | | | |
| Project Manager / Supervisor Signoff | Complete | Luke Graham | 13 November 2023 |
| Ocean Infinity Review | Complete | Luke Leydon | 23 November 2023 |

*Table 6: Processing Results Acceptable Signoff*

| Result Acceptance | | | |
|---|---|---|---|
| Assessment Criteria | Status | Completed By | Date |
| Point cloud classification accuracy | Complete | Woolpert/ AAM | 17 May 2024 |
| Point cloud classification consistency | Complete | Woolpert/ AAM | 17 May 2024 |
| Point Cloud LAS tiled deliverables | Complete | Woolpert/ AAM | 17 May 2024 |
| Hydro-flattened Digital Elevation Models | Complete | Woolpert/ AAM | 17 May 2024 |
| Digital Survey Models | Complete | Woolpert/ AAM | 17 May 2024 |
| Contours | Complete | Woolpert/ AAM | 17 May 2024 |
| Extents, Flight Lines, Break lines, Tile Index | Complete | Woolpert/ AAM | 17 May 2024 |
| | | | |
| Project Manager / Supervisor Signoff | Complete | Luke Graham | 17 May 2024 |
| Ocean Infinity Review | Complete | Luke Leydon | 06 June 2024 |

*Table 7: Processing Results Acceptable Signoff (Rev 1)*

# Appendix A: Lidar Quality Assurance Results

Provided as separate Documents in Appendix A upload

OCEAN INFINITY

# Waikato Local Authority Shared Services (WLASS) / CoLAB LiDAR Data Capture Services

# LiDAR Processing Report Blocks F&G (Rev 3)

Contract Number: AU411

Surveyed By: iXblue Pty Ltd / Ocean Infinity

Processing Completed By: Woolpert USA and Woolpert Australia

WOOLPERT AAM A WOOLPERT COMPANY

Prepared For: Colab (formerly WLASS)

COLAB BETTER TOGETHER Waikato Local Authority SHARED SERVICES

Document Date: 6 May 2024

Ocean Infinity (Australia) Pty Ltd
ABN 61 128 811 978
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## Document Revision

| Revision No | Issue Purpose | Prepared | Checked | Approved |
|---|---|---|---|---|
| 0 | Issue Blocks F&G LiDAR Processing Report | L Leydon | L Graham | D Field |
| 1 | Issue LiDAR Processing Report at resupply | L Leydon | L Graham | D Field |
| 2 | Issue LiDAR Processing Report at resupply | L Leydon | L Graham | D Field |
| 3 | Issue LiDAR Processing Report at resupply | L Leydon | L Graham | D Field |

## Approval for Issue

| Name | Signature | Date |
|---|---|---|
| Luke Leydon |  | 06 May 2024 |

# Revision History

| Item | Description of change | Section | Revision |
|---|---|---|---|
| 1 | New Section added to Introduction | 1.1 | 1 |
| 2 | Section added on building classification & vegetation and low-level noise classification | 2.8.1, 2.8.2 | 1 |
| 3 | New LP360 tables added | 4.3 | 1 |
| 4 | New Section added to setbacks and solutions | 6.3 | 1 |
| 5 | New Pointcloud statistics added | 4.2 | 1 |
| 6 | New results signoff table added | 7 | 1 |
| 7 | New Section added to Introduction | 1.2 | 2 |
| 8 | New Pointcloud statistics added | 4.2 | 2 |
| 9 | New Section added to setbacks and solutions | 6.4 | 2 |
| 10 | New results signoff table added | 7 | 2 |
| 11 | New Appendix added, defect spreadsheet completed | Appendix | 2 |
| 12 | New Section and figures added to Introduction | 1.3 | 3 |
| 13 | New Pointcloud statistics added | Figure 14 | 3 |
| 14 | New LP360 tables added | 4.3 | 3 |
| 15 | New Sections added to setbacks and solutions | 6.5 | 3 |
| 16 | New results signoff table added | 7 | 3 |
| | | | |

# Contents

# Tables

# Figures

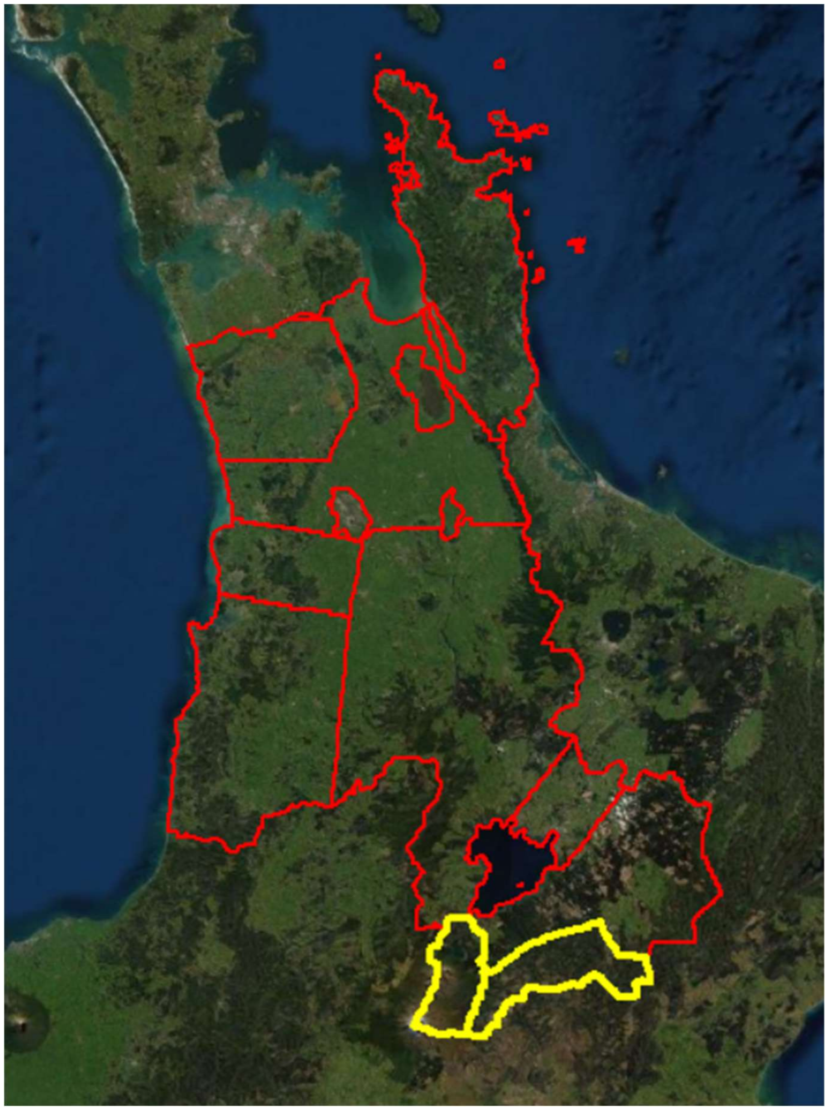


*Figure 1: Waikato Survey Area*

F&G illustrated in Yellow

# 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

- AU411_WLASS-Collection_Report-10052021.pdf.

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 Blocks F&G, as illustrated in yellow in Figure 1 - Waikato Survey.

This dataset was uploaded by Woolpert Australia after hours on 10 March 2023. This was transferred to WRC the following day (11 March 2023).

## 1.1 Resupply post WRC and LINZ QA

The original supply of Blocks F & G was failed by both LINZ and WRC. The failure was accompanied by a spreadsheet 'AU411 WRC_Raised_Defect_Tracking_Block_FG_v1'. This listed the failures and improvements required. It was supported by Geospatial files which showed the areas of failures.

The dataset was formally failed on Tuesday 30 May. A technical meeting was held between LINZ, WRC, Ocean Infinity and Woolpert Australia on Tuesday 06 June to discuss the failures and methodologies to correct.

Revision 1 of the data was uploaded to Amazon S3 bucket on Monday 14 August 2023. This report was supplied on Wednesday 16 August.

Please refer to the extensive commentary and supplied images in the AU411 WRC_Raised_Defect_Tracking_Block_FG_v1.xlsx spreadsheet provide in Appendix A of the upload for the corrections made to this dataset.

## 1.2 Resupply post WRC and LINZ QA (2nd round)

The revised (1) supply of Blocks F & G was failed by both LINZ and WRC. There were improvements made on the original supply but further rework was deemed necessary.

The failure was accompanied by a spreadsheet 'AU411 WRC_Raised_Defect_Tracking_Block_FG_v2'. This listed the failures and improvements required. It was supported by Geospatial files which showed the areas of failures.

Revision 2 of the data was uploaded to Amazon S3 bucket on Wednesday 11 October 2023. This report was supplied on Tuesday 24th October 2023.

Please refer to the extensive commentary and supplied images in the AU411 WRC_Raised_Defect_Tracking_Block_FG_v2.xlsx spreadsheet provide in Appendix A of the upload for the corrections made to this dataset.

## 1.3 Resupply post WRC and LINZ QA (3rd round)

Blocks F & G were resupplied to LINZ and WRC on 08 April 2024.

The failure and subsequent resupply was accompanied by a spreadsheet and returned with comments. 'AU411 WRC_Raised_Defect_Tracking_Block_FG_v5-Woolpert-Comments' This listed the failures and improvements required. It was supported by Geospatial files which showed the areas of failures.

Further corrections to the DEM/DSM over Lake Rotoaira, improving the hydroflattening were provided Monday 06 May 2024.

Thanks go to Emory Beck at LINZ for assistance with corrections to this dataset allowing publication.

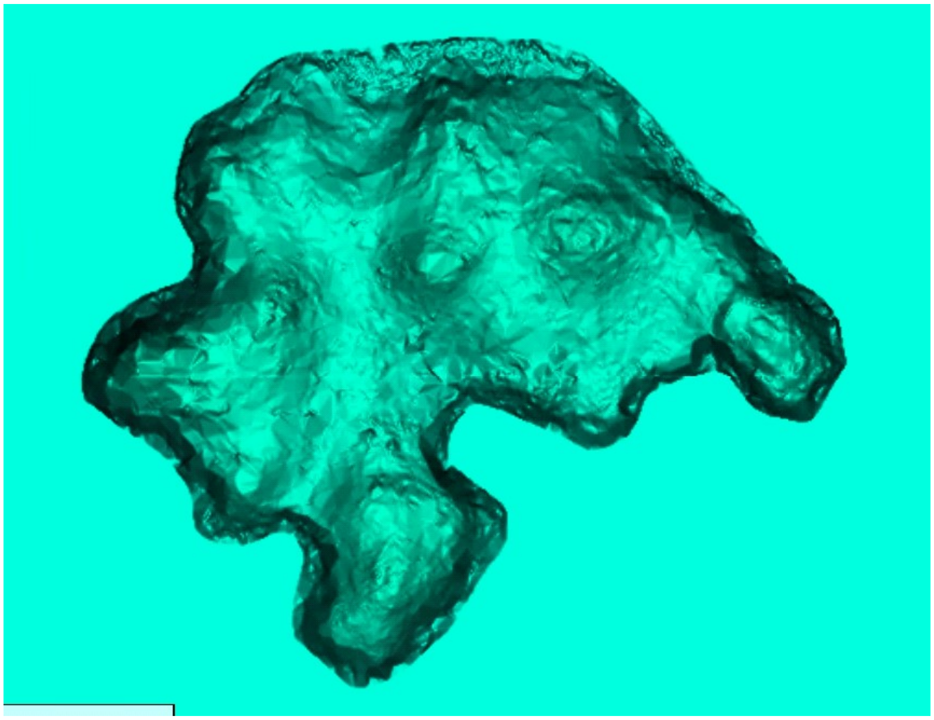


*Figure 2: Island in Lake Rotoaira – prior to correction*

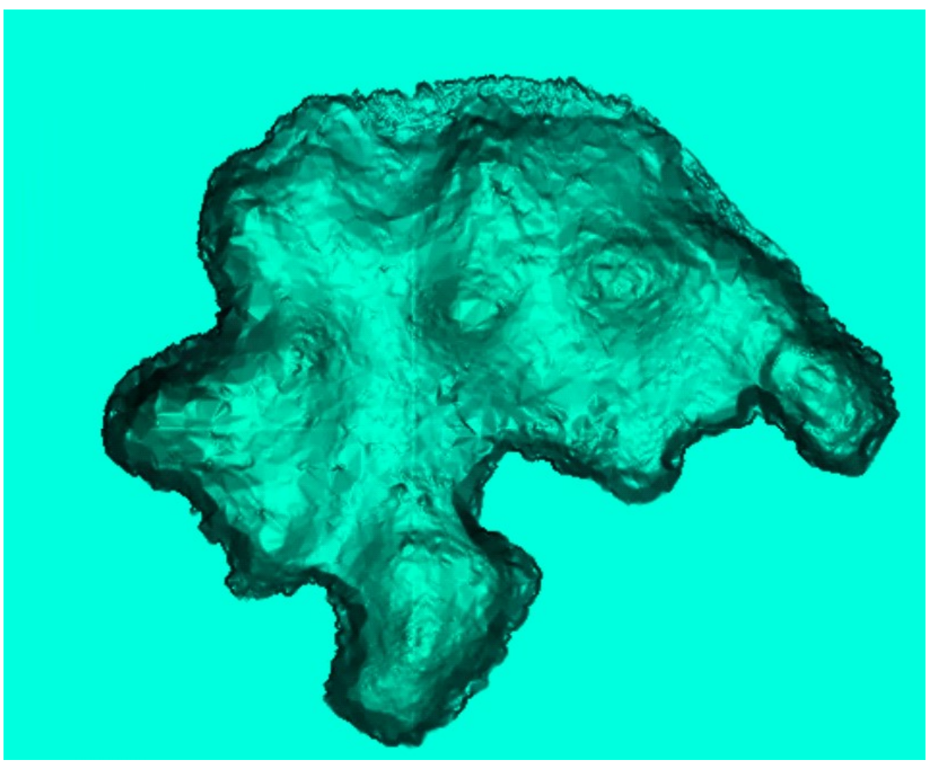


*Figure 3: Island in Lake Rotoaira – post correction*

# 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).

https://www.linz.govt.nz/system/files_force/media/doc/pgf_version_new_zealand_national_aerial_lidar_base_specification.pdf?download=1

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:

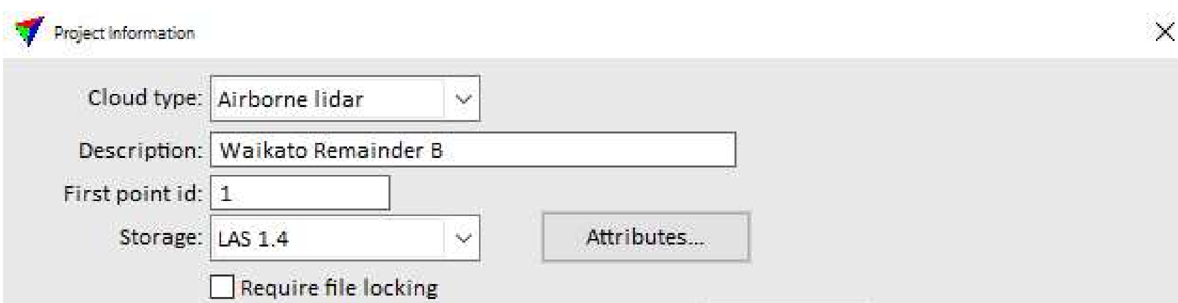



*Figure 4: LAS 1.4 being specified during project – example*

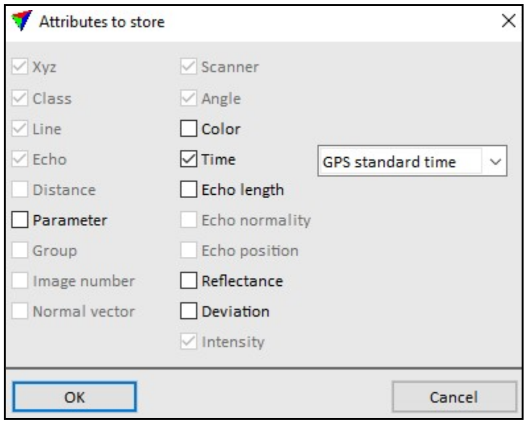
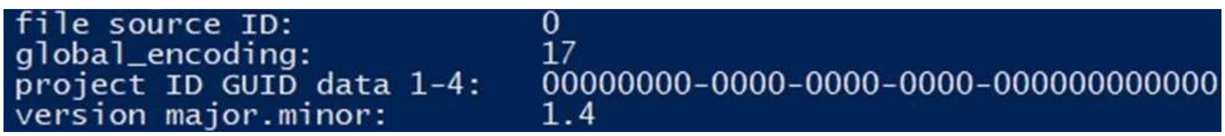



*Figure 5: Project settings used in TerraScan project when importing points into the project.*

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.



```
file source ID:              0
global_encoding:             17
project ID GUID data 1-4:    00000000-0000-0000-0000-000000000000
version major.minor:         1.4
```

*Figure 6: 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)

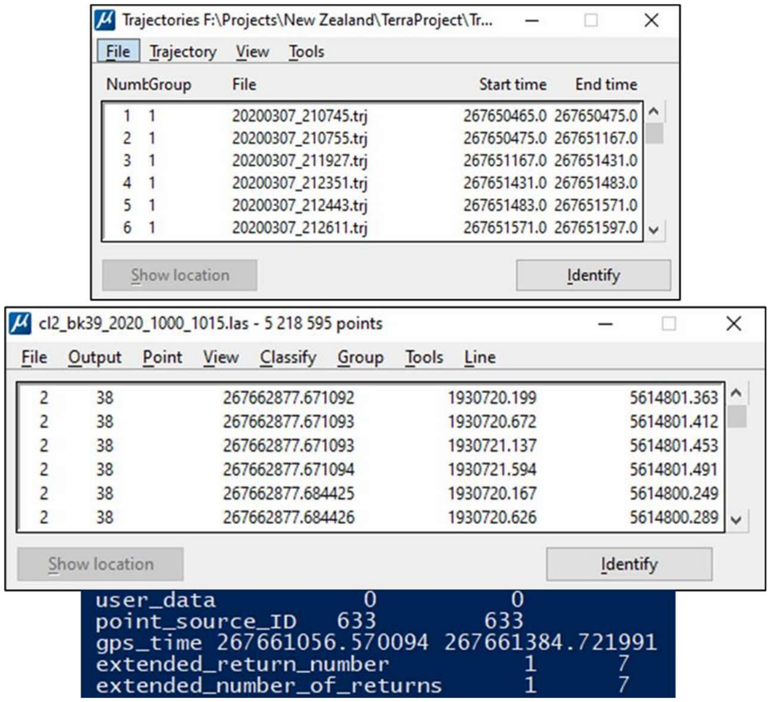



*Figure 7: Representative examples of LAS point attributes*

## 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.

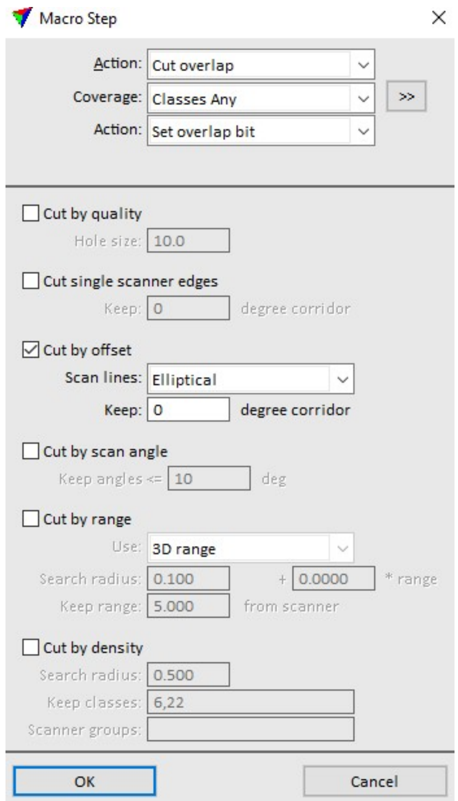



*Figure 8: Settings used when cutting overlap in Microstation.*

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:

| Code | Description |
|---|---|
| 1 | Processed, but unclassified |
| 2 | Ground |
| 3 | Low vegetation <2m |
| 4 | Medium vegetation |
| 5 | High vegetation >8m |
| 6 | Building |
| 7 | Low noise |
| 9 | Water |
| 17 | Bridge deck |
| 18 | High noise |

*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.

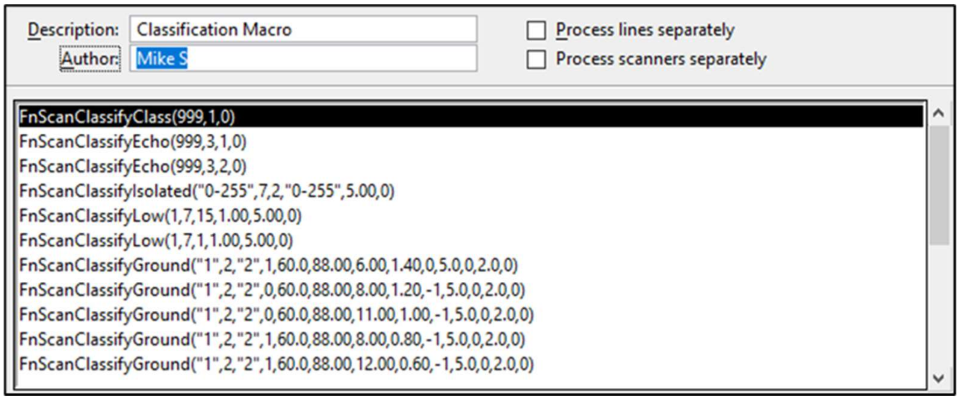



*Figure 9: Automatic classification macro developed for the project area.*

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.

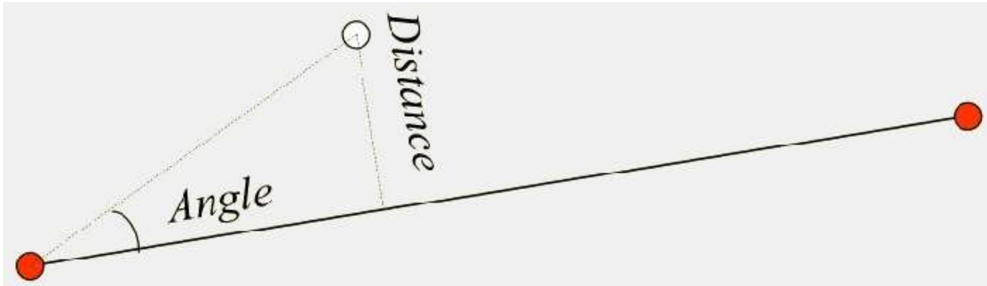



*Figure 10: Illustration of iteration angle and iteration distance parameters in the ground routine.*

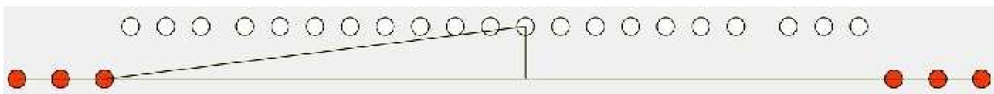


*Figure 11: A smaller iteration distance value avoids classification of ground points on low objects.*

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.

```
histogram of classification of points:
        1528010  unclassified (1)
     2949029832  ground (2)
      792030835  low vegetation (3)
     1878651495  medium vegetation (4)
     2513966571  high vegetation (5)
         831521  building (6)
      723568959  noise (7)
        1144991  water (9)
          64431  bridge deck (17)
       15287833  Reserved for ASPRS Definition (18)
 +-> flagged as withheld:  738856792
  +--->      723568959 of those are noise (7)
  +--->       15287833 of those are Reserved for ASPRS Definition (18)
 +-> flagged as extended overlap: 4688873644
  +--->         817892 of those are unclassified (1)
  +--->     1419157770 of those are ground (2)
  +--->      430825780 of those are low vegetation (3)
  +--->     1054698727 of those are medium vegetation (4)
  +--->     1384798231 of those are high vegetation (5)
  +--->         549777 of those are building (6)
  +--->      393234636 of those are noise (7)
  +--->         564900 of those are water (9)
  +--->          44304 of those are bridge deck (17)
  +--->        4181627 of those are Reserved for ASPRS Definition (18)
```

*Figure 12: Statistics showing the classes of all the LAS points within the project area (Block F).*

```
          26524  unclassified (1)
     1421073454  ground (2)
      820957841  low vegetation (3)
     2291775788  medium vegetation (4)
     8334381876  high vegetation (5)
          48530  building (6)
      416744149  noise (7)
         858253  water (9)
          12096  bridge deck (17)
       21036752  Reserved for ASPRS Definition (18)
 +-> flagged as withheld:  437780901
  +--->      416744149 of those are noise (7)
  +--->       21036752 of those are Reserved for ASPRS Definition (18)
 +-> flagged as extended overlap: 6565126277
  +--->          12287 of those are unclassified (1)
  +--->      688676655 of those are ground (2)
  +--->      407897676 of those are low vegetation (3)
  +--->     1121505365 of those are medium vegetation (4)
  +--->     4122900802 of those are high vegetation (5)
  +--->          33288 of those are building (6)
  +--->      215581162 of those are noise (7)
  +--->         469679 of those are water (9)
  +--->           9761 of those are bridge deck (17)
  +--->        8039602 of those are Reserved for ASPRS Definition (18)
```

*Figure 13: Statistics showing the classes of all the LAS points within the project area (Block G).*

```
      46144906  unclassified (1)
    5163752883  ground (2)
    1689471333  low vegetation (3)
    4616554361  medium vegetation (4)
   11872305404  high vegetation (5)
        883829  building (6)
    1109387457  noise (7)
       2150987  water (9)
         79116  bridge deck (17)
      27237049  Reserved for ASPRS Definition (18)
+-> flagged as withheld:  1136624506
 +--->      1109387457 of those are noise (7)
 +--->        27237049 of those are Reserved for ASPRS Definition (18)
+-> flagged as extended overlap: 12219098930
 +--->        27687918 of those are unclassified (1)
 +--->      2380374556 of those are ground (2)
 +--->       865306664 of those are low vegetation (3)
 +--->      2360642839 of those are medium vegetation (4)
 +--->      5965339902 of those are high vegetation (5)
 +--->          584398 of those are building (6)
 +--->       611651312 of those are noise (7)
 +--->         1134439 of those are water (9)
 +--->           55995 of those are bridge deck (17)
 +--->         6320907 of those are Reserved for ASPRS Definition (18)
```

*Figure 14: Statistics showing the classes of all the LAS points within Blocks F&G (Rev1).*

```
584507  unclassified (1)
3703758369  ground (2)
1096458573  low vegetation (3)
2462052088  medium vegetation (4)
3911928480  high vegetation (5)
830619  building (6)
423358202  noise (7)
1533510  water (9)
76754  bridge deck (17)
17599387  Reserved for ASPRS Definition (18)
+-> flagged as withheld:  440957589
+--->      423358202 of those are noise (7)
+--->       17599387 of those are Reserved for ASPRS Definition (18)
+-> flagged as extended overlap: 6081427451
+--->         418641 of those are unclassified (1)
+--->     1764135424 of those are ground (2)
+--->      590575783 of those are low vegetation (3)
+--->     1364074916 of those are medium vegetation (4)
+--->     2115086303 of those are high vegetation (5)
+--->         549107 of those are building (6)
+--->      241122678 of those are noise (7)
+--->         837569 of those are water (9)
+--->          53990 of those are bridge deck (17)
+--->        4573040 of those are Reserved for ASPRS Definition (18)
```

*Figure 15: Statistics showing the classes of all the LAS points within Blocks F&G (Rev2).*

```
         20954  unclassified (1)
      66577057  ground (2)
      12305458  low vegetation (3)
      27736240  medium vegetation (4)
      29497079  high vegetation (5)
         20243  building (6)
       8655076  noise (7)
       2772185  water (9)
           214  bridge deck (17)
        351985  Reserved for ASPRS Definition (18)
+-> flagged as withheld:  9007061
 +--->        8655076 of those are noise (7)
 +--->         351985 of those are Reserved for ASPRS Definition (18)
+-> flagged as extended overlap: 91527471
 +--->          17882 of those are unclassified (1)
 +--->       33834022 of those are ground (2)
 +--->        9129676 of those are low vegetation (3)
 +--->       20687115 of those are medium vegetation (4)
 +--->       21449556 of those are high vegetation (5)
 +--->           9925 of those are building (6)
 +--->        5165104 of those are noise (7)
 +--->        1049919 of those are water (9)
 +--->             20 of those are bridge deck (17)
 +--->         184252 of those are Reserved for ASPRS Definition (18)
```

*Figure 16: Statistics showing the classes of all the LAS points within Blocks F&G (Rev3).*

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.

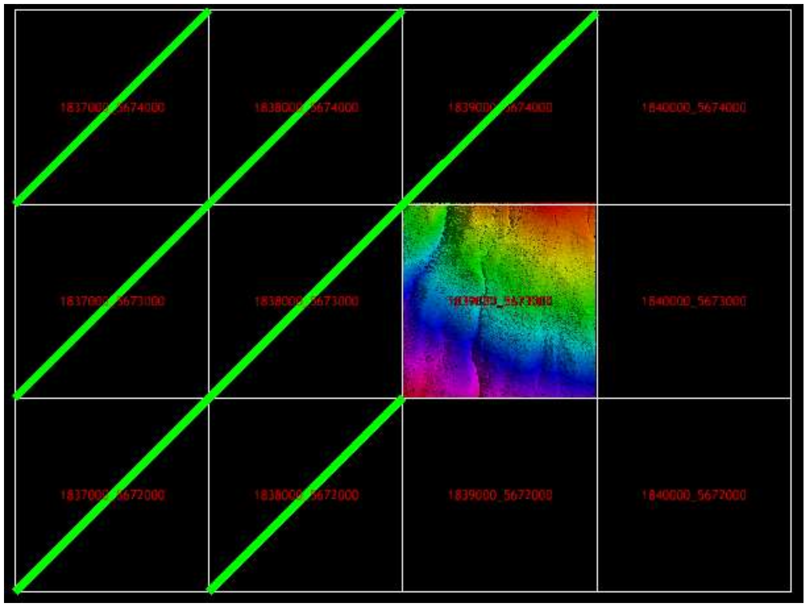



*Figure 17: The diagonal hatching seen above shows how the progress was tracked – Block F*

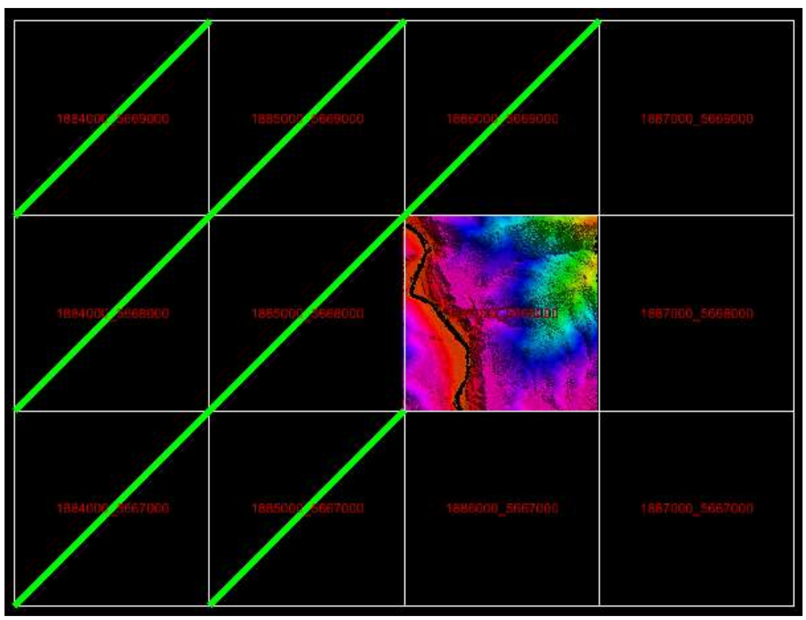



*Figure 18: The diagonal hatching seen above shows how the progress was tracked – Block G*

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.

### 2.8.1 Building Classification

The classification of building points has been undertaken by utilizing the TerraScan *buildings* routine. This routine classifies points on buildings which form a planar surface, several rules can be set to fine tune these results including the minimum building size/footprint, z tolerance of the point alignment along the roof line and use of echo information.

The use of echo information can further support the classification as points on roofs mostly belong to the echo type 'only echo' whereas vegetation usually contains a lot of 'first of many' and 'intermediate' echoes.

Additionally, the LINZ building footprint was also integrated into the building classification workflow to further constrain the classification and improve the overall output.

### 2.8.2 Vegetation & Low-Level Noise Classification:

In agreeance with all parties, Woolpert have classified the lower 0 – 0.3m of the low vegetation class to class 7 (low noise).

This was done to effectively remove the lower noise stratification points and unused ground points from class 3 over areas which do not represent vegetation e.g. man-made surfaces and structures (sealed roads).

The remaining vegetation points were classified using TerraScan's classify *By height from ground* which uses the ground surface to calculate the distance of each point above and below ground. All identified vegetation points were classified to the nominated classes using the height ranges specified in the *New Zealand Nation Aerial LiDAR Base Specification* (See below).

**Table 4 Minimum LAS point cloud classification scheme**

| Code | Description |
|---|---|
| 1 | Processed, but unclassified |
| 2 | Ground |
| 3 | Low vegetation <2m |
| 4 | Medium vegetation |
| 5 | High vegetation >8m |
| 6 | Building |
| 7 | Low noise |
| 9 | Water |
| 18 | High noise |

## 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.

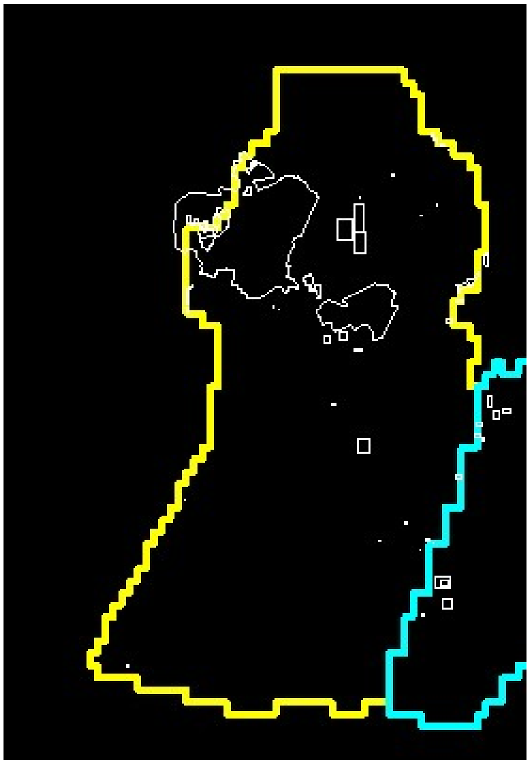


*Figure 19: The polygons are areas for further investigation – Block F*

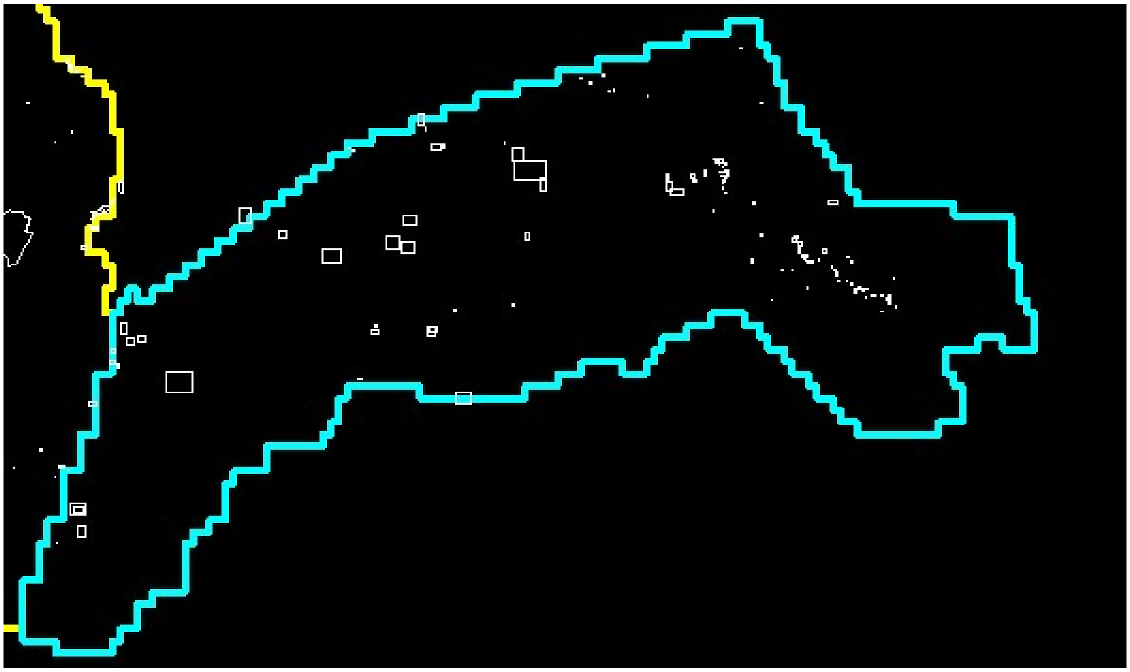


*Figure 20: The polygons are areas for further investigation – Block G*

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 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.

Further figures and commentary is contained within the defect spreadsheet supplied in Appendix A.

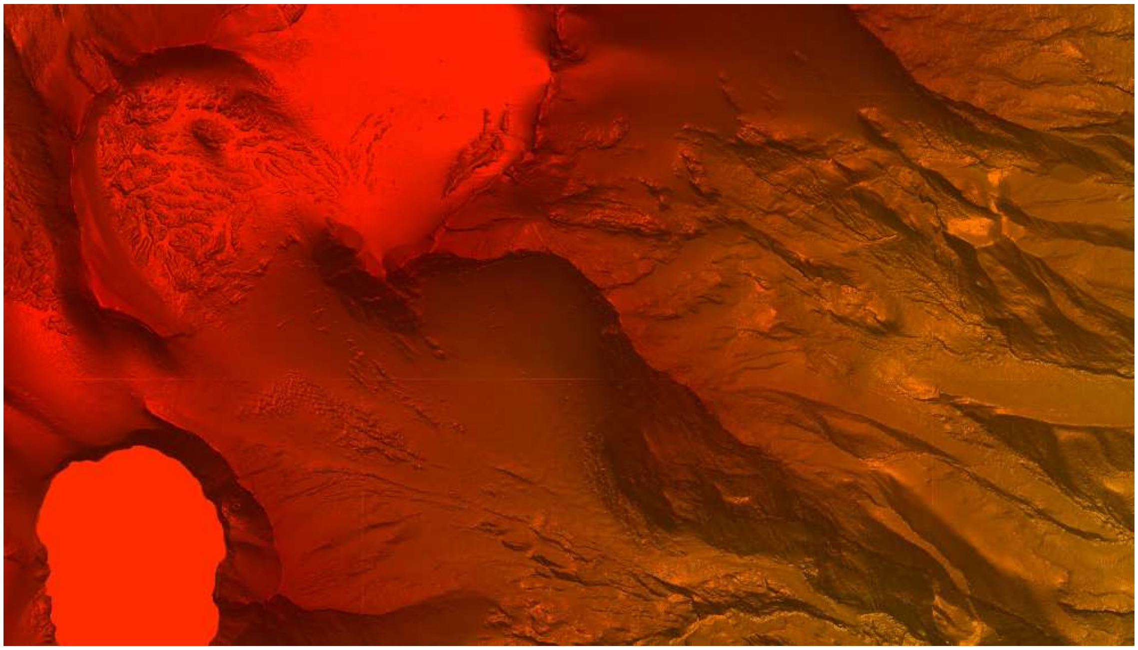


*Figure 21: Example overhead image of DEM over cliffs*

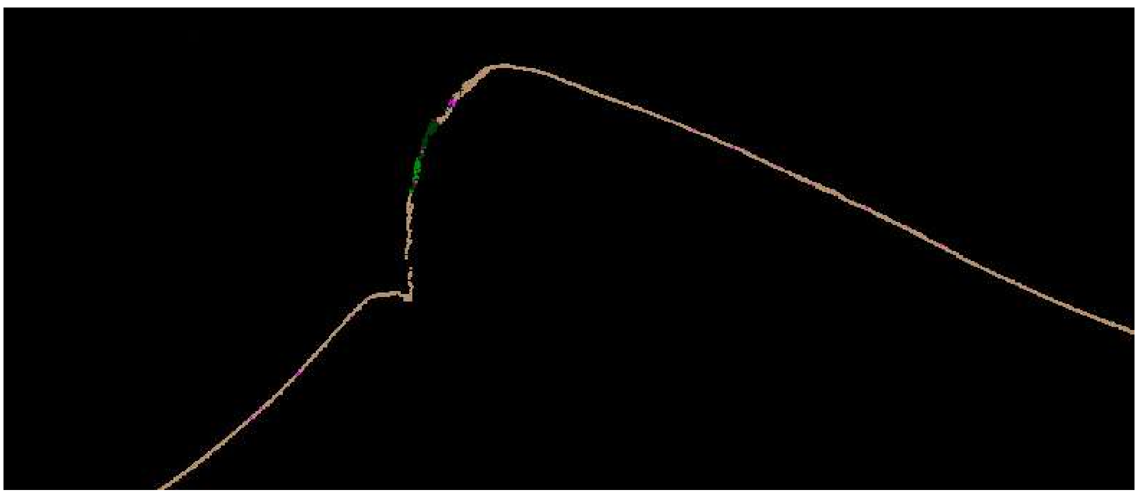


*Figure 22: LAS point cloud profile view from previous figure*

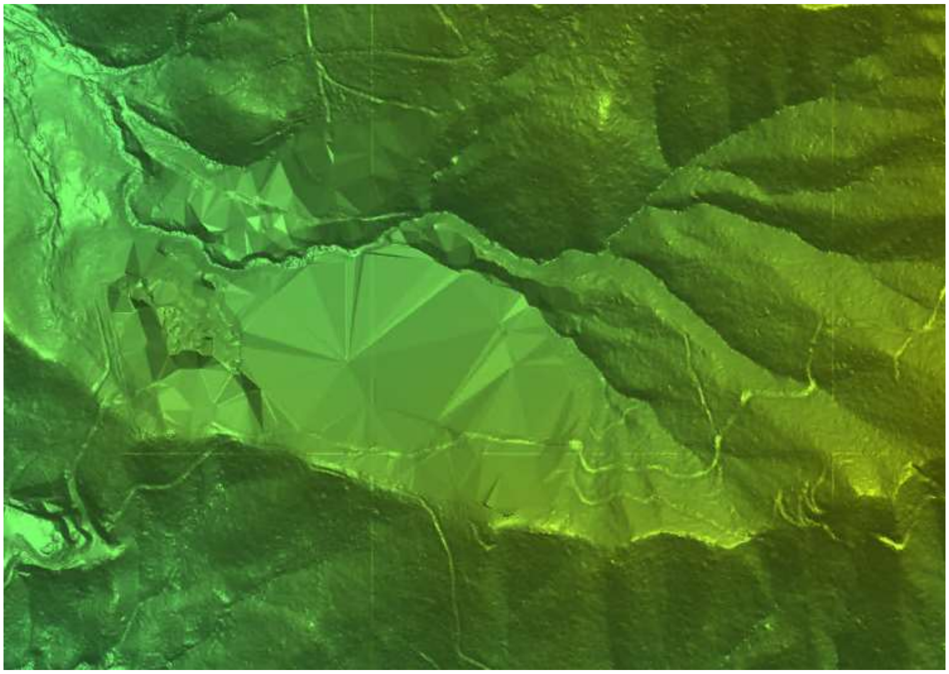


*Figure 23: Example overhead image of DEM interpolation*

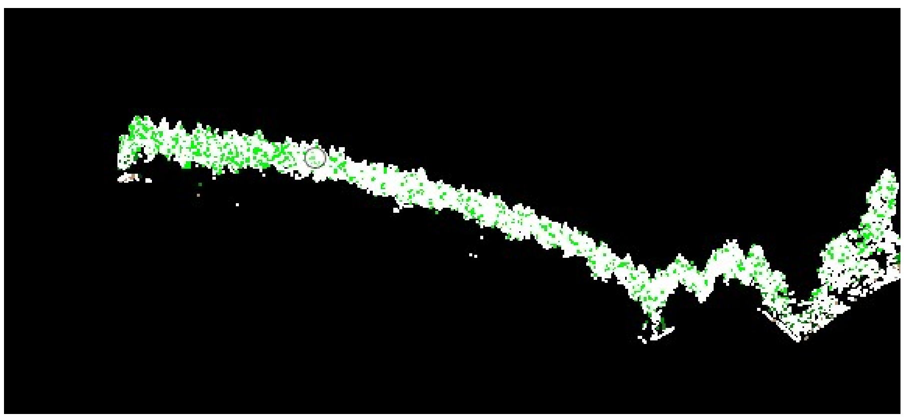


*Figure 24: LAS Point cloud view from previous figure*

## 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 – 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 examples shows the DEM where a bridge has been removed.

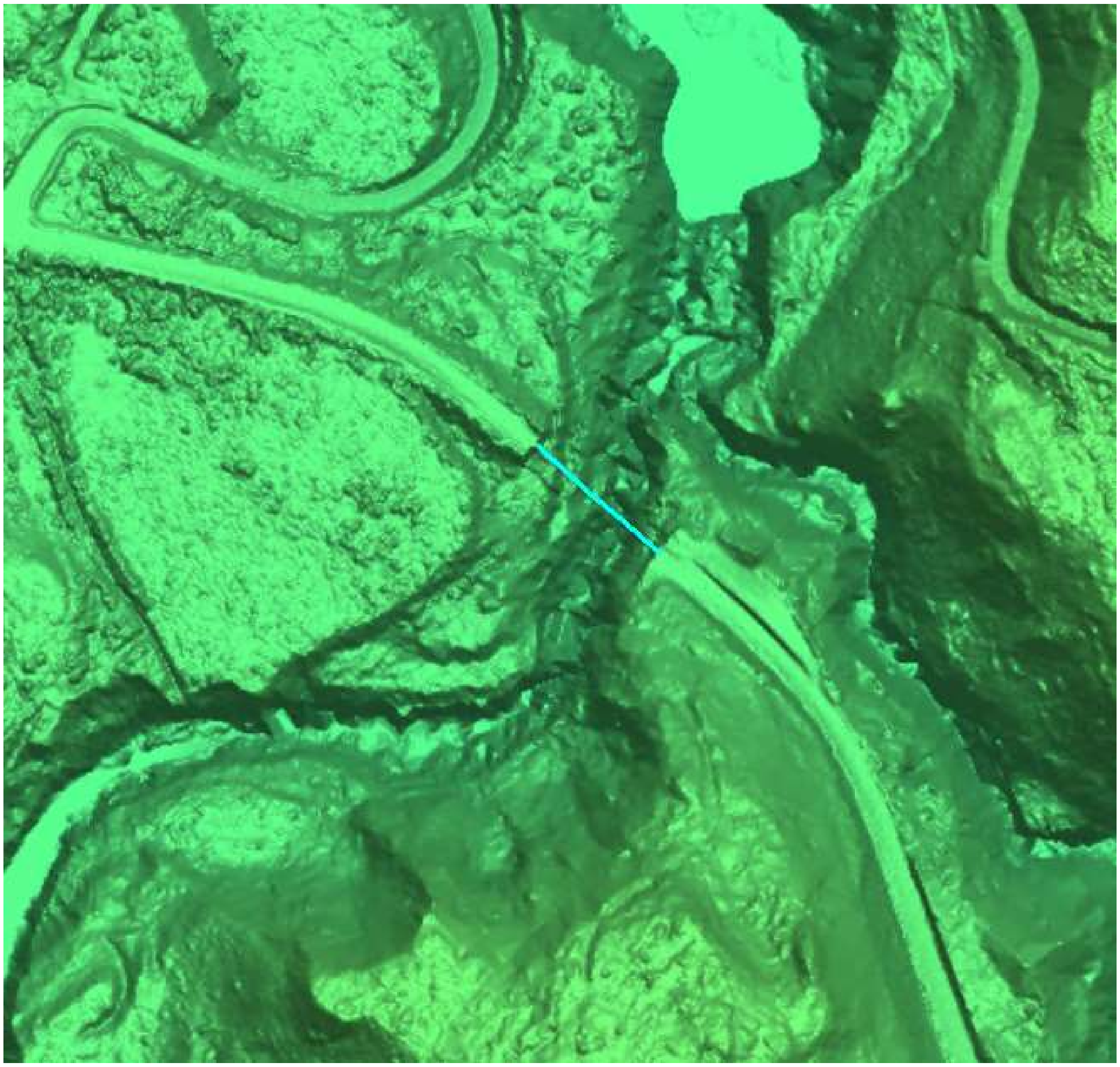


Figure 25: Tile DEM_BH35_2021_1000_4134 with LINZ bridge centreline

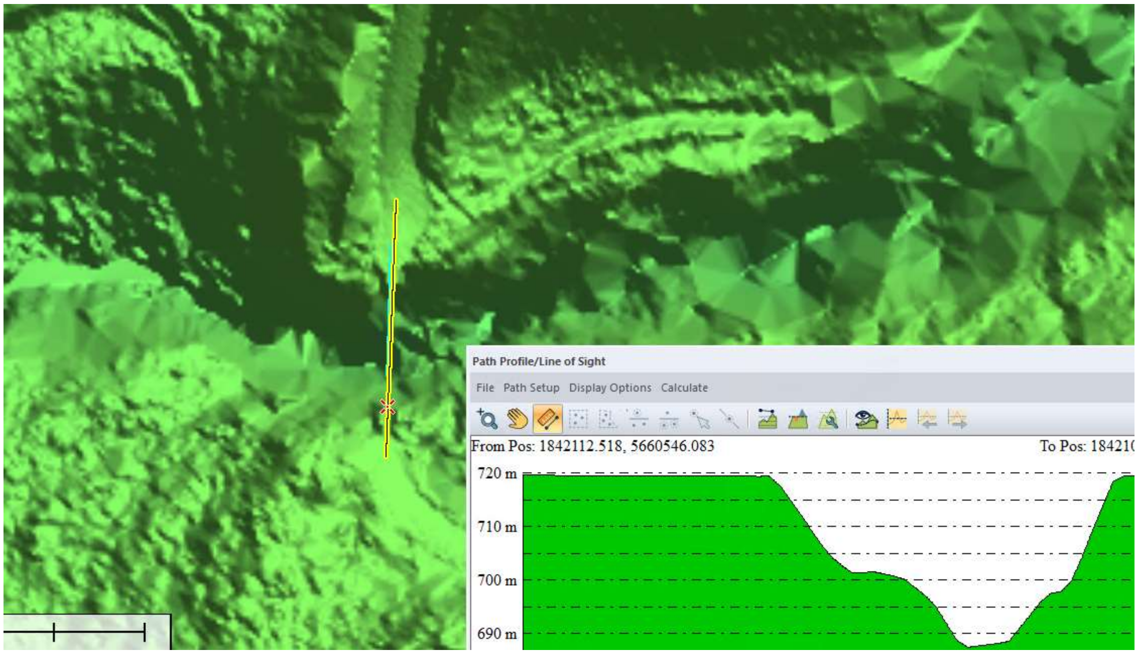



*Figure 26: DEM Tile BH35_2021_1000_4730*

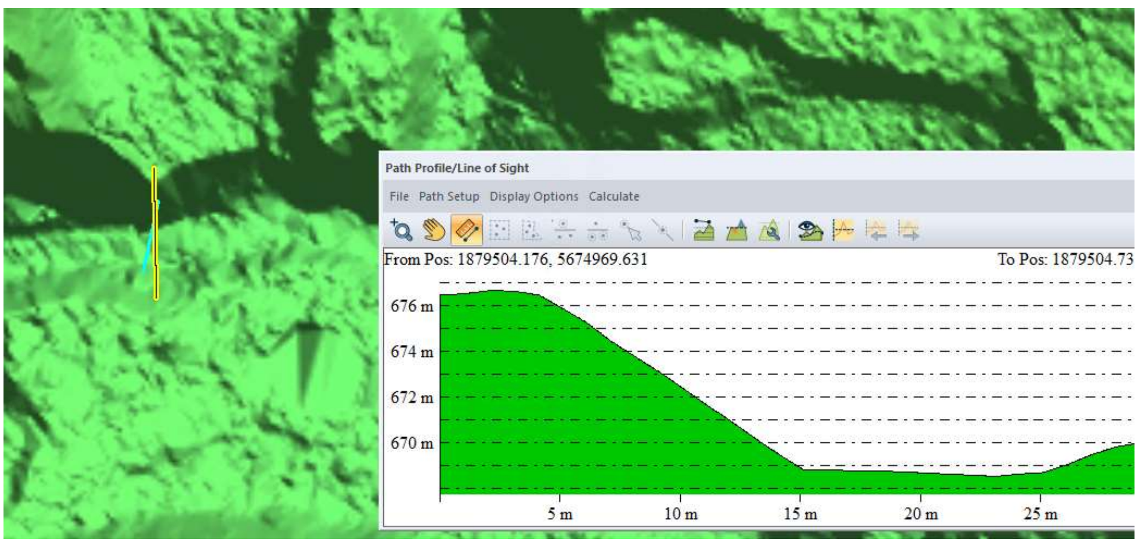



*Figure 27: DEM Tile BH37_2021_1000_2708*

# 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 000m$^2$ or larger in size.

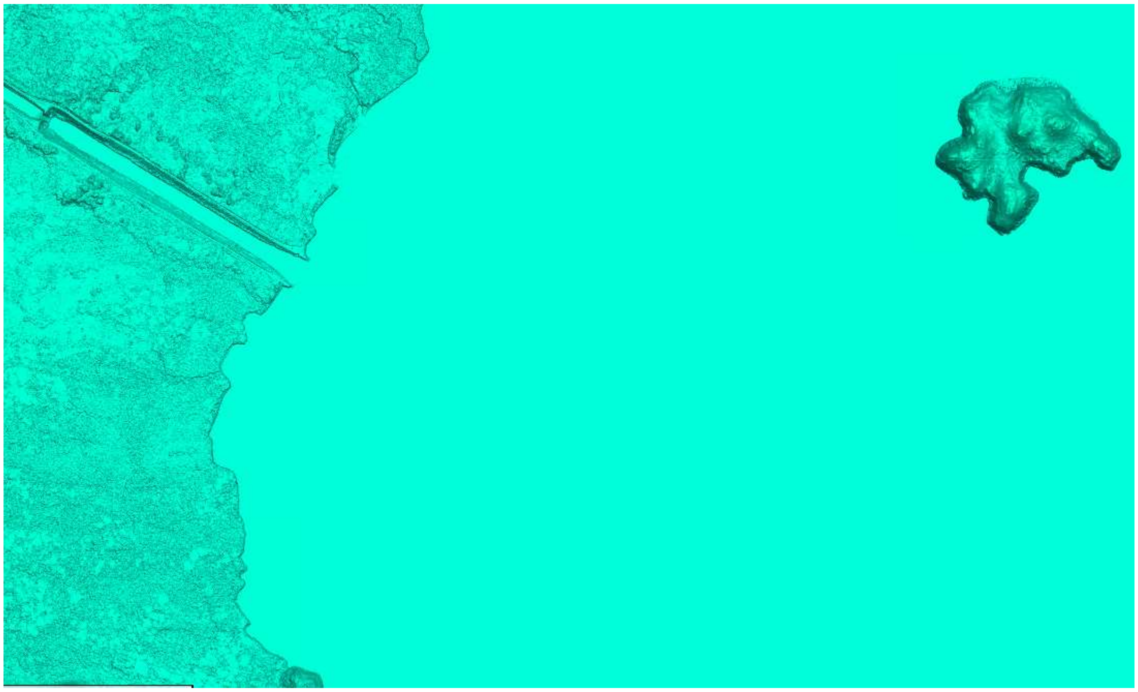


*Figure 28: Example of a hydro-flattened DEM Lake Tile DEM_BH35_2021_1000_2611*

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.

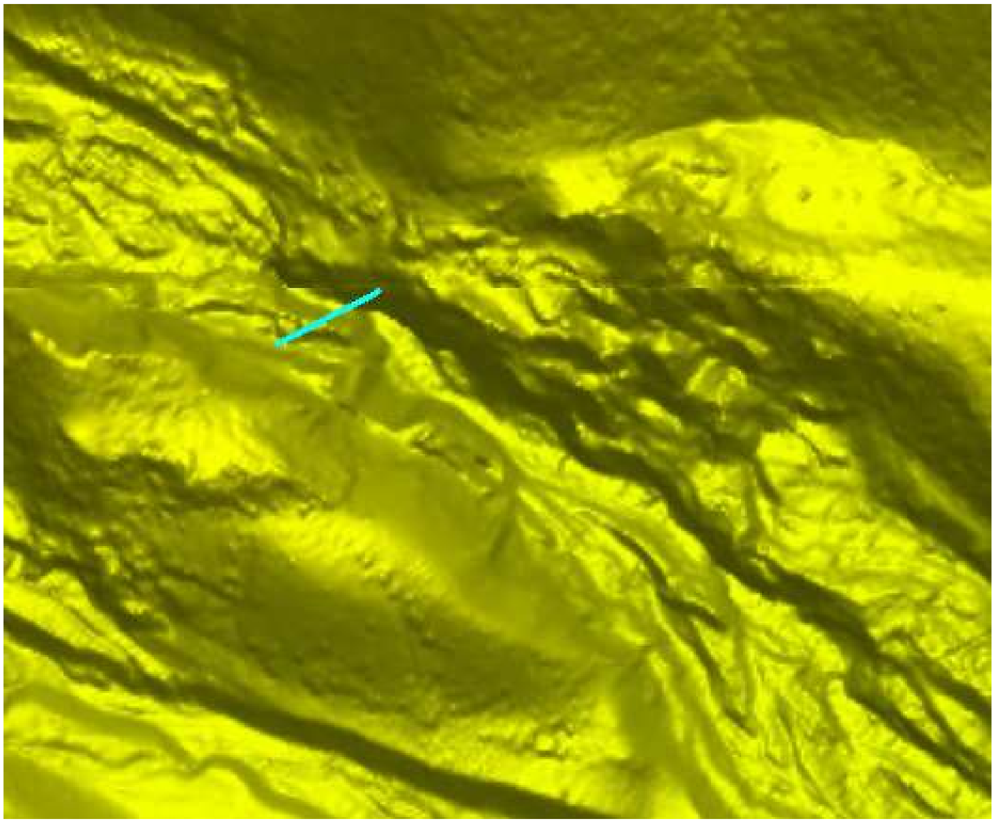


Figure 29: Example of Bridge with LINZ bridge centreline

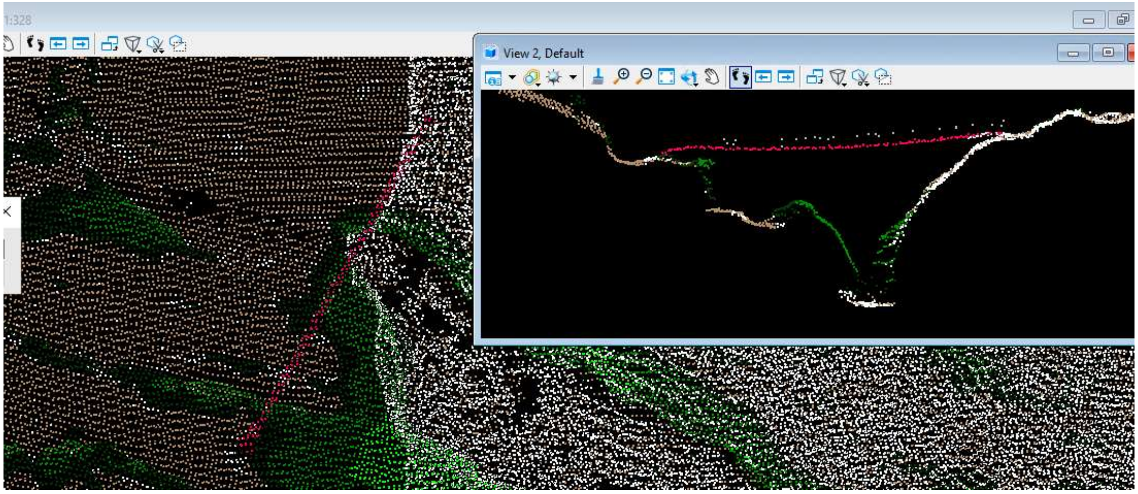



Figure 30: Same location as above DEM.

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.

| | | | |
|---|---|---|---|
| 1 | 1929744.8358 | 5615128.2638 | 7.7096 |
| 2 | 1929746.0769 | 5615130.8498 | 7.6863 |
| 3 | 1929746.4280 | 5615131.5996 | 7.6796 |
| 4 | 1929746.5107 | 5615131.7727 | 7.678 |
| 5 | 1929746.7841 | 5615132.3591 | 7.6728 |
| 6 | 1929748.0794 | 5615135.0799 | 7.6483 |
| 7 | 1929748.5703 | 5615136.1455 | 7.6388 |
| 8 | 1929749.4246 | 5615138.0643 | 7.622 |
| 9 | 1929749.8587 | 5615139.0742 | 7.6132 |
| 10 | 1929750.6288 | 5615140.9327 | 7.5973 |
| 11 | 1929751.0393 | 5615141.7916 | 7.5896 |
| 12 | 1929751.5292 | 5615142.7809 | 7.5805 |
| 13 | 1929754.3861 | 5615148.3485 | 7.529 |
| 14 | 1929754.7868 | 5615149.1041 | 7.5219 |
| 15 | 1929754.7991 | 5615149.1267 | 7.5217 |
| 16 | 1929757.3347 | 5615152.1834 | 7.4808 |
| 17 | 1929757.8445 | 5615152.7752 | 7.4594 |

*Figure 31: Excerpt of river points used to create the centreline*

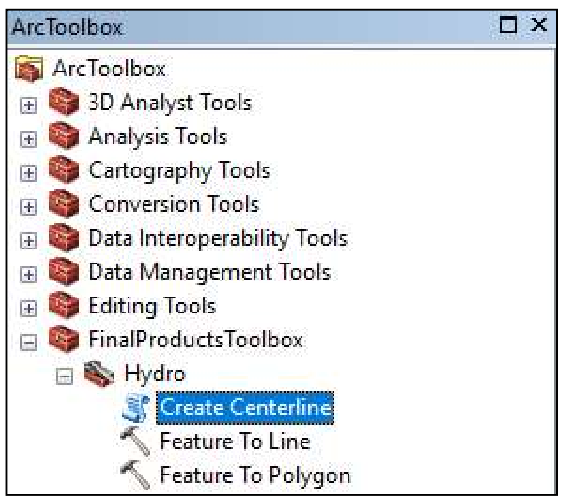



*Figure 32: Centreline for the stream within the project's survey*

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:

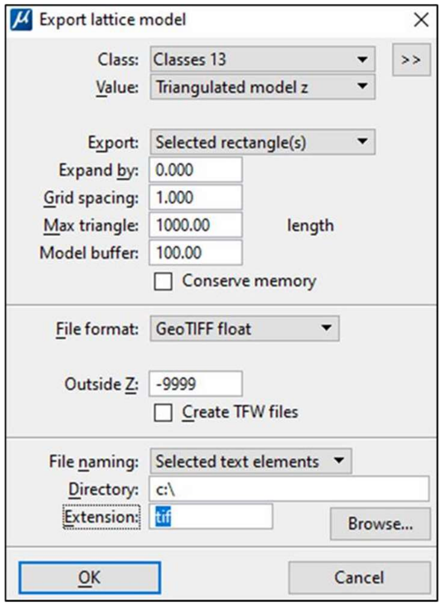



*Figure 33: Settings used to export lattice models.*

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.

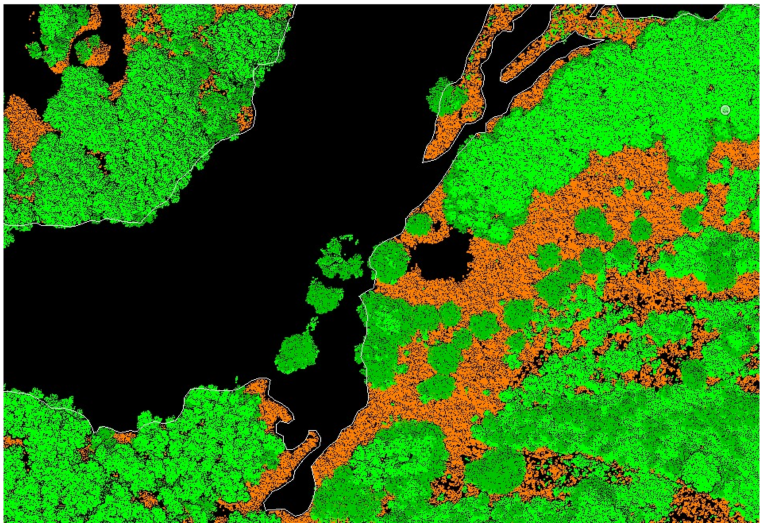


*Figure 34: Pre-filter, overhead view of ground and veg points with hydro lines*

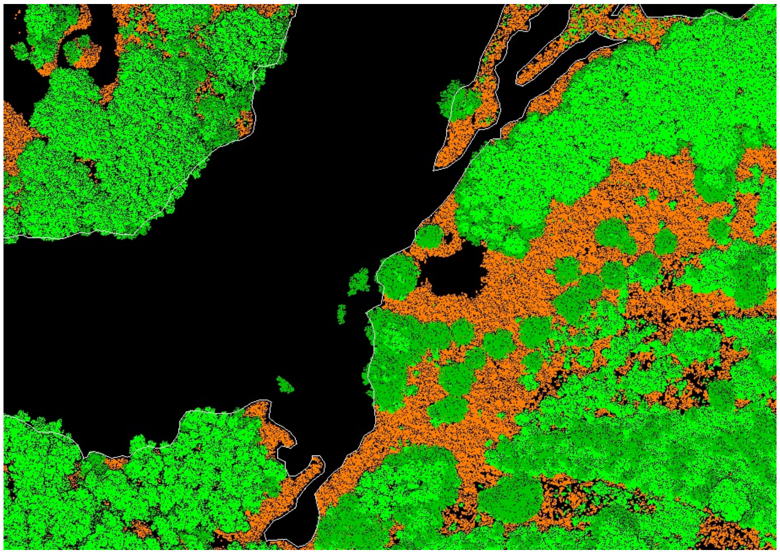


*Figure 35: Post-filter, overhead view of ground and veg points with hydro lines*

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 36: Point cloud – boulder filled stream*


*Figure 37: Imagery – boulder filled stream*

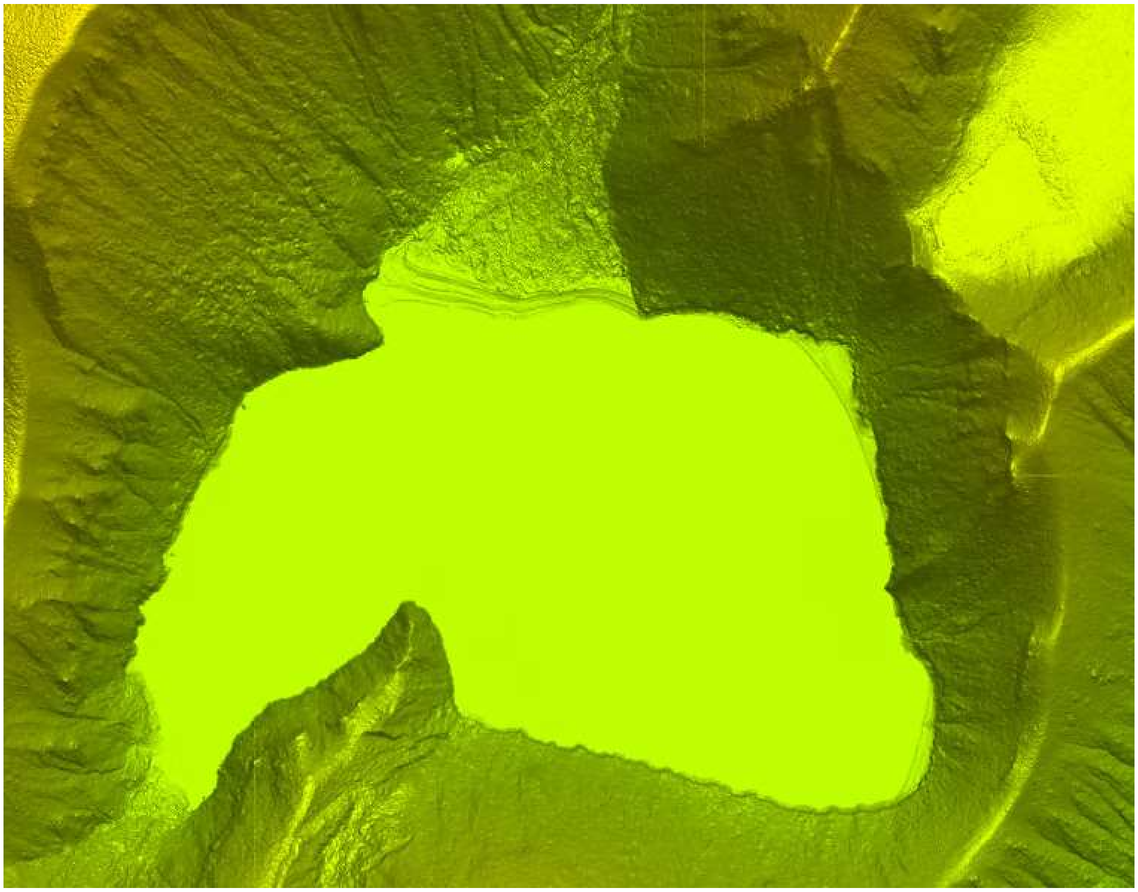


*Figure 38: Example of hydroflattened DEMs: DEM_BH34_2021_1000_4947*

# 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 F was captured using Leica TerrainMapper sensor 513 and 559, flown on day 25$^{th}$ January 2021. The extent of Block F can be seen in Figure 25. The flight lines relating to the area can be seen in Figure 28.

The data for Block G was captured using Leica TerrainMapper sensor 513 and 559, flown on days 25$^{th}$, 26$^{th}$ & 31$^{st}$ January 2021. The extent of Block G 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 figure 41.

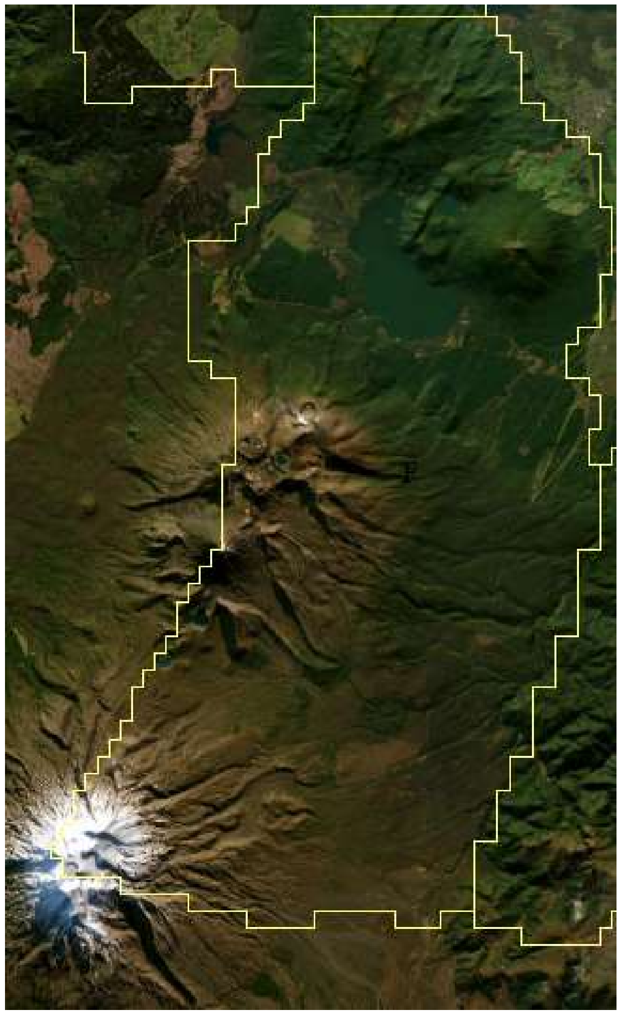


*Figure 39: Extent of deliverable data for Block F*

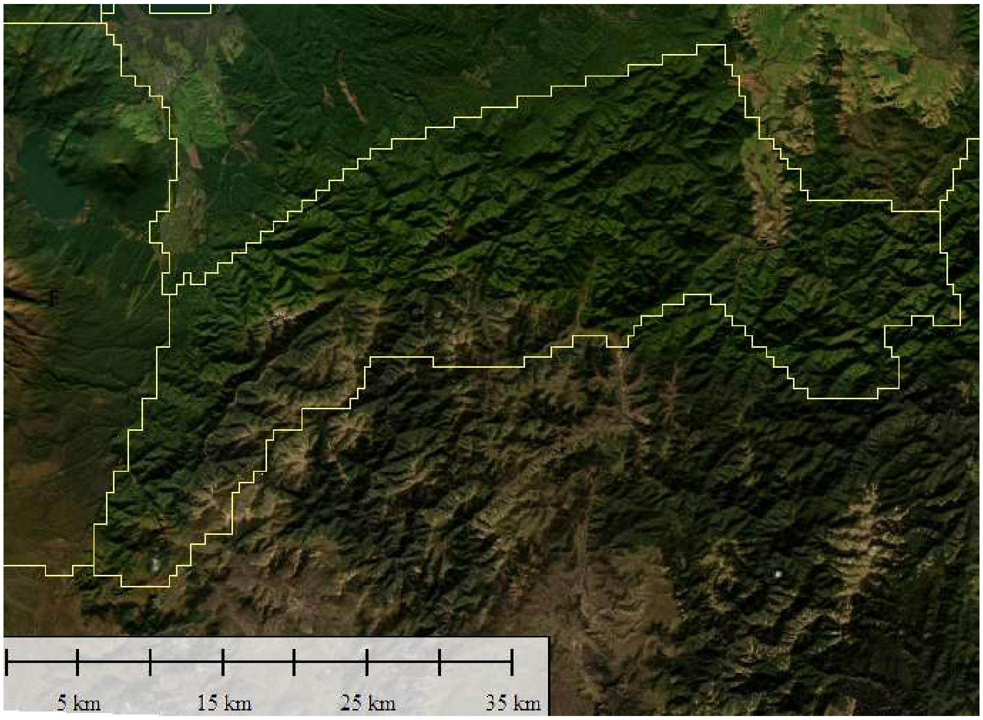



*Figure 40: Extent of deliverable data for Block G*

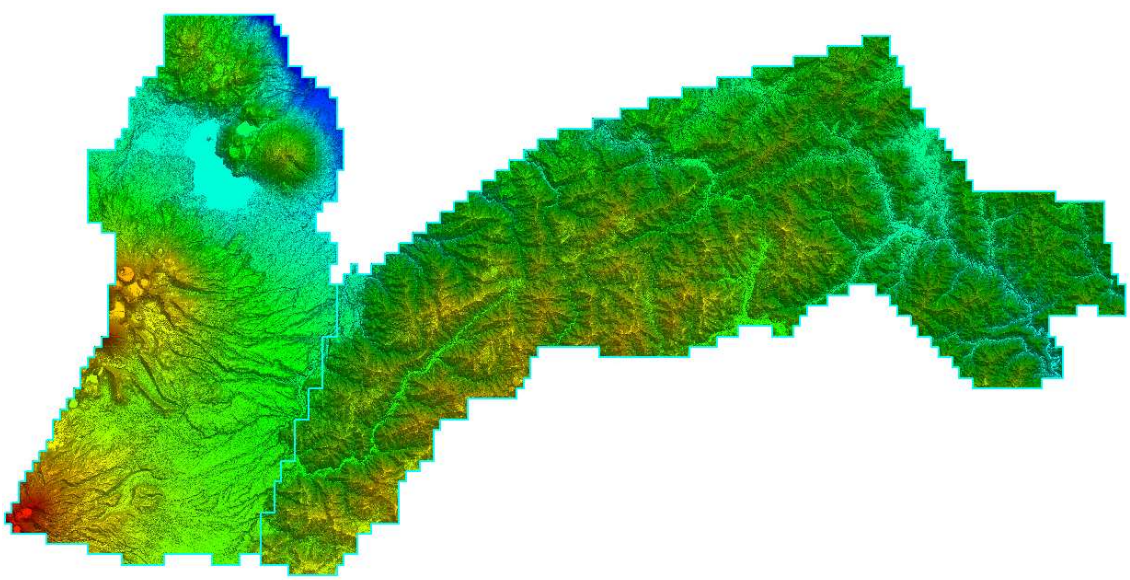


*Figure 41: Extent of deliverable data for Block F & G - DEM*

### 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.

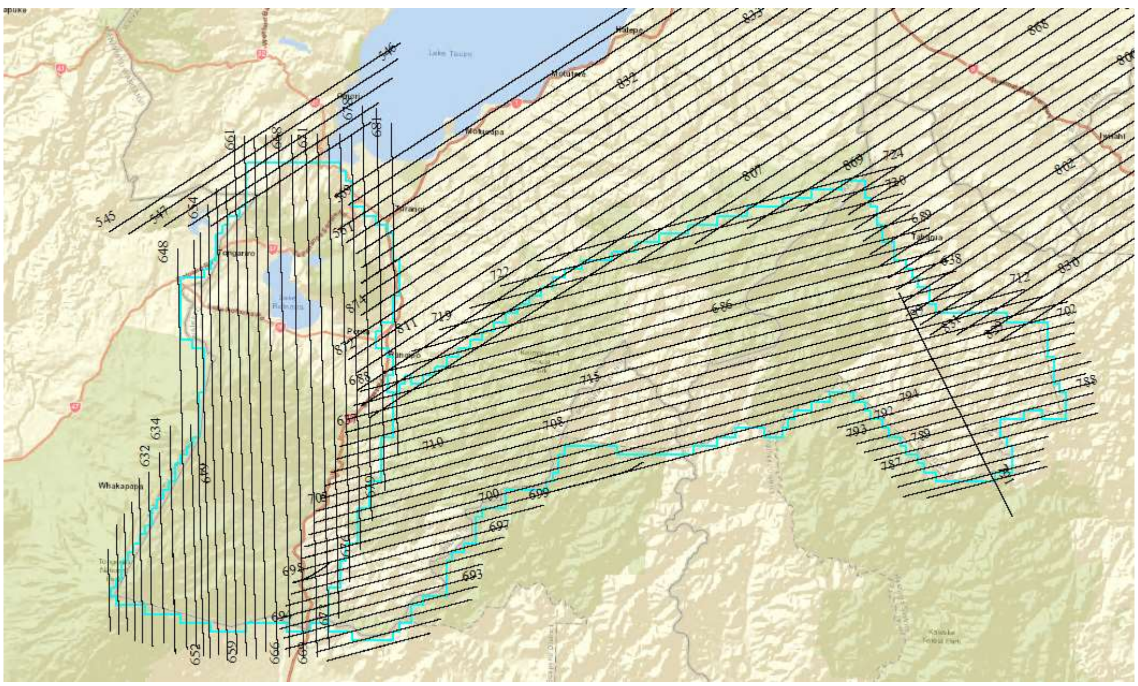


*Figure 42: Flight lines for 4ppm2 data coverage over Block F & G*

## 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 43: WKT of a LAS file shown by LASTools.*

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.

| File | Points | Version | File Signature | File Source ID | CRS is WKT | Coordinate System |
|---|---|---|---|---|---|---|
| CL2_BH35_2021_1000_4101.las | 4,832,688 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BH35_2021_1000_4102.las | 3,891,585 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BH35_2021_1000_4103.las | 3,829,035 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BH35_2021_1000_4104.las | 4,421,763 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BH35_2021_1000_4105.las | 3,242,130 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BH35_2021_1000_4106.las | 4,140,306 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BH35_2021_1000_4107.las | 3,918,064 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BH35_2021_1000_4108.las | 3,335,392 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BH35_2021_1000_4109.las | 4,151,556 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BH35_2021_1000_4110.las | 2,464,457 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BH35_2021_1000_4111.las | 4,105,340 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BH35_2021_1000_4112.las | 2,590,690 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BH35_2021_1000_4113.las | 3,965,798 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BH35_2021_1000_4114.las | 2,309,666 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BH35_2021_1000_4115.las | 4,815,002 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BH35_2021_1000_4116.las | 3,133,834 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BH35_2021_1000_4117.las | 4,476,117 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BH35_2021_1000_4118.las | 4,170,609 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BH35_2021_1000_4119.las | 4,831,415 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |
| CL2_BH35_2021_1000_4120.las | 6,304,948 | 1.4 | LASF | 0 | TRUE | NZGD2000 / NZGD2000 / New Zealand Transverse Mercator 2000 + NZVD2016 |

*Table 2: Representative output from LP360 illustrating LAS file specification compliance- Block F & G*

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 analysist 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.

It is noted for Blocks F & G due to the dense vegetation and steep terrain the penetration of the LiDAR to the ground in some areas is minimal (Figure 18 is a good example). This will show in the DEM as large, triangulated areas or give the impression of pitting where only isolated ground returns have been identified.
For these areas it is recommended to compare any potential DEM discrepancies with the point cloud to confirm the absence of available ground points.

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.

| File | Format | NoData Value | BPB | Bands | Data Type | Pixel Size | Coordinate System |
|---|---|---|---|---|---|---|---|
| DEM_BH35_2021_1000_4904.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BH35_2021_1000_4905.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BH35_2021_1000_4906.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BH35_2021_1000_4907.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BH35_2021_1000_4908.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BH35_2021_1000_4909.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BH35_2021_1000_4910.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BH35_2021_1000_4911.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BH35_2021_1000_4912.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BH35_2021_1000_4913.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BH35_2021_1000_4914.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BH35_2021_1000_4915.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BH35_2021_1000_4916.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BH35_2021_1000_4917.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BH35_2021_1000_4918.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BH35_2021_1000_4919.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BH35_2021_1000_4920.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BH35_2021_1000_4921.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BH35_2021_1000_4922.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DEM_BH35_2021_1000_4923.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |

*Table 3: Condensed output from LP360 illustrating DEM file specification compliance – Block F & G*

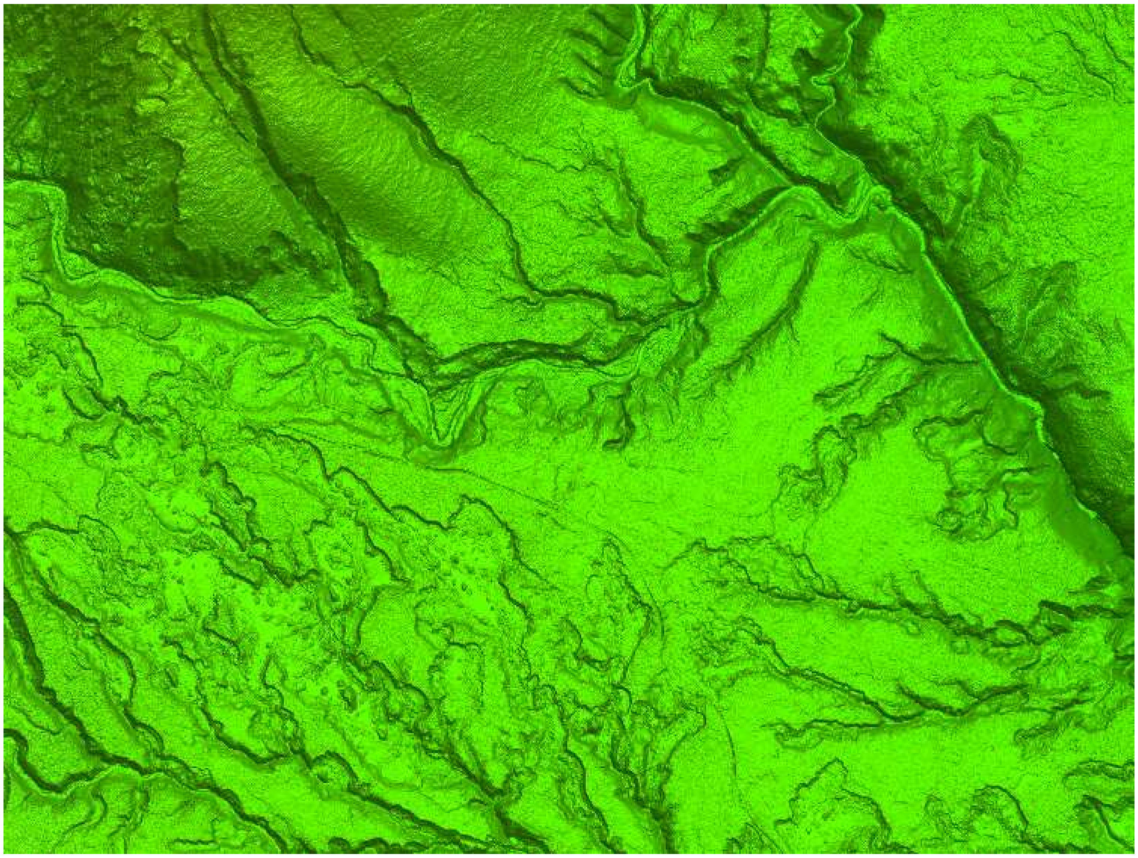


*Figure 44: DEM Example Tile DEM_BJ35_2021_1000_0314*

### 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.

*Figure 45: Excerpt from DSM_BH35_2021_1000_3428 – Block F*

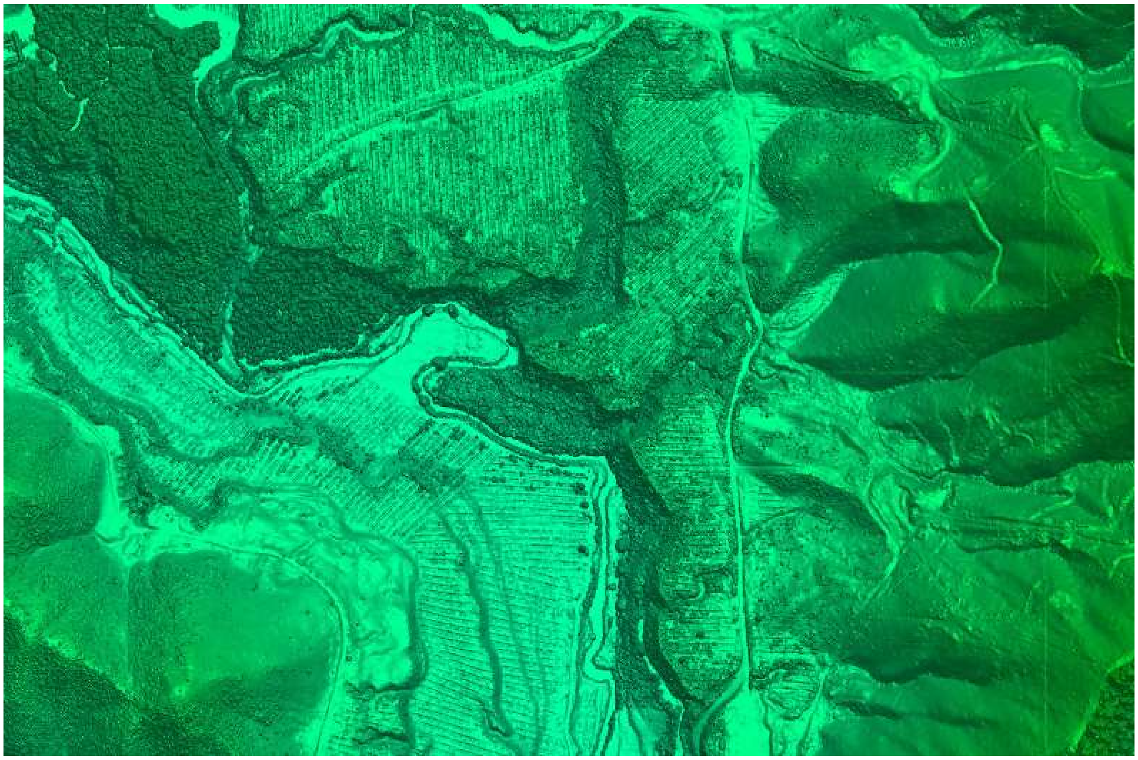


*Figure 46: Excerpt from DSM_BH37_2021_1000_3222 Block G*

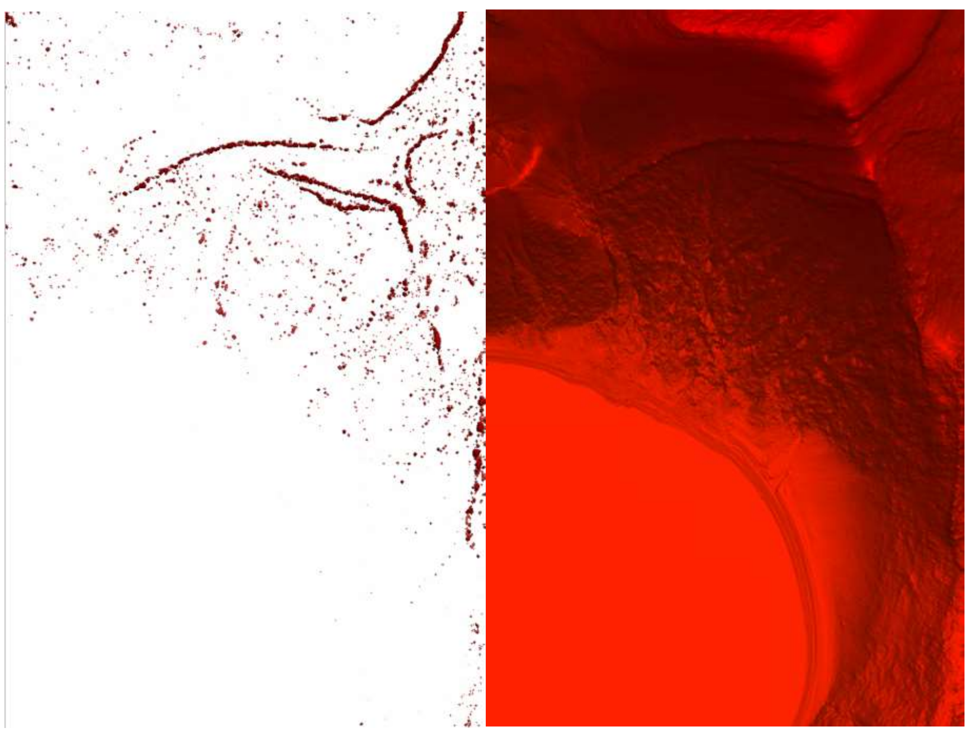
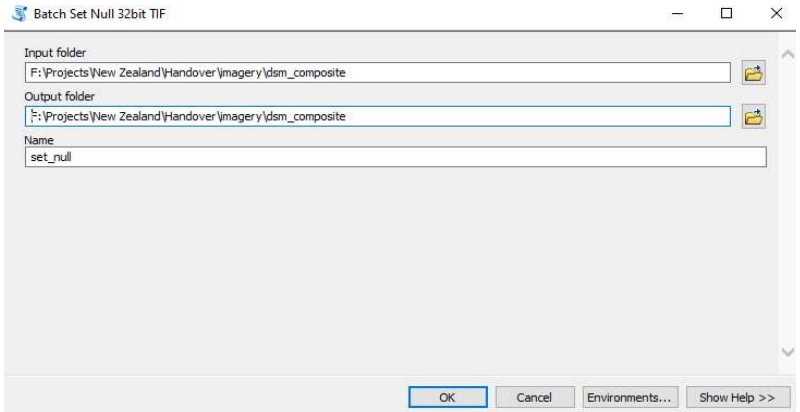


*Figure 47: Difference between DSM and DEM differences in height along cliff lines*

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.




| | |
|---|---|
| Format | IMAGINE Image |
| Source Type | Generic |
| Pixel Type | floating point |
| Pixel Depth | 32 Bit |
| NoData Value | -9999 |

*Figure 49: 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.

| File | Format | NoData Value | BPB | Bands | Data Type | Pixel Size | Coordinate System |
|---|---|---|---|---|---|---|---|
| DSM_BH35_2021_1000_4805.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BH35_2021_1000_4806.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BH35_2021_1000_4807.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BH35_2021_1000_4808.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BH35_2021_1000_4809.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BH35_2021_1000_4810.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BH35_2021_1000_4811.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BH35_2021_1000_4812.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BH35_2021_1000_4813.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BH35_2021_1000_4814.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BH35_2021_1000_4815.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BH35_2021_1000_4816.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BH35_2021_1000_4817.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BH35_2021_1000_4818.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |
| DSM_BH35_2021_1000_4819.tif | GTiff | -9999 | 32 | 1 | FLOAT | 1 | EPSG: 2193 |

*Table 4: LP360 DSM Results example table – Block F& G*

## 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.

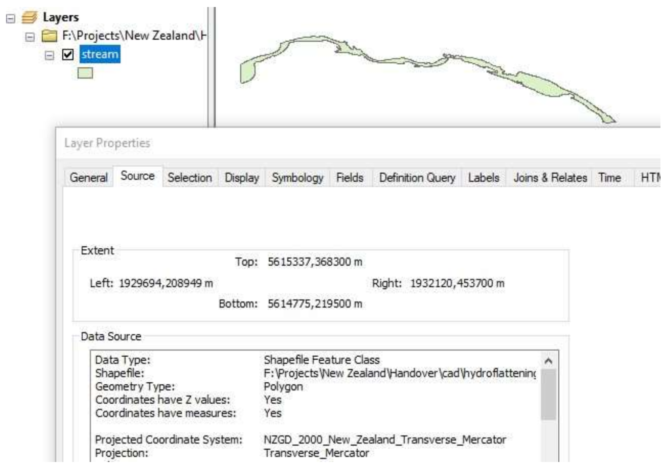



*Figure 50: Stream break line properties in ArcMap.*

## 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

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 samples have been provided including those that straddle block joins.

Contours will be generated at 1,5 and 10 metre markers. They will adopt a naming convention as per WRC suggestion e.g. CRT_BB35_2021_1000_1515.

CRT refers to Cartographic and opposed to engineering contours.

# 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_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.

o Check for presence of correct ESPG Codes for geodetic & vertical datums, and map projection

o 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.

| | | |
|---|---|---|
| Naming Convention for point clouds, DEMs, and other tiled products<br>*[product]_[sheet]_[year]_[scale]_[tile].[ext]* | | |
| **Product** | *DEM* | **CL2-Point Cloud Classification Level 2**<br>**DEM-Bare Earth Digital Elevation Model**<br>**DSM-Digital Surface Model**<br>DTM-Digital Terrain Model<br>UNC-Unclassified Point Cloud<br>INT-Intensity image<br>CHM – Canopy Height Model<br>IMG-Aerial photography<br>etc |
| **Sheet** | *BK34* | LINZ Topo50 identifier (4 characters) |
| **Year** | *2016* | Year of survey commencement |
| **Scale** | *1000* | Nominal scale of NZTopo50 subtiles |
| **Tile** | *4118* | Row number (41), Column number (18) of tile with respect to an upper left origin |
| **ext** | *tif* | File extension according to format conventions<br>las<br>tif<br>shp<br>etc |
| *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-flatting break line bank line strings
│       │ └───stream_islands – Hydro-flatting 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 Blocks F&G

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 Resupply of Blocks F&G

Blocks F & G required extensive manual rework. The dense vegetation including Beech forests present in this area caused issues with the automated classification. This was compounded by the lack of LiDAR penetration through this vegetation. The automated classification incorrectly classified the tops of vegetation as ground, due to the lack of penetration. This has been rectified with the most recent supply. Further information can be found in the defect spreadsheet.

## 6.4 Resupply of Blocks F&G (Rev2)

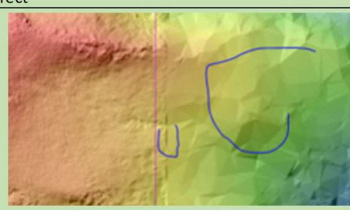
Further manual rework was carried out on these blocks supported by information supplied by LINZ and WRC. Repairs were made to the Pointcloud, DEM and DSM. Please refer to the spreadsheet for explanation of what was required and the fixes implemented.

## 6.5 Resupply of Blocks F&G (Rev3)

Further manual rework was carried out on these blocks supported by information supplied by LINZ and WRC. Repairs were made to the Pointcloud, DEM and DSM.

Specific Polygons were provided by WRC where any small, innocuous vegetation that was present was mandated to turn to ground classification.

Below is a table showing one of the pages of the tracking spreadsheet which was supplied by WRC and LINZ and reviewed and commented on by Ocean Infinity and/or Woolpert. This was further supplemented by shapefiles, geodatabase files, reference images / snips and other information to support identification, rectification and repair.

| Date | Item | Product | Raised By | Description | Status | Woolpert Comment |
|---|---|---|---|---|---|---|
| 12/03/2024 | 1156 | DSM | DanB | See WRC_Issues_points; Spike in DSM | Fixed | Spikes not identified in laser. Rasters regeneration |
| | | | |  | | |
| 12/03/2024 | | DEM | RossM | See WRC_issues_polygons; Disasterous triangulation on DEM surface introduced since v2. Fix patch, check boundary of patch for linear texture defect | Fixed | Spikes not identified in laser. Rasters regeneration |
| | | | |  | | |
| | | | | | | |
| 12/03/2024 | | All | EmoryB | See LINZ_failed items and LINZ shapefiles | Fixed | Fixed where issues raised. Vegetation in ground over alpine areas hasn't as per initial WRC instructions |
| | | | | | | |
| | | | | | | |
| 12/03/2024 | | PC | DanB | [I51 PC HDR COORDSYS WKT] - Two las tiles with a coordinate system string which parses to NZTM, but is inconsistent with master WKT coordsys string. Please refer to image [PGF LAS WKT COORDSYS]. | Fixed | Updated - BJ34-937 & BJ34-938 |
| | | | | | | |
| 12/03/2024 | | PC | DanB | [I54 POINT SOURCE FLIGHLINE] - One tile CL2_BH35_2021_1000_3930.las with no corresponding flightline data. | Fixed | Updated - Incorrect timestamp for 2030 fixed |
| | | | DanB | See PGF LAS WKT COORDSYS.tiff | Fixed | Updated - BJ34-937 & BJ34-938 |
| 12/03/2024 | | DEM | DanB | Triangles - see PGF DEM TRIANGLE DETECTION.tiff | Fixed | Corrected in latest DEM/DSM generation |

# 7 Results Acceptance & Signoff

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

| Result Acceptance | | | |
|---|---|---|---|
| Assessment Criteria | Status | Completed By | Date |
| Point cloud classification accuracy | Complete | Woolpert/ AAM | 09 May 2023 |
| Point cloud classification consistency | Complete | Woolpert/ AAM | 09 May 2023 |
| Point Cloud LAS tiled deliverables | Complete | Woolpert/ AAM | 09 May 2023 |
| Hydro-flattened Digital Elevation Models | Complete | Woolpert/ AAM | 09 May 2023 |
| Digital Survey Models | Complete | Woolpert/ AAM | 09 May 2023 |
| Contours | Complete | Woolpert/ AAM | 09 May 2023 |
| Extents, Flight Lines, Break lines, Tile Index | Complete | Woolpert/ AAM | 09 May 2023 |
| | | | |
| Project Manager / Supervisor Signoff | Complete | Luke Graham | 16 May 2023 |
| Ocean Infinity Review | Complete | Luke Leydon | 19 May 2023 |

*Table 6: Processing Results Acceptable Signoff*

| Result Acceptance | | | |
|---|---|---|---|
| Assessment Criteria | Status | Completed By | Date |
| Point cloud classification accuracy | Complete | Woolpert/ AAM | 12 August 2023 |
| Point cloud classification consistency | Complete | Woolpert/ AAM | 12 August 2023 |
| Point Cloud LAS tiled deliverables | Complete | Woolpert/ AAM | 12 August 2023 |
| Hydro-flattened Digital Elevation Models | Complete | Woolpert/ AAM | 12 August 2023 |
| Digital Survey Models | Complete | Woolpert/ AAM | 12 August 2023 |
| Contours | Complete | Woolpert/ AAM | 12 August 2023 |
| Extents, Flight Lines, Break lines, Tile Index | Complete | Woolpert/ AAM | 12 August 2023 |
| | | | |
| Project Manager / Supervisor Signoff | Complete | Luke Graham | 12 August 2023 |
| Ocean Infinity Review | Complete | Luke Leydon | 16 August 2023 |

*Table 7: Processing Results Acceptable Signoff (Rev1)*

| Result Acceptance | | | |
|---|---|---|---|
| Assessment Criteria | Status | Completed By | Date |
| Point cloud classification accuracy | Complete | Woolpert/ AAM | 10 October 2023 |
| Point cloud classification consistency | Complete | Woolpert/ AAM | 10 October 2023 |
| Point Cloud LAS tiled deliverables | Complete | Woolpert/ AAM | 10 October 2023 |
| Hydro-flattened Digital Elevation Models | Complete | Woolpert/ AAM | 10 October 2023 |
| Digital Survey Models | Complete | Woolpert/ AAM | 10 October 2023 |
| Contours | Complete | Woolpert/ AAM | 10 October 2023 |
| Extents, Flight Lines, Break lines, Tile Index | Complete | Woolpert/ AAM | 10 October 2023 |
| | | | |
| Project Manager / Supervisor Signoff | Complete | Luke Graham | 10 October 2023 |
| Ocean Infinity Review | Complete | Luke Leydon | 24 October 2023 |

*Table 8: Processing Results Acceptable Signoff (Rev2)*

| Result Acceptance | | | |
|---|---|---|---|
| Assessment Criteria | Status | Completed By | Date |
| Point cloud classification accuracy | Complete | Woolpert/ AAM | 08 April 2024 |
| Point cloud classification consistency | Complete | Woolpert/ AAM | 08 April 2024 |
| Point Cloud LAS tiled deliverables | Complete | Woolpert/ AAM | 08 April 2024 |
| Hydro-flattened Digital Elevation Models | Complete | Woolpert/ AAM | 08 April 2024 |
| Digital Survey Models | Complete | Woolpert/ AAM | 08 April 2024 |
| Contours | Complete | Woolpert/ AAM | 08 April 2024 |
| Extents, Flight Lines, Break lines, Tile Index | Complete | Woolpert/ AAM | 08 April 2024 |
| | | | |
| Project Manager / Supervisor Signoff | Complete | Luke Graham | 08 April 2024 |
| Ocean Infinity Review | Complete | Luke Leydon | 06 May 2024 |

*Table 9: Processing Results Acceptable Signoff (Rev3)*

# Appendix A: Lidar Quality Assurance Results

Provided as separate Documents in Appendix A upload