Land Information New Zealand
Toitū te whenua

New Zealand National Aerial LiDAR Procurement Guidance

Land Information New Zealand

November 2016

Contents

1 Foreword

1.1 Purpose and summary

This document is intended as guidance to local councils and others procuring aerial LiDAR data that will contribute to the Land Information New Zealand (LINZ) led National Elevation Programme.

Such procurements must meet minimum requirements per the New Zealand National LiDAR Base Specification (National Specification) (reference 1), however, most procuring agencies (Contract Authorities) will have additional requirements.

This document is intended to facilitate procurements by taking advantage of the rigour of the National Specification and providing guidance for the inclusion of common upgrades and additional deliverables. The Template section of this document is intended to be edited for inclusion in procurement documents such as Request For Proposals (RFPs) and contracts.

1.2 Background

This document was developed with the National Specification, and provides additional information and guidance which is outside the scope of the National Specification.

1.3 References

1. New Zealand National LiDAR Base Specification, Land Information New Zealand, 2016
2. LiDAR Base Specification version 1.2, United States Geological Survey, November 2014

1.4 Intended use of template

The template is intended to be copied into the applicable sections of RFPs and contracts for LiDAR data and deliverables that may be used by the National Elevation Programme.

The **bold text** is intended to be copied verbatim or modified as relevant for RFPs and contracts, the highlighted text in [square brackets] is to be updated by the Contract Authority, and the *italicised text* is commentary that should be deleted. For ease of reference, the applicable section in the specification is referenced in the commentary.

2 Template

2.1 Copyright and Creative Commons

[Section 3. Repeated from the National Specification as it is commonly included separately from technical requirements in procurement documents.]

[The Contract Authority] requires unrestricted copyright to all delivered data and reports, allowing it to release data for widespread re-use with a Creative Commons Attribution 3.0 New Zealand licence (CC BY) with attribution to [the Contract Authority] in line with the New Zealand Government Open Access Licensing framework (NZGOAL).

2.2 Summary of Deliverables and Quality Requirements

[*Add additional deliverables and increased quality requirements to the summary table below to reflect requirements beyond the National Specification requirements/deliverables.]*

The deliverables in this procurement are to meet the requirements and provide the deliverables of the New Zealand National LiDAR Base Specification (National Specification) plus any ADDITIONAL requirements and deliverables specified. In summary, the following is required:

Deliverables:		
A	**1m gridded bare earth digital elevation model (DEM)**	**NZTM2000, NZVD2016**
B	**1m gridded digital surface model (DSM)**	**NZTM2000, NZVD2016**
C	**Classified (tiled) point cloud**	**[LAS v1.4], NZTM2000, NZVD2016**
D	**Breaklines**	**NZTM2000**
E	**Project reports and metadata**	
F	**...**	
Quality requirements:		
Vertical Accuracy (95%)		**≤20 cm**
Horizontal Accuracy (95%)		**≤100 cm**
Pulse density		**≥ 2 pls/m2**

2.3 Exceptions to requirements

[Section 4. Any exceptions to the national requirements are understood to be by the Contract Authority with agreement of those contributing funding or in-kind support to the applicable dataset, including LINZ if it is hosting the data.]

The delivery is expected to meet or exceed the minimum requirements set in the National Specification, plus the additional requirements in this tender document. Technical alternatives that enhance the data or associated products are encouraged, may be submitted with any tender response, and will be given due professional consideration by the Contract Authority.

The following requirements in this document are exceptions to, and override, the National Specification requirements:

[None]

2.4 Collection

2.4.1 Collection area

[Section 5.1. Describe the collection area. Include a map and shape file of the project extent, and the area of coverage in square kilometres. If it is buffered, state this and delete the below statement.]

The vendor shall indicate the width of all buffers that will be included in the collection to ensure the delivered products are free of edge effects and not missing data. The unbuffered project extent specified by the Contract Authority shall be adequately buffered by the vendor to avoid edge effects and ensure against missing data.

2.4.2 Capture delivery and timeframes

[Describe the required timeframes for capture and delivery, including "leaf-off" periods if relevant. Rather than specifying the delivery dates, this could be requested from the vendor.]

(a) Data is to be captured beginning [insert date], with a requirement for all data to be captured before [insert date].

(b) A first delivery of 5km^2 minimum is to be delivered before [insert date].

(c) Final delivery for all datasets is [insert date].

A detailed delivery and payment schedule will be developed in the contract.

2.4.3 Quality level

[Section 5.2. The minimum acceptable point cloud quality level for the National Specification is per below. This quality level is considered the minimum acceptable for regional scale data capture, and individual procurements may require better accuracy and greater pulse density, especially for urban areas and dense forests. If so, insert these requirements below.

Note that that the achievable accuracy is related to the capture altitude, and as a result more stringent accuracy requirements will result in increased cost.

The ≤100 cm horizontal accuracy requirement is in line with what can be achieved when meeting the ≤20.0 cm vertical accuracy requirement. If higher accuracy surveys are desired it is recommended that the Contract Authority seeks vendor information on the tradeoffs between cost, accuracy, and precision.

Rigour, expertise, and experience is required in order for the vendor to meet the requirement for the base requirement of ≤20.0 cm (95%) vertical accuracy. As part of the RFP it is highly recommended to request that the vendor describes the methodologies that will be used to achieve the required accuracy, how this will be independently verified, and proposed course of action if the required quality criteria are not met at check sites. The vendor should also provide examples of other projects they have delivered that have achieved this level of accuracy, including references.]

The minimum acceptable point cloud quality is:

Vertical Accuracy (95%)	**≤20 cm**
Horizontal Accuracy (95%)	**≤100 cm**
Aggregate Nominal Pulse Density (ANPD)	**≥ 2pls/m^2**

Describe the methodologies that will be used to achieve this required accuracy, how this will be independently verified, and actions that will be taken if the required quality criteria is not met at check sites. Provide examples (including references) of other projects you have delivered that have achieved this level of accuracy.

2.4.4 Multiple discrete returns

[Section 5.3. If more than three returns per pulse is required, indicate it here.]

2.4.5 Data voids

Section 5.5. Data voids are gaps in the point cloud first return coverage, caused by problems such as instrumentation failure, processing anomalies, surface non-reflectance, improper survey planning, etc.

The National Specification is aimed at regional scale initiatives and does not set requirements for survey planning criteria such as flying altitudes, scan angles, or overlapping coverage aimed at ensuring adequate ground coverage beyond the ANPD in unobstructed areas.

Data voids will occur where features such as buildings, trees, and steep terrain will obstruct the line of sight of the LiDAR instrument. If this is not acceptable, for example because there would be data voids in urban canyons or steep gorges, then the project expectations should be noted here. The expectations of void-free coverage and the proposed flight planning should be discussed with the vendor prior to contracting to ensure the project requirements are achieved.]

The vendor shall include their proposed flight planning including flying altitudes, scan angles, and swath overlap to ensure the project expectations are met.

2.4.6 Collection conditions

[Section 5.6. Insert any additional collection condition criteria, such as a more stringent low tide window, tidal restriction beyond the Coastal Marine Area, flood stages, river level and flows, crop or plant growth cycles. Clarify if there are specific floodplains or wetlands that require special consideration. In some cases, such as with simultaneous bathymetry data capture or for steep and rugged coastlines, the tidal requirement may be relaxed. Note that tidal window requirement can have a significant impact on data capture efficiency.]

2.4.7 Photographic imagery

[It is not a National Specification requirement to collect imagery simultaneously with the LiDAR capture, but for systems that have integrated digital cameras it may be desirable for applications such as colouring the point cloud or contributing to classification. Modify and include the following if relevant.]

Where an acquisition system has integrated digital cameras, it is highly desirable that imagery is to be captured simultaneously with the LiDAR when flying during suitable light conditions. All imagery shall be delivered per the tiling and naming convention in the specification. This deliverable should be included in the proposal as a line item.

2.5 Data Processing and Handling

2.5.1 LAS file format

[Section 6.1. Select the desired version and delete the others. If unsure, discuss with LINZ, a data supplier, or other industry professional.

LAS v1.4, supplied in the LAZ format, is the preferred format for National Elevation Programme LiDAR point cloud data. It provides additional functionality including more classifications, capacity to include additional data such as near-infrared (NIR) and Normalised Difference Vegetation Index (NDVI), extended point formats, custom Domain Profiles, and increased return count. Uptake by industry has been varied and some software packages may not yet support this format.

The Contract Authority may prefer delivery in LAS v1.2 or LAS v1.3. This is acceptable for datasets where the extra functionality of LAS v1.4 is not needed.

LAS v1.3 includes additional functionality for waveform data.

LAS v1.2 has been the most common in recent New Zealand procurements.

LAZ is a lossless compressed format of LAS that offers about 10x compression.]

ASPRS LAS Version 1.4, using Point Data Record Format 6, 7, 8, 9 or 10

or

ASPRS LAS Version 1.2

or

ASPRS LAS Version 1.3

2.5.2 Full waveform data

[Specify if full waveform data is required, including the required format. Use of full waveform data is mainly by specialists who can advise further on their requirements, and it is not common in government procurements.]

2.5.3 Datums and coordinate reference system

[Section 6.3. The National Specification specifies NZGD2000, NZVD2016, and NZTM2000 as the required geodetic datum, height system, and projection. The use of NZTM2000 allows for consistent overlays of spatial data collected at different times New Zealand's tectonically active landscape. If deliverables are ALSO required to be in a different datum, height system, or projection, make a general note here and be specific in the applicable sections. There may be cases where ellipsoidal coordinates referenced to the epoch of collection are desired, for example when using temporally spaced datasets to examine displacements or strain across fault zones. In such cases this should be explicitly specified in terms of the applicable International Terrestrial Reference Frame (ITRF), and the Contract Authority is advised to contact LINZ for further guidance.]

Deliverables shall be provided in terms of both:

- **NZGD2000, NZVD2016, NZTM2000 and**
- **[insert geodetic datum name], [insert vertical datum name], [insert projection name]**

2.5.4 Positional accuracy validation

[Section 6.4. The National Specification specifies the number of check sites based on the size of the survey area, and requires that the project vertical accuracy requirement is met at every check site and the project horizontal accuracy is met at every applicable check site. An adequate number of check sites is crucial to accurately estimate the survey positional accuracy.

The National Specification only requires accuracy assessment of the point cloud in non-vegetated areas. If additional accuracy assessments are required, such as for vegetated areas or to check the DEM, include these requirements here.

In some circumstances it may also be appropriate to obtain third-party quality assurance/quality control (QA/QC) by another contractor.

The contract should include the consequences if the LiDAR data does not meet the positional accuracy requirement at any check site.

The National Specification requires a QA/QC report but does not require the supply of check site data, and the Contract Authority should request this as a deliverable if they intend to do their own data verification.]

The vendor shall state the proposed quantity and locations of check sites in the proposal, and the details of the local check sites. The preferred check site is to be made up of 25 or more points on a grid with 5 metre spacing on a flat and smooth surface.

The point cloud is expected to comply with the required vertical and horizontal accuracies at all check sites before the vendor undertakes further classification and processing. If the project accuracy requirements are not met at any check site then this must be investigated and reported to and discussed with [the Contract Authority]. The cause of non-compliance must be identified and a repeat LIDAR survey of the local area, at the vendors expense, may be required if the LiDAR data is determined to be the cause of significant non-compliance. In special cases the [Contract Authority] may agree to minor excursions from the required accuracy. This must be documented in the project QA/QC report.

2.5.5 Point Classification

[Section 6.7. Delete the classification rows (beyond the minimum requirements) that are not required, and insert any custom classifications if required. If requesting vegetation classsifications, review and modify the vegetation ranges as necessary so they are representative of local conditions.]

The following LAS classification is required:

Code	Description
1	**Processed, but unclassified (a minimum requirement)**
2	**Ground (a minimum requirement)**
3	Low vegetation (<0.5m)
4	Medium vegetation (0.5m-2m)
5	High vegetation (>2m)
6	Building
7	**Low noise (LAS v1.4), noise (LAS v1.2/3) (a minimum requirement)**
9	**Water (a minimum requirement)**
10	Rail
11	Road surface
12	Overage (LAS v1.2/3 only)
13	Wire – guard (shield)
14	Wire – conductor (phase)
15	Transmission tower
16	Wire-structure connector (insulator)
17	Bridge deck
18	**High noise (LAS v1.4) (a minimum requirement)**
64-255	User defined in LAS v1.4

2.5.6 Classification accuracy

[Section 6.8. The National Specification requires Classification Level 2 or higher that within any 1km x 1km area, no more than 2 percent of non-withheld points will have demonstrable errors in the classification value. Insert any further specific classification accuracy requirements here. The following classification levels are provided for reference:

Level 0 – Undefined (CL0)

All points allocated class 0 (not processed for classification) or 1 (default – not further classified) by LiDAR processing software with no classification algorithms applied. No specified classification accuracy.

Level 1 - Automated and Semi-Automated Classification (CL1)

Fully or semi-automated, batch processing of the point cloud data into, at a minimum, the following classes: 1 (unclassified), 2 (ground), 7 (low/high points and noise), 9 (water). At Level 1, some of these classes such as water (9) might be derived with the assistance of masking or other semi-automated techniques. Classification accuracy required: 95% for Ground points (minimum), and other classes as specified.

Level 2 - Ground surface improvement (CL2) (national minimum)

Automated processing of point cloud data into, at a minimum, the following classes: 1 (not further classified into a specific category), 2 (ground), 7 (low/high points and noise), 9 (water). Data is further enhanced, using automated and manual methods, by the removal of significant anomalies which remain in the ground class (2). Classification accuracy required: 98% for Ground points (minimum), and other classes as specified.

Level 3 - Ground Correction (CL3)

Significant and highly supervised (often manual or semi-automated) effort is generally required for this level to ensure that only actual ground points are assigned to class 2. Typically, this editing will both remove and add points to the ground, vegetation and water classes derived using the automated algorithms. Full manual line scan editing of batch output may be required in highly complex environments.

Typically this level of classification would only be undertaken to meet highly specific project requirements (such as hydrological modelling) over localised areas which typically make up a small proportion of the total survey area such as vegetation along water courses.

Features which may require special attention include water and areas where the ground surface may be obscured including: densely vegetated water courses, rainforest, dense coastal vegetation or grass, rocky outcrops/boulders, contour/levee banks, wood/rubbish piles and islands. Classification accuracy required: 99% for ground points (minimum), and other classes as specified.

Level 4 - Detailed Classification and Correction (CL4)

Detailed classification and correction of all specified classes. When specified, each class must achieve the required classification accuracy. Typically this level of classification would only be undertaken to meet highly specific project requirements. Classification accuracy required: 99% for all specified classes.

Level 3 and 4 may often require reference imagery to achieve the required specifications.]

2.6 Hydro-flattening

[Section 7. Hydro-flattening is the process of creating a LiDAR-derived DEM in which water surfaces appear as they would in traditional topographic DEMs created from photogrammetric digital terrain models (DTMs).

LiDAR data consists solely of mass points, and by itself remains limited in its ability to precisely define the boundaries or locations of distinct linear features such as water bodies, streams, and rivers. The lack of breaklines in the intermediate triangulated irregular network (TIN) data structure causes triangulation to occur across water bodies, producing a water surface filled with irregular, unnatural, and visually unappealing triangulation artefacts. These artefacts are then carried into the derived DEM, and ultimately into contours developed from the DEM.

To achieve the same character and appearance of a traditional topographic DEM (or to develop a hydrologically enforced DEM) from LiDAR source data, breaklines must be developed separately using other techniques. These breaklines are then integrated with LiDAR points as a complete DTM, or used to modify a DEM previously generated without breaklines. The final DEM shall be a hydro-flattened (not hydro-enforced) topographic DEM suitable for integration into the National Elevation Model.

The use of breaklines is the predominant method used for hydro-flattening. The National Elevation Programme requires the delivery of breaklines for all flattened water bodies, and any other breaklines developed for each project.

Hydroflattening and breaklines are required for the following per the National Specification:

- *Inland ponds and lakes of 10,000 m^2 (1 hectare) or larger.*
- *Inland streams and rivers of a 30-m and greater nominal width.*
- *Non-tidal boundary waters.*
- *Tidal waters.*
- *Permanent islands 5,000 m^2 or larger.*

Modify (or delete) the example below to provide any ADDITIONAL hydroflattening and breakline requirements, and provide sufficient detail that it is clear to the vendor what is expected. It is recommended to specify which river section require hydro-flattening since the requirement for a 30-m nominal width is open to interpretation, especially for braided rivers.]

The following river sections require hydro-flattening: [describe]

The following ADDITIONAL breaklines are required to be collected and incorporated into the DEMs and DSMs, and delivered as ESRI shapefiles:

Single line streams: [describe]

Double line stopbanks: [describe]

Levees: [describe]

Seawalls: [describe]

Dams: [describe]

…

2.7 Deliverables

2.7.1 Reporting

[Section 8.1. The National Specification requires detailed project reporting for the overall project and the individual required products. Include any additional reporting requirements here. Note that LINZ produces dataset specific metadata to accompany the datasets hosted in the LINZ Data Service, based on the project reports provided from the vendor. If structured or dataset specific metadata is required directly from the vendor, include that here.]

2.7.2 Survey data

[The delivery of the survey data is not a national requirement; however the Contract Authority should request this to allow for independent QA.]

All survey control data (with adequate metadata) used in meeting the requirements of this contract must be supplied to ensure independent Quality Assurance (QA) of the survey operations.

2.7.3 Raw point cloud swaths

[Either edit or delete as applicable. The raw point cloud data is not a national requirement; however vendors are required to keep a copy of all project source data for a minimum of five years. There may be cases where the raw point cloud swaths are a desirable deliverable. Insert the desired coordinate reference system in (e). This is a specialist product, and the end users should review the RFP requirements to ensure their needs are met.]

The raw point cloud swaths are required. This is the swath data, prior to editing such as removing points from outside the buffered project extent. All collected swaths shall be delivered as part of the raw point cloud deliverable, including calibration swaths and crossties. Raw point cloud deliverables shall include or conform to the following procedures and specifications:

(a) All collected points, fully calibrated, georeferenced, and adjusted to ground, organised and delivered in their original swaths, one swath per file. If production processing required segmentation of the swath files, then multiple files per swath is acceptable.

(b) Each swath shall be assigned a unique File Source Identification (ID), and each point within the swath shall be assigned a Point Source ID equal to the File Source ID.

(c) Fully compliant [LAS v1.4, Point Data Record Format 6-10], or [LAS v1.2/3], delivered in LAZ format.

(d) If collected, waveform data in external PulseWaves auxiliary files with the extension .pls.

(e) Delivered in the [insert CRS] coordinate reference system. Correct and properly formatted georeference information as Open Geospatial Consortium (OGC) well known text (WKT) in all LAS file headers.

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

(g) Height values reported to 3 decimal places (nearest mm). (While not significant for accuracy, this supports numerical processing and reduces the number of identical values caused by rounding.)

(h) Intensity values, normalised to 16-bit by multiplying the value by 65,536/(intensity range of the sensor) per LAS v1.4.

2.7.4 Classified point cloud tiles

[Section 8.2. Delivery of a classified point cloud is required in the National Specification and is to be provided in the NZTM2000 coordinate system/projection and the NZVD2016 normal-orthometric vertical datum. Insert any additional requirements here, such as the need for a copy in a different coordinate system (such as ITRF) or datum (such as the local vertical datum).]

2.7.5 Bare-earth and surface raster elevation models

[Section 8.3. Delivery of a gridded bare-earth DEM and a surface (first return/highest feature) DSM is required in the National Specification and is to be provided in the NZTM2000 coordinate system and the NZVD2016 vertical datum. Review the details in the National Specification, then insert any additional requirements here, such as the need for a copy in a local vertical datum, a different reference system, a different grid spacing that 1-m, a different format than geotiff, etc.]

2.7.6 Breaklines

[Section 8.4. The National Specification requires the delivery of the breaklines representing all hydro-flattened features in a project, delivered as ESRI Shape files (.shp) using the NZTM2000 projection. If these are also required in a different format/projection, enter that here.]

2.7.7 Contours

[The National Specification does not require the delivery of contours, however, this is a commonly requested product and is included below. Delete or modify as appropriate.]

(a) The required contour interval is [2] metres.

(b) Contour lines are required to edge match across all tiles.

(c) Contour lines will be smoothed to give an acceptable cartographic appearance, but not to the point of loss of integrity in the elevation values.

(d) Contours will include attributed height values in the [insert datum] vertical datum.

(e) Contours will be interpolated through data gaps caused by man-made features, except in the case of large buildings (>3000m^2) where contours should go around the buildings. The methodology for this will be discussed with the Contract Authority prior to project commencement.

(f) Contours are expected to go around, and not through, lakes, dams and other large bodies of water.

2.7.8 Additional deliverables

[Include any additional deliverables required, such as:

- *Full waveform data*
- *Bathymeric data capture and products.*

- *Extracted buildings: Roof outlines with maximum elevation or height above ground as an attribute.*
- *Top-of-Canopy (first return) Raster Surface: Raster representing the highest return within each cell.*
- *Canopy height model: a difference between Digital Surface Model (DSM), being developed from first returns and the digital elevation model (DEM) created from the ground returns.*
- *Intensity images (8 or 16-bit gray scale, tiled):*
  - Interpolation based on first returns.

    or
  - Interpolation based on all-returns, summed.
- *Colourised pixels (RGB values typically from simultaneous photography)*
- *Hydrologically enforced (Hydro-Enforced) DTMs as an additional deliverable.*
- *Hydrologically conditioned (Hydro-Conditioned) DTMs as an additional deliverable.*

etc]

2.7.9 Global Navigation Satellite System (GNSS) data

[Section 8.5. The National Specification requires the delivery of GNSS data for all base station occupations of existing or new benchmarks in excess of 6 hours. If new marks are to be incorporated into the LINZ survey control system as order 4 or better, compliance with the relevant specifications and standards is required. Contact LINZ prior to adding this as a requirement.]

2.8 Tiles and file naming

[Section 9. The National Specification requires 1:1000 NZTopo50 subtiles for the DEM, DSM, and point cloud, based on NZTM2000 coordinates, with a standard file naming convention. Enter any additional tile requirements here and/or under the applicable deliverable. If an alternate tiling scheme or naming convention is specified for the core National Elevation Programme deliverables then duplicate deliveries of the same dataset will be required.]

3 Glossary

Note: Many of the following terms and definitions are from the US Geological Survey LiDAR Base Specification (reference 2) and are used with permission.

Term	Meaning
accuracy	The closeness of agreement between a test result or measurement result and the true value. *As used in this specification accuracy refers to* <u>*local accuracy*</u> *and is the uncertainty of the bare-earth point cloud and DEM data relative to 4th order or better control. See the LINZ Standard for Geospatial Accuracy Framework for accuracy related definitions. See* precision.
aggregate nominal pulse density (ANPD)	*The total density of pulses (not points) recorded by the LiDAR instrument per specified unit area resulting from the aggregate of all collections such as overlap or multiple passes.* A variant of nominal pulse density that expresses the total expected or actual density of pulses occurring in a specified unit area resulting from multiple passes of the light detection and ranging (LiDAR) instrument, or a single pass of a platform with multiple LiDAR instruments, over the same target area. In all other respects, ANPD is identical to nominal pulse density (NPD). In single coverage collection, ANPD and NPD will be equal. See aggregate nominal pulse spacing, nominal pulse density, nominal pulse spacing.
aggregate nominal pulse spacing (ANPS)	A variant of nominal pulse spacing that expresses the typical or average lateral distance between pulses in a LiDAR dataset resulting from multiple passes of the LiDAR instrument, or a single pass of a platform with multiple LiDAR instruments, over the same target area. In all other respects, ANPS is identical to nominal pulse spacing (NPS). In single coverage collections, ANPS and NPS will be equal. See aggregate nominal pulse density, nominal pulse density, nominal pulse spacing.
artefacts	An inaccurate observation, effect, or result, especially one resulting from the technology used in scientific investigation or from experimental error. In bare-earth elevation models, artefacts are detectable surface remnants of buildings, trees, towers, telephone poles or other elevated features; also, detectable artificial anomalies that are introduced to a surface model by way of system specific collection or processing techniques. For example, corn-row effects of profile collection, star and ramp effects from multidirectional contour interpolation, or detectable triangular facets caused when vegetation canopies are removed from LiDAR data.
attitude	The orientation of a body, described by the angles between the axes of that body's coordinate system and the axes of an external coordinate system. In photogrammetry, the attitude is the angular orientation of a camera (roll, pitch, yaw), or of the photograph taken with that camera, with respect to some external reference system. With LiDAR, the attitude is normally defined as the roll, pitch and heading of the instrument at the instant an active pulse is emitted from the sensor.
bare earth	The terrain, free from vegetation, buildings and other man-made structures. Elevations of the ground.
bare earth digital elevation model (DEM)	See digital elevation model (DEM)
boresight	Calibration of a LiDAR sensor system equipped with an Inertial Measurement Unit (IMU) and global positioning system (GNSS) to determine or establish the accurate: • Position of the instrument (x, y, z) with respect to the GNSS antenna; and • Orientation (roll, pitch, heading) of the LiDAR instrument with respect to straight and level flight.

breakline	A linear feature that describes a change in the smoothness or continuity of a surface. The two most common forms of breaklines are as follows: • A ***soft breakline*** ensures that known *z* values along a linear feature are maintained (for example, elevations along a pipeline, road centerline, crest of a stopbank or seawall, or drainage ditch), and ensures that linear features and polygon edges are maintained in a triangulated irregular network (TIN) surface model, by enforcing the breaklines as TIN edges. They are generally synonymous with three-dimensional (3D) breaklines because they are depicted with series of x, y, z coordinates. Somewhat rounded ridges or the trough of a drain may be collected using soft breaklines. • A ***hard breakline*** defines interruptions in surface smoothness (for example, to define streams, rivers, shorelines, dams, ridges, building footprints, and other locations) with abrupt surface changes. Although some hard breaklines are 3D breaklines, they are typically depicted as two-dimensional (2D) breaklines because features such as shorelines and building footprints are normally depicted with series of *x, y* coordinates only, often digitised from digital orthophotos that include no elevation data.
bridge	A structure carrying a road, path, railroad, canal, aircraft taxiway, or any other transit between two locations of higher elevation over an area of lower elevation. A bridge may traverse a river, ravine, road, railroad, or other obstacle. "Bridge" also includes aqueduct, drawbridge, flyover, footbridge, overpass, span, trestle, and viaduct. In mapping, the term "bridge" is distinguished from a roadway over a culvert in that a bridge is a man-made, elevated deck which is not underlain with earth or soil. See culvert.
calibration (LiDAR systems)	The process of quantitatively defining a system's responses to known, controlled signal inputs. LiDAR system calibration falls into two main categories: • **instrument calibration** Factory calibration includes radiometric and geometric calibration unique to each manufacturer's hardware, and tuned to meet the performance specifications for the model being calibrated. Instrument calibration can only be assessed and corrected by the instrument manufacturer. • **data calibration** The lever arm calibration determines the sensor-to-GNSS-antenna offset vector (the lever arm) components relative to the antenna phase center. The offset vector components are redeterminded each time the sensor or aircraft GNSS antenna is moved or repositioned. Because normal aircraft operations can induce slight variations in component mounting, the components are normally field calibrated for each project, or even daily, to determine corrections to the roll, pitch, yaw, and scale calibration parameters.
cell (pixel)	A single element of a raster dataset. Each cell contains a single numeric value of information representative of the area covered by the cell.
check site	A surveyed point or area used to estimate the positional accuracy of a geospatial dataset against an independent source of greater accuracy. Check sites are independent from, and may never be used as, control points on the same project.
classification (of LiDAR)	The classification of LiDAR point cloud returns in accordance with a classification scheme to identify the type of target from which each LiDAR return is reflected. The process allows differentiation between bare-earth terrain points, water, noise, vegetation, buildings, other man-made features and objects of interest.
Coastal Marine Area	The foreshore, seabed, and coastal water, and the air space above the water— (a) of which the seaward boundary is the outer limits of the territorial sea (b) of which the landward boundary is the line of mean high water springs, except that where that line crosses a river, the landward boundary at that point shall be whichever is the lesser of: (i) 1 kilometre upstream from the mouth of the river; or (ii) the point upstream that is calculated by multiplying the width of the river mouth by 5

confidence level	The percentage of points within a dataset that are estimated to meet the stated accuracy. The 95% confidence interval is used for stating positional accuracy requirements in this document and means that 95% of the population distribution is contained in the confidence interval. LiDAR specifications and procurement requirements often refer to one-sigma (σ) positional accuracy meaning that 68.27% of the population distribution is contained in the confidence interval. The 95% confidence requirements stated in this document are 1.96 times the one sigma requirement, ie +/-20cm (95%) is equal to +/-10cm (σ or RMSE).
control point (calibration point)	A surveyed point used to geometrically adjust a LiDAR dataset to establish its positional accuracy relative to the real world. Control points are independent from, and may never be used as, check sites on the same project.
culvert	A tunnel carrying a stream or open drainage under a road or railroad, or through another type of obstruction to natural drainage. Typically, constructed of formed concrete or corrugated metal and surrounded on all sides, top, and bottom by earth or soil.
data void	In LiDAR, a gap in the point cloud coverage, caused by surface non-reflectance of the LiDAR pulse, instrument or processing anomalies or failure, obstruction of the LiDAR pulse, or improper collection flight planning. Any area greater than or equal to (four times the aggregate nominal pulse spacing [ANPS]) squared, measured using first returns only, is considered to be a data void.
datum	Parameter or set of parameters that define the position of the origin, the scale, and the orientation of a coordinate system. Horizontal datums (for example NZGD2000) are used for describing a point on the Earth's surface, in latitude and longitude or another coordinate system. Vertical datums (for example NZVD2016) are used to measure elevations or depths.
digital elevation model (DEM)	A uniformly spaced bare-earth elevation model, devoid of vegetation and man-made structures.
digital elevation model resolution	The linear size of each cell of a raster DEM. Features smaller than the cell size cannot be explicitly represented in a raster model. DEM resolution may also be referred to as cell size, grid spacing, or ground sample distance.
digital surface model (DSM)	An elevation model that depicts the highest surface, including buildings, trees, towers, and other features. LiDAR DSMs are especially relevant for telecommunications management, air safety, forest management, 3D modeling and simulation, etc.
digital terrain model (DTM)	A bare-earth elevation model, devoid of vegetation and man-made structures, made up of irregularly, but strategically spaced mass points and breaklines.
discrete return LiDAR	LiDAR system or data in which important peaks in the waveform are captured and stored. Each peak represents a return from a different target, discernible in vertical or horizontal domains. Most modern LiDAR systems are capable of capturing multiple discrete returns from each emitted laser pulse. See waveform LiDAR.
elevation	The distance measured upward along a plumb line between a point and the geoid. The elevation of a point is normally the same as its orthometric height, defined as H in the equation: $H = h - N$, where h is equal to the ellipsoid height and N is equal to the geoid height.
first return	The first important measurable part of a return LiDAR pulse.
flight	A flight is a single takeoff and landing cycle for the LiDAR data collecting aircraft.
flightline	A single pass of the collection aircraft over the target area. Commonly misused to refer to the data resulting from a flightline of collection. *See* swath.
geographic information system (GIS)	A system of spatially referenced information, including computer programs that acquire, store, manipulate, analyse, and display spatial data.
horizontal accuracy	Positional accuracy of a dataset with respect to a horizontal datum.

hydrologic modelling	The computer modeling of rainfall and the effects of land cover, soil conditions, and terrain slope to estimate rainfall runoff into streams, rivers, and lakes. Digital elevation data are used as part of hydrologic modeling.
hydrologically conditioned (hydro-conditioned)	Processing of a DEM or TIN so that the flow of water is continuous across the entire terrain surface, including the removal of all isolated sinks or pits. The only sinks that are retained are the real ones on the landscape. Whereas 'hydrologically enforced' is relevant to drainage features that generally are mapped, 'hydrologically conditioned' is relevant to the entire land surface and is done so that water flow is continuous across the surface, whether that flow is in a stream channel or not. The purpose for continuous flow is so that relations and (or) links among basins and (or) catchments can be known for large areas.
hydrologically flattened (hydro-flattened)	Processing of a LiDAR-derived surface (DEM or TIN) so that mapped water bodies, streams, rivers, reservoirs, and other cartographically polygonal water surfaces are flat and, where appropriate, level from bank-to-bank. Additionally, surfaces of streams, rivers, and long reservoirs demonstrate a gradient change in elevation along their length, consistent with their natural behavior and the surrounding topography. In traditional maps that are compiled photogrammetrically, this process is accomplished automatically through the inclusion of measured breaklines in the DTM. However, because LiDAR does not inherently include breaklines, a DEM or TIN derived solely from LiDAR points will depict water surfaces with unsightly and unnatural artefacts of triangulation. The process of hydro-flattening typically involves the addition of breaklines along the banks of specified water bodies, streams, rivers, and ponds. These breaklines establish elevations for the water surfaces that are consistent with the surrounding topography, and produce aesthetically acceptable water surfaces in the final DEM or TIN. Unlike hydro-conditioning and hydro-enforcement, hydro-flattening is not driven by any hydrologic or hydraulic modeling requirements, but solely by cartographic mapping needs.
hydrologically enforced (hydro-enforced)	Processing of mapped water bodies so that lakes and reservoirs are level and so that streams and rivers flow downhill. For example, a DEM, TIN or topographic contour dataset with elevations removed from the tops of selected drain- age structures (bridges and culverts) so as to depict the terrain under those structures. Hydro-enforcement enables hydrologic and hydraulic models to depict water flowing under these structures, rather than appearing in the computer model to be dammed by them because of road deck elevations higher than the water levels. Hydro-enforced TINs also use breaklines along shorelines and stream centerlines, for example, where these breaklines form the edges of TIN triangles along the alignment of drainage features. Shore breaklines for streams and rivers would be 3D breaklines with elevations that decrease as the stream flows downstream; however, shore breaklines for lakes or reservoirs would have the same elevation for the entire shoreline if the water surface is known or assumed to be level throughout.

intensity (LiDAR)	For discrete-return LiDAR instruments, intensity is the recorded amplitude of the reflected LiDAR pulse at the moment the reflection is captured as a return by the LiDAR instrument. LiDAR intensity values can be affected by many factors, such as the instantaneous setting of the instrument's automatic gain control and angle of incidence and cannot be equated to a true measure of energy. In full-waveform systems, the entire reflection is sampled and recorded, and true energy measurements can be made for each return or overall reflection. Intensity values for discrete returns derived from a full-waveform system may or may not be calibrated to represent true energy. LiDAR intensity data make it possible to map variable textures in the form of a gray-scale image. Intensity return data enable automatic identification and extraction of objects such as buildings and impervious surfaces, and can aid in LiDAR point classification. In spite of their similar appearance, LiDAR intensity images differ from traditional panchromatic images in several important ways: • LiDAR intensity is a measure of the reflection of an active laser energy source, not natural solar energy. • LiDAR intensity images are aggregations of values at point samples. The value of a pixel does not represent the composite value for the area of that pixel. • LiDAR intensity images depict the surface reflectivity within an extremely narrow band of the infrared spectrum, not the entire visible spectrum as in panchromatic images. • LiDAR intensity images are strongly affected by the angle of incidence of the laser to the target, and are subject to unnatural shadowing artefacts. • The values on which LiDAR intensity images are based may or may not be calibrated to any standard reference. Intensity images usually contain wide variation of values within swaths, between swaths, and between flights. For these reasons, LiDAR intensity images must be interpreted and analysed with unusually high care and skill.
LAS	An open file format for the interchange of 3D point cloud data between data users. The file extension is .las.
last return	The last important measurable part of a return LiDAR pulse, which mostly will be from the ground surface (unless thick vegetation) or the top of a structure/building.
lever arm	A relative position vector of one sensor with respect to another in a direct georeferencing system. For example, with aerial mapping cameras, lever arms are positioned between the inertial center of the IMU and the phase center of the GNSS antenna, each with respect to the camera perspective center within the lens of the camera.
LiDAR	A laser based instrument that measures distance to a reflecting object by emitting timed pulses of light and measuring the time difference between the emission of a laser pulse and the reception of the pulse's reflection(s). The measured time interval for each reflection is converted to distance, which when combined with position and attitude information from GNSS, IMU, and the instrument itself, allows the derivation of the 3D-point location of the reflecting target's location.
local accuracy	The uncertainty of the bare-earth point cloud and DEM data relative to 4^{th} order or better control. See the LINZ Standard for Geospatial Accuracy Framework for accuracy related definitions.
metadata	Any information that is descriptive or supportive of a dataset, including formally structured and formatted metadata files (for example, eXtensible Markup Language [XML]-formatted ISO metadata), reports (collection, processing, quality assurance/quality control [QA/QC]), and other supporting data (for example, survey points, shapefiles).

nominal pulse density (NPD)	A common measure of the density of a LiDAR dataset; NPD is the typical or average number of pulses occurring in a specified areal unit. The NPD is typically expressed as pulses per square metre (pls/m^2). This value is predicted in mission planning and empirically calculated from the collected data, using only the first (or last) return points as surrogates for pulses. As used in this specification, NPD refers to single swath, single instrument data, whereas aggregate nominal pulse density describes the overall pulse density resulting from multiple passes of the LiDAR instrument, or a single pass of a platform with multiple LiDAR instruments, over the same target area. The term NPD is more commonly used in high-density collections (greater than 1 pls/m^2), with its inverse, nominal pulse spacing (NPS), being used in low-density collections (less than or equal to 1 pls/m^2). NPD can be calculated from NPS using the formula $NPD = 1/NPS^2$. See aggregate nominal pulse density, aggregate nominal pulse spacing, nominal pulse spacing.
nominal pulse spacing (NPS)	A common measure of the density of a LiDAR dataset, NPS the typical or average lateral distance between pulses in a LiDAR dataset, typically expressed in metres and most simply calculated as the square root of the average area per first return point. This value is predicted in mission planning and empirically calculated from the collected data, using only the first (or last) return points as surrogates for pulses. As used in this specification, NPS refers to single swath, single instrument data, whereas aggregate nominal pulse spacing describes the overall pulse spacing resulting from multiple passes of the LiDAR instrument, or a single pass of a platform with multiple LiDAR instruments, over the same target area. The term NPS is more commonly used in low density collections (greater than or equal to 1 metre NPS) with its inverse, nominal pulse density (NPD), being used in high-density collections (less than 1 meter NPS). NPS can be calculated from NPD using the formula $NPD = 1 / NPS^2$. See aggregate nominal pulse density, aggregate nominal pulse spacing, nominal pulse density.
Non-vegetated vertical accuracy (NVA)	The vertical accuracy at the 95-percent confidence level in non-vegetated open terrain, where errors should approximate a normal distribution.
overage	Those parts of a swath that are not necessary to form a complete single, non-overlapped, gap-free coverage with respect to the adjacent swaths. In collections designed using multiple coverage, overage are the parts of the swath that are not necessary to form a complete non-overlapped coverage at the planned depth of coverage. In the LAS Specification version 1.4, these points are identified by using the incorrectly named "overlap" bit flag. *See* overlap.
overlap	Any part of a swath that also is covered by any part of any other swath. The term overlap is incorrectly used in the LAS Specification version 1.4 to describe the flag intended to identify overage points. *See* overage.
pixel	*See* cell.
point classification	The assignment of a target identity classification to a particular LiDAR point or group of points.
Point (return)	a discrete point measured from the return pulse to the LiDAR instrument. In vegetated areas there are often multiple points/returns per pulse.
point cloud	A collection of datapoints in 3D space. One of the fundamental types of geospatial data (others being vector and raster), a point cloud is a large set of three dimensional points, typically from a LiDAR collection. As a basic GIS data type, a point cloud is differentiated from a typical point dataset in several key ways: • Point clouds are almost always 3D, • Point clouds have an order of magnitude more features than point datasets, and • Individual point features in point clouds do not typically possess individually meaningful attributes; the informational value in a point cloud is derived from the relations among large numbers of features *See* raster, vector.

precision	**A measure of the repeatability of a set of measurements.** The closeness with which measurements agree with each other, even though they may all contain a systematic bias. *See* accuracy.
point family	The complete set of multiple returns reflected from a single LiDAR pulse.
pre processing	In LiDAR, the preprocessing of data most commonly refers to those steps used in converting the collected GNSS, IMU, instrument, and ranging information into an interpretable *x, y, z* point cloud, including generation of trajectory information, calibration of the dataset, and controlling the dataset to known ground references.
post processing	In LiDAR, post processing refers to the processing steps applied to LiDAR data point clouds, including point classification, feature extraction (for example, building footprints, hydrographic features, and others), tiling, and generation of derivative products (DEMs, intensity images, and others).
pulse	A pulse of laser light emitted from the LiDAR instrument.
raster	An array of cells (or pixels) that each contain a single piece of numeric information representative of the area covered by the cell. Raster datasets are spatially continuous; with respect to DEMs this quality creates a surface from which information can be extracted from any location. As spatial arrays, rasters are always rectangular; cells are most often square. Co-located rasters can be stored in a single file as layers, as with color digital images. One of the fundamental types of geospatial data (others being vector and point cloud). *See* raster, vector.
resolution	The smallest unit a sensor can detect or the smallest distance a raster elevation model depicts.
Return	See point.
root mean square difference (RMSD)	The square root of the average of the set of squared differences between two dataset coordinate values taken at identical locations. The term RMSD differentiates from root mean square error (RMSE) because neither dataset is known to be more or less accurate and the differences cannot be regarded as errors. An RMSD value is used in LiDAR when assessing the differences between two overlapping swaths of data. *See* RMSE.
root mean square error (RMSE)	The square root of the average of the set of squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy for identical points. The RMSE is used to estimate the accuracy of both horizontal and vertical coordinates when standard or accepted values are known, as with GNSS-surveyed check sites of higher accuracy than the data being tested.
spatial distribution	In LiDAR, the regularity or consistency of the point density within the collection. The theoretical ideal spatial distribution for a LiDAR collection is a perfect regular lattice of points with equal spacing on *x* and *y* axes. Various factors prevent this ideal from being achieved, including the following factors: • Altitude variations, • Instrument design (oscillating mirrors), • Mission planning (difference between along-track and cross-track pulse spacing), and • In-flight attitude variations (roll, pitch, and yaw).
standard deviation	A measure of spread or dispersion of a sample of errors around the sample mean error. It is a measure of precision, rather than accuracy; the standard deviation does not account for uncorrected systematic errors.
swath	The data resulting from a single flightline of collection. *See* flightline.
systematic error	An error whose algebraic sign and, to some extent, magnitude bears a fixed relation to some condition or set of conditions. Systematic errors follow some fixed pattern and are introduced by data collection procedures, processing or given datum.
triangulated irregular network (TIN)	A vector data structure that partitions geographic space into contiguous, non-overlapping triangles. In LiDAR, the vertices of each triangle are LiDAR points with *x, y,* and *z* values. In most geographic applications, TINs are based on Delaunay triangulation algorithms in which no point in any given triangle lies within the circumcircle of any other triangle.

uncertainty (of measurement)	a parameter, associated with the result of measurement, that characterises the dispersion of measured values. The range in which the "true" value most likely lies. Standard uncertainty refers to uncertainty expressed as a standard deviation.
vector	A geospatial data structure that is geometrically described by *x* and *y coordinates,* and potentially *z* values. Vector data subtypes include points, lines, and polygons. A DTM composed of mass points and breaklines is an example of a vector dataset; a TIN is a vector surface. One of the fundamental types of geospatial data (others being raster and point cloud), *See* point cloud, raster.
waveform LiDAR	LiDAR system or data in which the entire reflection of the laser pulse is fully digitised, captured, and stored. Discrete return point clouds can be extracted from the waveform data during post processing. *See* discrete return LiDAR.
withheld	Within the LAS file specification, a single bit flag indicating that the associated LiDAR point is geometrically anomalous or unreliable and should be ignored for all normal processes. These points are retained because of their value in specialised analysis. Withheld points typically are identified and tagged during preprocessing or through the use of automatic classification routines. Examples of points typically tagged as withheld are listed below: • Spatial outliers in either the horizontal or vertical domains, and • Geometrically unreliable points near the edge of a swath.

4 Example of RFP Requirements

The following example illustrates how a procurement requirements section could look when using this template. This fictitious example is for a survey of the entire Northland Region captured at a base level, with additional requirements applicable to one sub-area. The Contract Authority is the fictitious Northern Council.

4.1 Copyright and Creative Commons

The Northern Council requires unrestricted copyright to all delivered data and reports, allowing it to release data for widespread re-use with a Creative Commons Attribution 3.0 New Zealand licence (CC BY) with attribution to NRC in line with the New Zealand Government Open Access Licensing framework (NZGOAL).

4.2 Summary of deliverables and quality requirements

The deliverables in this procurement are to meet the requirements and provide the deliverables of the New Zealand National LiDAR Base Specification (National Specification) plus any ADDITIONAL requirements and deliverables specified. In summary, the following is required:

Deliverables:		
A	**1m gridded bare earth digital elevation model (DEM)**	NZTM2000, NZVD2016 and NZTM2000, ONTPHT1964
B	**1m gridded digital surface model (DSM)**	NZTM2000, NZVD2016 and NZTM2000, ONTPHT1964
C	**Classified (tiled) point cloud**	LAS v1.4, NZTM2000, NZVD2016 and LAS v1.4, NZTM2000, ONTPHT1964
D	**Breaklines**	NZTM2000
E	**Project reports and metadata**	
F	2m contours	NZTM2000, ONTPHT1964
G	1m intensity image	NZTM2000
Quality requirements:		
Vertical Accuracy (95%)		≤20 cm
Horizontal Accuracy (95%)		≤100 cm
Pulse density		≥ 2 pls/m^2 ≥ 4 pls/m^2 in specified area

4.3 Exceptions to requirements

The delivery is expected to meet or exceed the minimum requirements set in the National Specification plus the additional requirements in this tender document. Technical alternatives that enhance the data or associated products are encouraged, may be submitted with any tender response, and will be given due professional consideration by the Northern Council.

4.4 Collection

4.4.1 Collection area

The collection area is for the entire Northland region, as shown below in Figure 1. The required pulse density is 2 pulses per square metre, with the exception of the Kaikohe area 56km^2) shown in Figures 3 which requires 4 pulses per square metre. The capture area has been configured in LINZ 1k tiles, which cover a total area of 13,725km^2. Delivery is expected as full tiles – no partial tiles. Adequate buffering is expected such that the required tiles are free from data gaps and edge effects. Refer to attached shape files:

Figure 1 – Northland Region capture extent at 2 pulses/sqm. See NorthlandRegionTiles.shp.

Figure 2 – Kaikohe high density capture area.

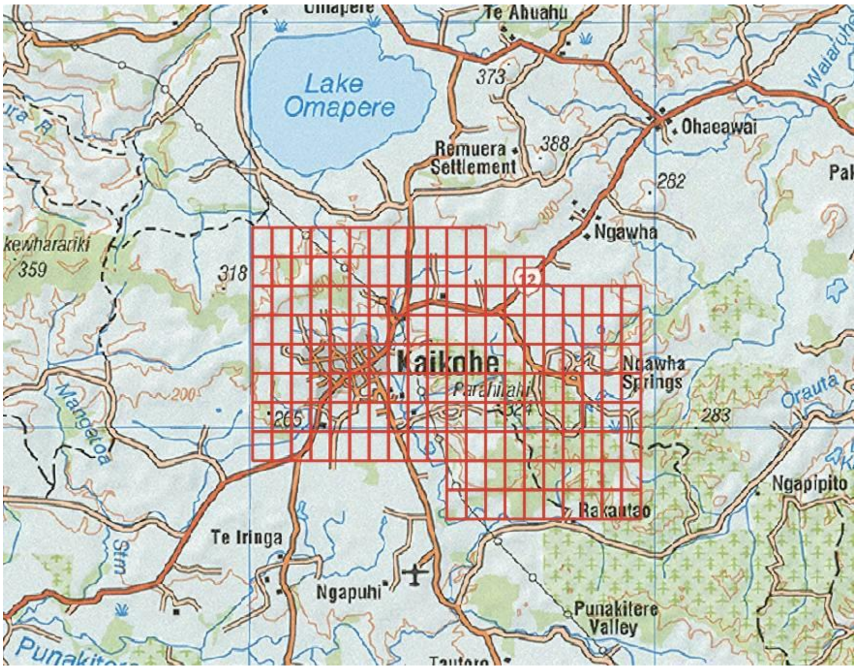

Figure 3 - Kaikohe capture extent at 4 pulses/sqm. See KaikoheTiles.shp.

4.4.2 Capture and delivery timeframes

(a) Data is to be captured beginning 1 May 2017, with a requirement for all data to be captured before 1 December 2019. Area shown in Figure 3 is to be captured during "leaf-off", 1 July through 1 October.

(b) Vendor shall provide an indicative date for a first delivery of 5km^2 minimum point cloud, DEM, and DSM.

(c) Vendor shall provide an indicative date for final delivery for all datasets. No later than 1 June 2020 is desired.

A detailed delivery and payment schedule will be developed in the contract.

4.4.3 Quality level

The minimum acceptable point cloud quality is:

Vertical Accuracy (95%)	**≤20 cm**
Horizontal Accuracy (95%)	**≤100 cm**
Aggregate Nominal Pulse Density (ANPD)	**≥ 2pls/m^2** **≥ 4pls/m^2 (Fig. 3 area)**

Describe the methodologies that will be used to achieve this required accuracy, how this will be independently verified, and actions that will be taken if the required quality criteria is not met at check sites. Provide examples (including references) of other projects you have delivered that have achieved this level of accuracy.

4.4.4 Data voids

Data voids resulting from obstructions caused by surface features such as buildings and gorges are not acceptable in the area defined in Figure 3.

The vendor shall include their proposed flight planning including flying altitudes, scan angles, and swath overlap to ensure these project expectations are met.

4.4.5 Photographic imagery

Where an acquisition system has integrated digital cameras, it is highly desirable that imagery is to be captured simultaneously with the LiDAR when flying during suitable light conditions. All imagery shall be delivered per the tiling and naming convention in the specification. This deliverable should be included in the proposal as a line item.

4.5 Data processing and handling

4.5.1 LAS file format

ASPRS LAS Version 1.4, using Point Data Record Format 6, 7, 8, 9 or 10, delivered as LAZ files. As an alternative, the Northern Council will accept LAS v1.2 or LAS v1.3 if LAS v1.4 cannot be supplied. This must be identified in the proposal and will affect the classification definitions used.

4.5.2 Datums and coordinate reference system

Deliverables shall be provided in terms of both:

- **NZGD2000, NZVD2016, NZTM2000, and**
- **NZGD2000, ONTPHT1964, NZTM2000**

4.5.3 Positional accuracy validation

The vendor shall state the proposed quantity and locations of check sites in the proposal, and the details of the local check sites. The preferred check site is to be made up of 25 or more points on a grid with 5 metre spacing on a flat and smooth surface.

The point cloud is expected to comply with the required vertical and horizontal accuracies at all check sites before the vendor undertakes further classification and processing. If the project accuracy requirements are not met at any check site then this must be investigated, reported and discussed with the Northern Council. The cause of non-compliance must be identified and a repeat LIDAR survey of the local area, at the vendors expense, may be required if the LiDAR data is determined to be the cause of significant non-compliance. In special cases the Council may agree to minor excursions from the required accuracy. This must be documented in the project QA/QC report.

4.5.4 Point classification

The following LAS classification is required:

Code	Description
1	Processed, but unclassified
2	Ground
3	Low vegetation (<0.5m)
4	Medium vegetation (0.5m-2m)
5	High vegetation (>2m)
6	Building
7	Low noise
9	Water
18	High noise

4.6 Hydro-flattening

The Wairoa River shall be hydro-flattened downstream of the confluence with the Waiotama River (-35.8162, 174.0583) NE of Tangiteroria. No other rivers require hydro-flattening.

<u>All</u> lakes, ponds, and reservoirs over 10,000m^2 – as an indication 357 were identified using LINZ mapping polygons.

4.7 Deliverables

4.7.1 Classified point cloud tiles

Two sets of classified point cloud tiles are required:

1. ***NZTM2000, NZVD2016 and***
2. ***NZTM2000, ONTPHT1964***

4.7.2 Bare-earth and surface raster elevation models

Two sets of DEM and DSM tiles are required:

1. ***NZTM2000, NZVD2016 and***
2. ***NZTM2000, ONTPHT1964***

4.7.3 Contours

(a) The required contour interval is 2 metres.

(b) Contour lines are required to edge match across all tiles.

(c) Contour lines will be smoothed to give an acceptable cartographic appearance, but not to the point of loss of integrity in the elevation values.

(d) Contours will include attributed height values in the ONTPHT1964 vertical datum.

(e) Contours will be interpolated through data gaps caused by man-made features, except in the case of large buildings (>3000m^2) where contours should go around the buildings. The methodology for this will be discussed with the Northern Council prior to project commencement.

(f) Contours are expected to go around, and not through, lakes, dams and other large bodies of water.

(g) Contours are to be delivered as ESRI shapefiles (Polyline Z).

(h) Examples of contouring must be provided to the Northern Council for acceptance prior to final contour generation and delivery.

4.7.4 Additional deliverables

Intensity image:

16-bit gray scale, 1m grid, interpolation based on first returns, NZTM2000 tiles.