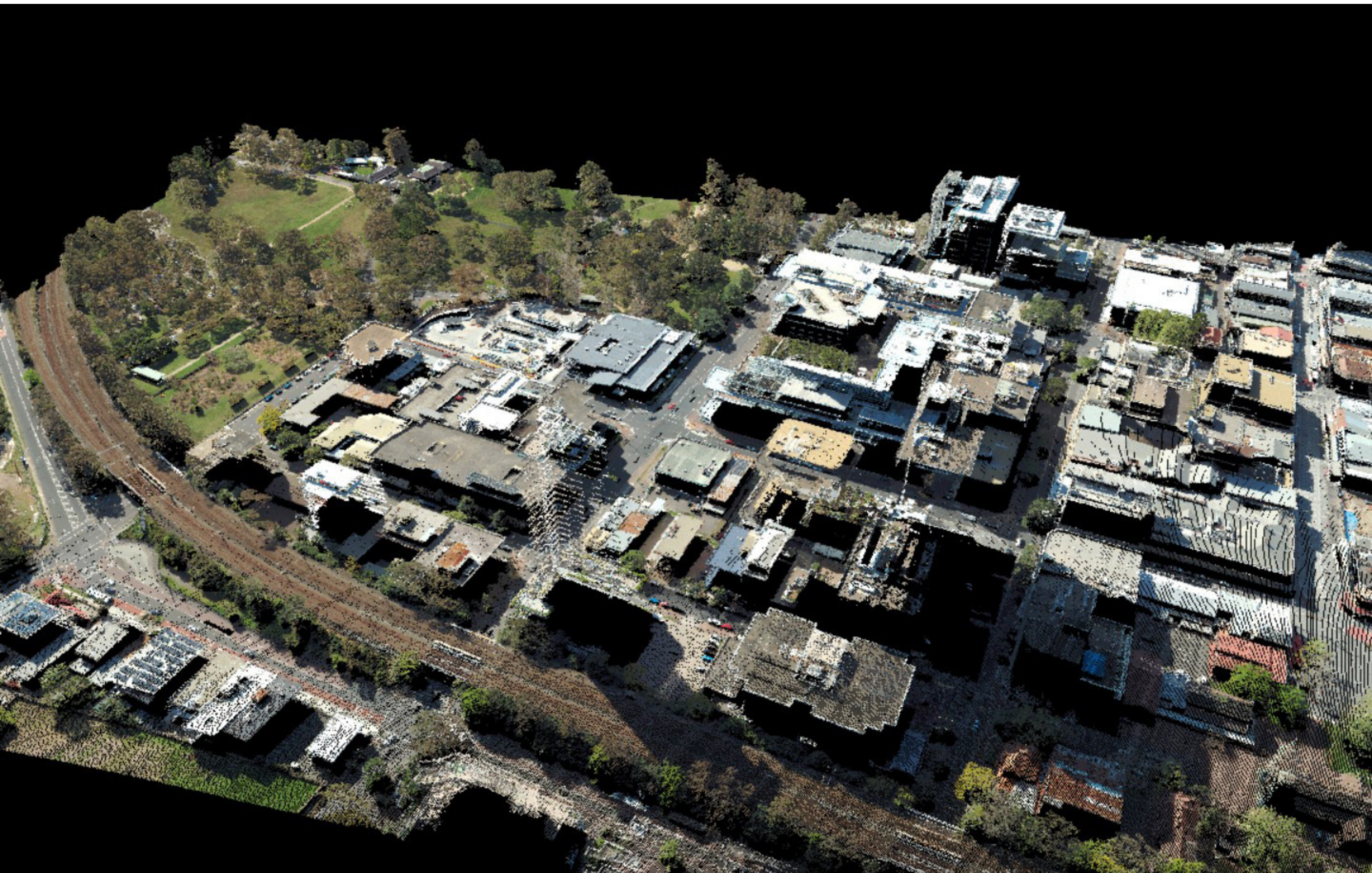
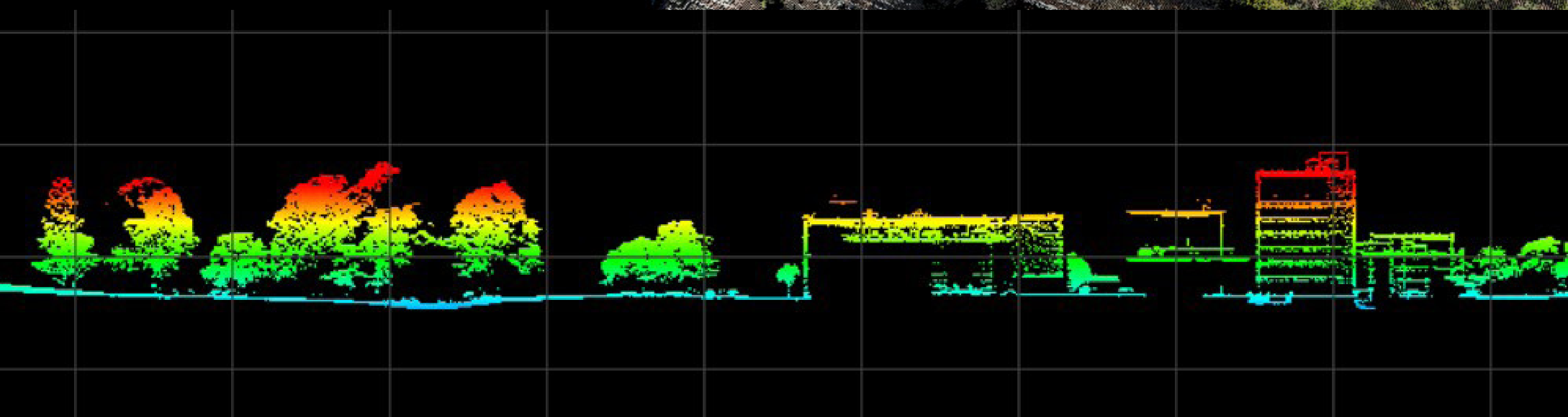
ICSM Australian Airborne LiDAR Acquisition Specification

Version 2.0





Intergovernmental Committee on Surveying and Mapping (ICSM)
Elevation, Depth, and Imagery Working Group (EDIWG)

Document Revision

Version	Date	Description/Comments	Contribution
2.0	07/07/2025	Endorsed for Publication	Elevation, Depth and Imagery Working Group

Revisions to this document are coordinated by the ICSM Elevation Depth and Imagery Working Group. Feedback and suggestions for changes may be provided at any time to icsm@ga.gov.au.

Contents

Abbreviations

AHD	Australian Height Datum
ANPD	Aggregate Nominal Pulse Density
ANPS	Aggregate Nominal Pulse Spacing
AOI	Area Of Interest
ASPRS	American Society for Photogrammetry and Remote Sensing
AVWS	Australian Vertical Working Surface
CHM	Canopy Height Model
COG	Cloud Optimised GeoTIFF
COPC	Cloud Optimised Point Cloud
COTS	Commercial Off-The-Shelf
CRS	Coordinate Reference System
DEM	Digital Elevation Model
DHM	Digital Height Model
DSM	Digital Surface Model
DTM	Digital Terrain Model
EDIWG	Elevation, Depth and Imagery Working Group
ELL	Ellipsoid
ELVIS	Elevation Information System
ESRI	Environmental Systems Research Institute
FCM	Foliage Cover Model
FSDF	Foundation Spatial Data Framework
FVA	Fundamental Vertical Accuracy
GDA	Geocentric Datum of Australia

GNSS	Global Navigation Satellite System
GPS	Global Position System
GUID	Global Unique Identifier
HA	Horizontal Accuracy
ICSM	Intergovernmental Committee on Surveying and Mapping
IMU	Inertial Measurement Unit
LAS	Industry standard point cloud file format
LAZ	Compressed version of LAS
LiDAR	Light Detection And Ranging
LZW	Lossless data compression
MGA	Map Grid of Australia
NIR	Near Infrared
NPD	Nominal Pulse Density
NPS	Nominal Pulse Spacing
NVA	Non-Vegetated Vertical Accuracy
PDRF	Point Data Record Format
QL	Quality Level
QA	Quality Assurance
RMSD	Root Mean Square Difference
RMSDz	Root Mean Square Difference in the z direction
RMSE	Root Mean Square Error
RMSEz	Root Mean Square Error in the z direction
RTK	Real Time Kinematics
SVA	Supplemental Vertical Accuracy
TIN	Triangular Irregular Network

Preface

The recent significant increase in light detection and ranging (LiDAR) data acquisition investment across all Australian jurisdictions has resulted in the Intergovernmental Committee on Surveying and Mapping (ICSM) requesting a review of the specifications published in 2010.

Significant advances in sensor and platform technologies, data processing techniques, systems infrastructure, and the increased accessibility of big data via streaming services has seen the demand for LiDAR data acquisition evolve from the initial exclusive realm of highly technical surveys to use in commercial products including vehicles and mainstream household consumer appliances.

A review of the 2010 specifications provides ICSM, through the Elevation Depth and Imagery Working Group (EDIWG), with the opportunity to reconnect with existing users and establish relationships with emerging sources of foundation spatial data; ensuring maximum use and future functionality of information collected. It provides a first step in the potential development of specifications based interactive support and online tools to improve usability and project outcomes while delivering on the broader objectives of the Elevation and Depth 2030 Strategy, Intergovernmental Committee on Surveying and Mapping (2018).

This document is based on a review of internationally published LiDAR specifications, guidelines, and feedback from recent government and industry forums. The target audience for this document is government agencies, academic, and private entities engaged in LiDAR acquisition and aims to ensure fit for purpose LiDAR procurement by addressing commonly raised issues.

A Digital Elevation Model created from LiDAR.

Foreword

Purpose and Summary – why these specifications matter

LiDAR technologies are increasingly being used to generate three-dimensional (3D) models of natural and human-made environments with accuracy, precision, and flexibility. The elevation and depth information generated is fundamental to emergency management, water security, environmental management, climate change studies, maritime navigation, natural resource exploration, urban planning, engineering, construction, and the definition of maritime and administrative boundaries.

Precise 3D elevation and depth information is increasingly becoming a keystone foundation for digital twins and our future knowledge-based digital economy. However, the continued rapid advancement of airborne LiDAR technology and remote sensing platforms, along with the size, cost and complexity of data acquisition has traditionally made the datasets difficult to integrate in addressing regional, state, and national issues. The standardisation of specifications during capture will provide for the development of more efficient processing and consistency across jurisdictions and improve decision making.

This specification provides the opportunity for public sector procured airborne LiDAR data to be seamlessly integrated and trusted as a source of authoritative foundation spatial data. A standardised approach to capture will reduce uncertainty for suppliers and consumers in the data acquisition process by establishing a common level of understanding of the specifications required.

Background – ICSM 2010 LiDAR Specifications

The Australian Intergovernmental Committee for Surveying and Mapping (ICSM) Elevation Working Group released Version 1.0 of the Guidelines for Digital Elevation Data acquisition in late 2008.

The original document was developed primarily for use by the Australian public sector to further improve on the quality, consistency, utility, and compatibility of data being captured by government and commercial off-the-shelf (COTS) products increasingly being offered by the private sector.

The aims of this specification included the provision of a mechanism for greater collaborative investment in LiDAR acquisitions across all levels of government with the capacity to reduce tender and compliance costs for investors and providers.

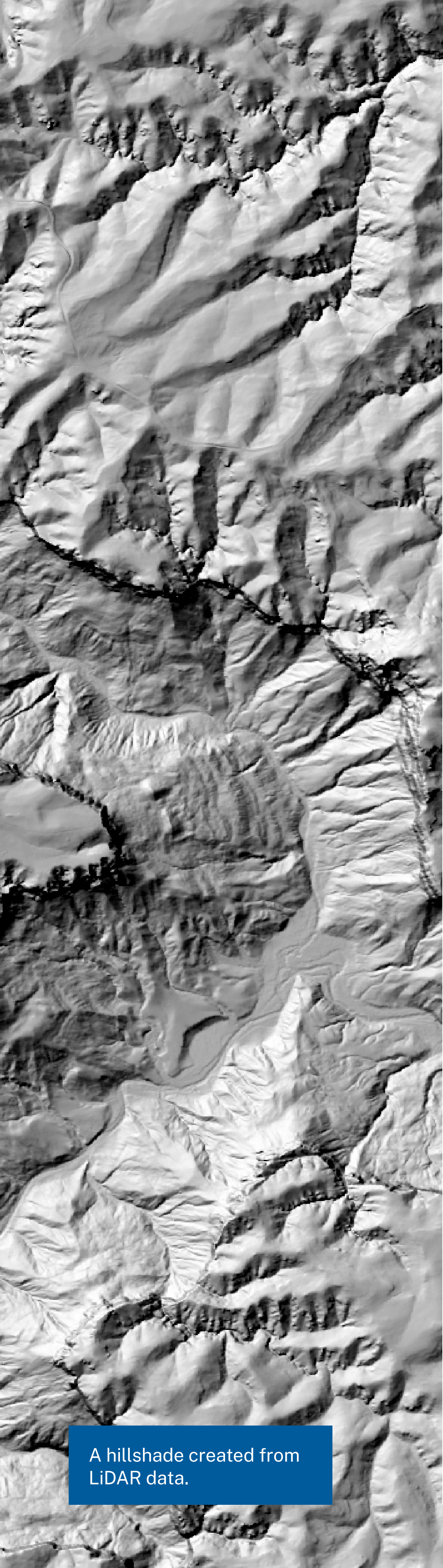
A combination of significant advances in sensor and platform technologies and maturity of the international airborne LiDAR surveying industry, has seen several international jurisdictions releasing improved specifications to support objectives similar to those of ICSM.

The development of this updated version (2025) builds on the original release, with the aim to respond to the needs of all tiers of government for an updated national guideline for acquisition of airborne LiDAR data, while incorporating the latest international best-practice, and issues and opportunities raised in recent government and industry forums.

Acknowledgements

These specifications and guidelines have been developed in consultation with government, industry, and academia. This includes a review of published international best practice LiDAR specifications and guidelines documentation to provide a comprehensive evaluation for the establishment of this document.

The ICSM Elevation Depth and Imagery Working Group would like to thank all the government entities, suppliers, and other stakeholders who provided consultation and feedback which contributed to the original 2008 version and this updated version. Their time and effort ensures this national specification remains fit for purpose and establishes an important foundation for industry and the community.



A hillshade created from LiDAR data.

1 Scope

1. Scope

1.1 Intended use of specification

Using this specification throughout the LiDAR data procurement process, will help to ensure that consistent and accurate LiDAR point cloud data, derived elevation datasets and their associated metadata are delivered to a standard that can contribute to the national Foundation Spatial Data Framework (FSDF). Offering the broadest potential re-use for all.

These specifications will ensure that LiDAR point cloud data and derived products can be easily integrated and ingested into the Elvis Elevation and Depth Portal (https://elevation.fsdf.org.au/) providing increased discoverability and access to the broader user community.

This guideline aims to provide advice to federal, state, and local government entities and government-owned corporations who seek to understand, plan, and acquire airborne LiDAR data. This document refers to these entities as the Contracting Authority, for the purposes of defining specifications from a tendering and contract management perspective.

1.2 National consistency for foundation data

Digital elevation data which describes Australia's landforms and seabed is crucial for addressing issues relating to the impacts of climate change, disaster management, water security, environmental management, urban planning, and infrastructure design. In recent years dramatic developments in LiDAR technologies and industry capabilities have revolutionised our ability to address these issues at the local level. Inconsistent, and diverse product specifications, and variable data quality often make it difficult to integrate datasets to address regional, state, and national issues. A national base specification adopted by all projects and jurisdictions, defining a set of minimum specifications and products, is required to optimise investment and the value of existing and future data collections.

1.3 Minimum requirements approach

LiDAR is still considered a relatively new technology even though research and commercial mapping applications have used the data for more than two decades. Instrumentation, software, processes, applications, and understanding are constantly being advanced and improved. It would not be possible to develop a single set of guidelines and specifications that address and remain consistent with all these advances.

This document is not intended to be prescriptive, instead enabling flexibility for industry in areas of development and innovation. Allowing options for Contracting Authorities in refining project scope to balance acquisition costs and maximise capture extent. It includes mandatory minimum requirements and tolerances, and wherever practical, offers the standard of current industry best practice as a highly desirable preference.

1.4 Additional best-practice guidance to support improved value

The document has been structured to support a workflow involving planning, collection, processing, data validation and expected deliverables of airborne LiDAR data. It is intended that an additional best practice guide and templates will be released at a later date to accompany this document.

1.5 Terminology

Numerous references to industry specific terms used in this document may have different definitions or understandings in other application areas, guidelines, or specifications.

The use of the term Digital Elevation Model (DEM) is commonly used to represent a spatial product depicting a bare earth or ground surface terrain, however, in this document the term Digital Terrain Model (DTM) is the preferred nomenclature and is considered equivalent to a bare earth DTM. Both are considered uniformly spaced models representing the bare ground surface without any objects such as vegetation or buildings.

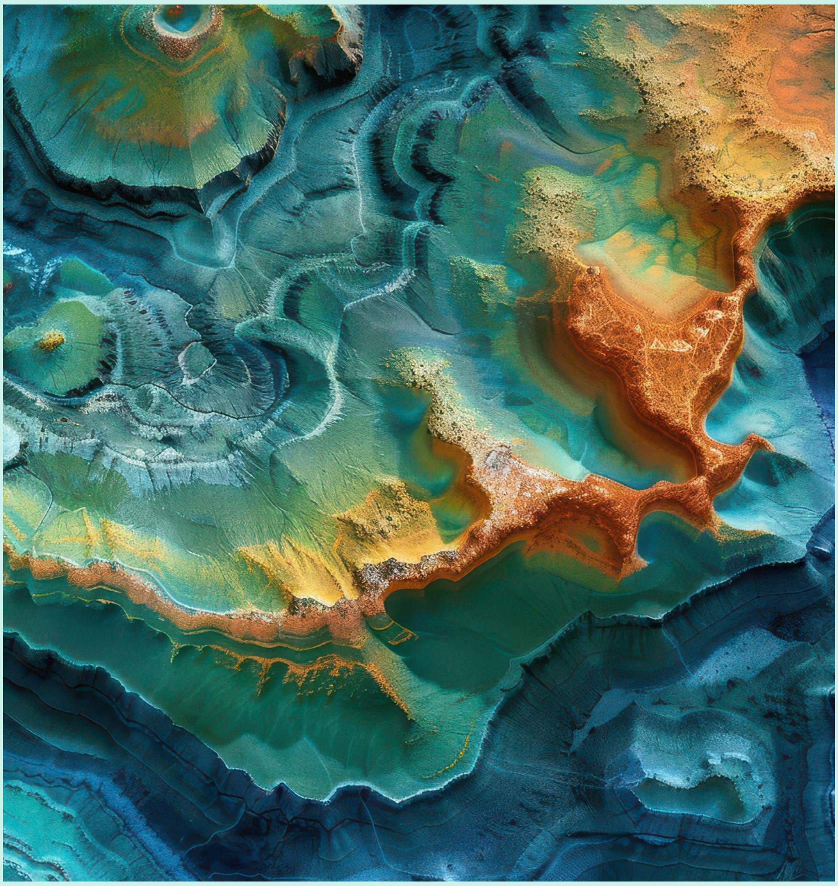
A Digital Surface Model (DSM) is considered a uniformly spaced surface that represents all features on the earth's surface including vegetation and human-made structures such as buildings.

1.6 Exceptions to requirements

The document does not expressly include LiDAR acquisition for bathymetric applications using airborne topo-bathymetric LiDAR systems or the requirements of hydrographic surveys.

The leading authority for bathymetric information in Australia is the Australian Hydrographic Office (https://www.hydro.gov.au/) who should be contacted for advice on bathymetric specifications.

Government-owned corporations with mature LiDAR data acquisition projects will have existing acquisition specifications and this guideline is intended to provide a basis for the harmonisation of requirements, where practical, across the Australian public sector to enable broadest re-use.



2

Collection Specifications

2. Collection Specifications

Perhaps more than other remote sensing technologies, LiDAR collection parameters are highly dependent on the environment of the project area. Terrain, land use, vegetative cover, degree of urbanisation, airspace control, and numerous additional factors can dictate different flight envelopes, instrument settings, data density, swath overlap, and many more parameters for specific project outcomes. Although these variations must be accepted, this section defines a number of collection requirements that must be met to achieve the consistent national LiDAR collection at the heart of elevation foundation spatial data.

2.1 Collection area

2.1.1 Coverage

- The project extent specified by the Contracting Authority must be adequately buffered (minimum of 100m) to avoid edge effects and safeguard against missing data.
- The Contracting Authority must provide a project extent in shapefile or file geodatabase format that encompasses the required extents of the AOI(s) in the required project coordinate reference system.

This will ensure the LiDAR acquisition and all associated deliverables will be completed to the extents of all tiles.

2.1.2 Scan angle

- The LiDAR sensor must have an appropriate scan angle depending on application.

The selection of a scan angle should consider vertical and horizontal accuracy requirements across the swath as well as the project objective.

2.1.3 Flight line overlap

- To provide sufficient data for interswath analysis, a minimum of flight line side overlap of 10% overlap is required to be maintained over the highest terrain.
- Any data with gaps between the geometrically usable portions of the swaths will be rejected.

2.2 Quality level

A tested and calibrated LiDAR sensor must be used in the capture of all LiDAR data. The quality level needs to be defined as per below.

Quality Level	QL0	QL1	QL2	QL3
Example Use	Modelling of large areas for preliminary route assessment	Modelling of inundation from floods or storm surges in areas with minimal infrastructure	Modelling of inundation from floods or storm surges in areas of high value assets	Surveys required for engineering and infrastructure design
Non-vegetated Vertical Accuracy (95% confidence interval (1.96 x RMSEz))	+/-1m	+/-0.6m	+/-0.30m*	<0.2m
Horizontal Accuracy (95% confidence interval (1.7308 x RMSE))	+/-3m	+/-1.8m	+/-0.80m*	<0.6m (typically 2 or 3 times the vertical accuracy)
Minimum Aggregate Nominal Pulse Density (ANPD)	≥0.5 pulses/m^2	≥2 pulses/m^2	≥4 pulses/m^2	≥8 pulses/m^2
Maximum Aggregate Nominal Pulse Spacing (ANPS)	≤1.41m	≤0.71m	≤0.50m	≤0.35m
Recommended contour interval	2m	1m	0.5m	<0.25m
Smooth Surface Repeatability (RMSEz)	≤0.12m	≤0.06m	≤0.06m	≤0.03m
Swath Overlap Difference (RMSEz)	≤0.16m	≤0.08m	≤0.08m	≤0.04m
Minimum grid cell size (DTM/DSM)	5m	2m	1m	<0.5m
Maximum tile size	4km x 4km	2km x 2km	2km x 2km	1km x 1km

* Note that previous reporting of vertical accuracy for the former ICSM Category 1 standard (now QL1) has generally referred to Fundamental Vertical Accuracy of ≤ +/-0.15m at the 68% confidence interval and Fundamental Horizontal Accuracy of at the ≤ +/-0.45m at the 68% confidence interval.

2.3 Survey control

- All survey control data used or derived from a contract must be supplied to the Contracting Authority to ensure independent Quality Assurance (QA) of the survey operations.
- All primary ground stations used in the collection of survey control must be referenced to the local datum specified above comprising State survey control marks with "established" GDA2020 coordinates and/or "accurate AHD" heights as defined in the relevant State Surveying regulation.
- All control surveys should align with the ICSM Standards and Practices for Control Surveys (SP1) (www.icsm.gov.au/sites/default/files/2020-12/Standard-for-Australian-Survey-Control-Network_v2.2.pdf).
- All ground surveys must be performed independently of any LiDAR GNSS operations.
- Unless requested by the Contracting Authority, the primary ground control and check point surveys must be referenced to the datums listed in Section 3.3.

Elevation data must be validated and corrected for systematic errors to ensure accuracy specifications are met. Documentation must describe how this has been achieved.

2.4 Multiple discrete returns

- The collection and delivery of discrete returns (points) from the ground and surface features such as shrubs, buildings, and trees are required.
- The LiDAR sensor must be capable of detecting multiple discrete returns.

Full waveform collection is regarded as supplemental information. The requirement for deriving and delivering multiple discrete returns is preferred.

2.5 Intensity values

- The LiDAR sensor must be capable of recording an intensity value for each return.
- Intensity or reflectance values are required for each discrete return.
- Intensity normalisation shall be strictly linear.

2.6 Nominal pulse density / nominal pulse spacing

Description	Specification
2.6.1 Aggregate Nominal Point Density (ANPD)	1. Aggregate Nominal Pulse Density (ANPD) shall meet the requirements of the project. 2. The ANPD must be achieved for each capture polygon. 3. The ANPD must be achieved for first returns on ground in clear terrain. Terrain undulation and capture conditions (e.g., prevalence of turbulence) must be accounted for to ensure the ANPD is achieved across the project area.
2.6.2 Aggregate Nominal Point Spacing (ANPS)	1. Aggregate Nominal Pulse Spacing (ANPS) shall meet the requirements of the project. 2. When calculating ANPS, it is necessary to measure between points across (along the scanner swath) and along (between the scanner swaths) the flight path. Measuring point spacing only at the centre of the swath is not an acceptable method for measuring the ANPS. The across/along track point spacing ratio is not to exceed 2/3.
2.6.3 Spatial distribution of geometrically usable points	1. The spatial distribution of geometrically usable points must be uniform and free from clustering to ensure consistent data densities throughout the project area.

2.7 Data voids

A data void is an area of >4xNPS^2 and are not acceptable except in the following circumstances:

- Where the data void is caused by water bodies.
- Where the data void is caused by areas of low near infra-red (NIR) reflectivity such as asphalt or composition roofing.
- Where the data void is appropriately filled-in by another swath.

The Contracting Authority is to provide details in the product metadata on how data voids are handled in derived products.

Data voids are gaps in the point cloud first return coverage, caused by problems including terrain/surface feature obstruction, instrumentation failure, processing anomalies, surface non-reflectance and improper survey planning. Flying altitudes, scan angles, overlap, flight line directions, tie runs, and other factors can be designed and planned to limit the risk of encountering data voids.

2.8 Collection conditions

LiDAR data must be collected when the following environmental conditions for capture are met (permission to modify collection conditions must be given by the Contracting Authority).

2.8.1 Illumination

- LiDAR data collection may be undertaken during all times of the day and night to accommodate project efficiencies such as reduced airspace restrictions during evening hours provided:
  - *Specifications for other environmental conditions can also be met.*
  - *Collection is compliant within any regulatory or legal conditions.*
  - *Safety requirements are given paramount attention.*
- If aerial imagery is to be collected concurrently with the LiDAR, the project illumination requirements will be dependent on the imagery product required. The Contract Authority should discuss options with the vendor.

2.8.2 Atmospheric

- LiDAR capture must be undertaken without cloud, fog, smoke, dust, haze, rain, snowfall, or other atmospheric interferents or precipitation present between the aircraft and the ground during all collection operations.

2.8.3 Surface water/ice/snow

- The surface should be free from flooding or extensive inundation, snow cover and ice build-up on shoreline or land areas. Dry land surface condition is recommended.
- LiDAR capture over floodplain or wetland areas should occur during times of base-flow and outside of significant surface inundation due to natural events and/or regulated environmental flows with the aim to maximise coverage of riverbanks and exposed floodplains. The Contracting Authority should discuss expectations of water levels with the vendor.

2.8.4 Astronomical tides

- Coastal and coastal estuary LiDAR capture over areas under tidal influence is recommended to be flown within 2 hours either side of low tide. Any low tide may be leveraged where multiple occur in single day. Capture outside these times require agreement from the Contracting Authority.
- Where possible, the Contracting Authority should supply a vector file of the tidal influence to the vendor.

2.8.5 Tie runs

- It is strongly recommended that cross-tie runs be collected to support data quality assessment and validation and used to support adjustment of data.

2.8.6 Overall consistency

- Collection of LiDAR data is to maintain a level of consistency across the entire project.

Visually noticeable and/or unexplained variations in flying altitudes, scan angles, overlap, and flight line directions, or significant variance in environmental conditions across a project capture may indicate other project specifications are unable to be met and be cause for rejection.

3

Data Processing and Handling Specifications

3. Data Processing and Handling Specifications

The utility of LiDAR is being increasingly recognised beyond the development of high-resolution DTMs. While generally there are differences to collection parameters for most projects, the most problematic variations between collections are traditionally the result of different processing techniques and approaches to data production across industry. This section defines the best practice outcomes sought for data production to ensure the quality and compatibility of elevation foundation spatial data without dictating specific tools or workflows.

3.1 Data file format

Description	Specification
3.1.1 LAS/LAZ File Format Standard	1. Collected LiDAR point cloud data should be stored in the American Society for Photogrammetry and Remote Sensing (ASPRS) LASer File Exchange format (LAS). 2. Point cloud deliverables are to be fully compliant with the LAS Specification Version 1.4 R-15 (ASPRS,2019) using Point Data Record Formats (PDRFs) 6 - 10 for discrete pulse data (referred to as LAS v1.4). 3. Only open LAS format is to be used and no proprietary formats are acceptable. 4. For bulk storage of data, LAS files can be compressed into the lossless LAZ (LAS zip) format.
3.1.2 Point Data Record Format	1. The vendor must select the most appropriate PDRF from PDRFs 6 - 10 depending on the information being encoded with each point (e.g., if points are encoded with RGB/NIR and/or waveform data). 2. A minimum standard for LAS/LAZ deliverables is PDRF 6. 3. Refer to the ASPRS LAS Specification for further detail (https://www.asprs.org/wp-content/uploads/2019/07/LAS_1_4_r15.pdf)
3.1.3 Global Unique Identifier	1. The Contracting Authority will advise of the requirement to assign a Global Unique Identifier (GUID) for a given project.s 2. In this instance, the GUID shall be appropriately set for all LAS/LAZ deliveries, such that it is the same for all files within a project.
3.1.4 System Identifier	1. The System Identifier field in the LAS/LAZ file header shall be populated in all delivered files. The field shall be populated with different entries depending on if the LAS/LAZ file is a raw strip of data, or if it is a tile containing overlapping strips of data. 2. If the file contains raw LiDAR strip data, the System Identifier field shall contain the make and model of the LiDAR system, followed by the serial number of the LiDAR system. 3. If the file contains tiled LiDAR data from overlapping strips, the System Identifier field shall contain the make and model from all sensors used within that tile.
3.1.5 Attribute Completeness	1. LAS files must be complete and accurate for all standard attributes, including: – *Intensity values (native radiometric resolution).* – *Return number.* – *Unique timestamps for each pulse (see Section 3.1.6).* – *Flight line number (File Source ID) (see Section 3.1.7).* – *Georeference (see Section 3.1.8).* – *Scanner Channel Bit Field (channel/head) – to be set to 0 for a single channel/head 0-3 for multiple channels/heads.*
3.1.6 Time Stamp of Navigational Data	2. Each GNSS aircraft positional measurement must be time stamped using Adjusted GPS Time (Standard [satellite] GPS time minus $1*10^9$), at a precision sufficient to allow a unique timestamp for each LiDAR pulse.
3.1.7 File Source ID	1. A unique file identifier (File ID) for individual flight swaths must be applied prior to data processing and available to identify each swath to source as identified in LAS 1.4 specification. 2. Each point within the swath must also be assigned a point source identifier (Point Source ID) that equals the unique file identifier. 3. The unique file and point identifier must be persistent and preserved through the data processing steps.

Description	Specification
3.1.8 Georeference	1. Correct and complete spatial reference system information must be embedded into each LAS file header. The embedded spatial reference system information must be capable of being correctly interpreted by a variety of spatial data systems including but not limited to: ESRI software, QGIS, LASTools, Python, Quick Terrain Modeler, ERDAS Imagine, Global Mapper, and TerraSolid.
3.1.9 Overlap	1. Overlap points are to be identified by setting the overlap flag as defined in the LAS 1.4 specification.
3.1.10 Withheld Pulses	1. Withheld pulses due to noise, erroneous data points, and geometrically unreliable points should be retained using withheld flag as per the LAS 1.4 specification.
3.1.11 Model Points	1. Model points are to be identified by setting the key-point flag as defined in the LAS 1.4 specification. 2. Model key points are a subset of class 2 that should be retained when thinning.
3.1.12 Measurement Units	1. Measurements are in metres (m) and must be specified to a minimum of 2 decimal places.

3.2 Full waveform

Waveform data is optional and may be requested at the discretion of the Contracting Authority. If required, it must be stipulated in tender documentation and deliverables are to use external auxiliary files with the wdp extension (.wdp) for the storage of waveform packet data.

3.3 Datums and coordinate reference system

Description	Specification
3.3.1 Horizontal Datum	1. The recommended horizontal datum for latitude and longitude is the Geocentric Datum of Australia 2020 (GDA2020) unless requested otherwise by the Contracting Authority.
3.3.2 Vertical Datum (Ellipsoid)	1. All deliverables specified as ellipsoidal will be in terms of the GDA2020 reference frame unless required otherwise by the Contracting Authority. 2. The source of the ellipsoidal height control shall be explained in the Post-Survey Spatial Accuracy Report (see Section 3.9).
3.3.3 Vertical Datum (Physical)	1. All deliverables specified as physical heights may be referenced to either of 1) the Australian Height Datum 1971 (AHD); or 2) the Australian Vertical Working Surface (AVWS) – as determined by the geoid model used to transform from ellipsoidal to physical heights. 2. For Tasmanian based captures, deliverables may be referenced to Australian Height Datum (Tasmania) AHD83.
3.3.4 Geoid Model	1. The most recent ICSM-approved geoid model shall be used to transform ellipsoidal heights to physical heights. 2. AHD heights must use AUSGeoid2020; AVWS heights must use the Australian Gravimetric Quasigeoid.. *Refer to the following for the most recent approved Geoid model:* http://www.ga.gov.au/geodesy/ausgeoid/
3.3.5 Coordinate Reference System	1. The Coordinate Reference System (CRS) for all deliverables in this specification is the Map Grid of Australia (MGA) projection in the appropriate zone with AHD orthometric heights. 2. The Contracting Authority will need to discuss with the vendor their data processing preferences in situations where the project area encompass multiple MGA zones.

3.4 Spatial accuracy validation

Spatial accuracy of the survey must meet the requirements of the project and Quality Level as defined by the Contracting Authority in Section 2.2. 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 is expected to apply best practice in assessing the project accuracy and achieving compliance with this specification. The vendor must deliver a detailed report of each of the validation processes used as part of the Post-Survey Spatial Accuracy Report (see Section 3.9).

Description	Specification
3.4.1 Non-Vegetated Vertical Accuracy	1. For FSDF Elevation LiDAR collections, validation of the Fundamental Vertical Accuracy (FVA) of the point cloud dataset is replaced with the measure of Non-Vegetated Vertical Accuracy (NVA). 2. The NVA for the point cloud is to be assessed by comparing AHD elevations for check points located in open, relatively flat terrain, where there is a very high probability that the sensor will have detected the ground surface and produces only a single LiDAR return. 3. Vertical accuracy testing of point data will use a Triangular Irregular Network (TIN) model to conduct the comparison between point data and ground survey check points. 4. First returns and only pulse data will be used to create the TIN. 5. The TIN will be used to extract an interpolated value at the same location the ground sample check point was collected.
3.4.2 Horizontal Accuracy	1. It is the responsibility of the vendor to establish appropriate methodologies, applicable to the technologies used, to verify that the Horizontal Accuracy (HA) meets the stated requirement. 2. Where practical, it is highly desirable that the HA assessment requires analysis of distinct linear features which are identifiable in the elevation data (e.g., fences), seen using interpolated intensity images, and comparison with other data sources such as horizontal check points (see Section 3.6.3) or high-resolution imagery with known horizontal accuracy. 3. Where the lack of distinct surface features makes horizontal accuracy testing difficult or impossible, the vendor should report on the expected HA of elevation products as determined from system and sensor calibration studies. In this instance a “compiled to meet” statement of horizontal accuracy at 95% confidence should be reported. 4. Independent accuracy assessments may also be carried out by the Contracting Authority.
3.4.3 Adjustment to local AHD	1. The vendor is expected to apply best practice in assessing the project accuracy. 2. Adjustment to “local” AHD is required under the following circumstances: – *Where the NVA is exceeded when the Geoid derived orthometric heights are validated against local AHD, or* – *Where a bias in the vertical validation resulting from anomalies in the Geoid model or other sources is identified across the whole project area.* 3. Details of this adjustment are required as part of the Post-Survey Spatial Accuracy Report (see Section 3.9).

3.5 Positional accuracy validation

- Before classifying and developing derivative products from the point cloud, the positional accuracy of the point cloud must be verified by the vendor.
- The accuracy assessment should be conducted within the geometrically usable portion of the swath (typically the centre 95% of the swath width).
- The vendor is expected to apply best practice in assessing the project accuracy and achieving compliance with this specification.

Description	Specification
3.5.1 Intraswath Precision	1. The Intraswath Precision (also known as Smooth Surface Repeatability) of the survey must meet the requirements of the Quality Level of the project with a minimum of QL1 attained for FSDF Elevation LiDAR collections (≤6cm). 2. Assessment of precision will be made on hard surfaced areas (for example, parking lots) containing only single return LiDAR points. 3. At a minimum, precision shall be assessed for each flight (take-off and landing cycle). 4. Precision shall be reported by way of a polygon shapefile delineating the sample areas checked and attributed with the following and using the cells within each polygon as sample values: – *Minimum slope-corrected range (numeric)* – *Maximum slope-corrected range (numeric)* – *RMSDz of the slope-corrected range (numeric)*
3.5.2 Interswath Overlap Consistency	1. The Interswath Overlap Consistency of the survey must meet the requirements of the Quality Level of the project with a minimum of QL1 attained for FSDF Elevation LiDAR collections (≤8cm). 2. Overlap consistency will be assessed at multiple locations within overlap in non-vegetated areas of only single returns. 3. Assessment is limited to areas of <10 degree slope. To the degree that the data allow, test areas should be located such that the full width of the overlap is represented. 4. The overlap areas that will be tested are those between the following: – *adjacent, overlapping parallel swaths within a project* – *cross-tie swaths and a sample of intersecting project swaths in both flight directions* – *adjacent, overlapping lifts* 5. As with precision, the Overlap Consistency shall be reported by way of a polygon shapefile delineating the sample areas checked and attributed with the following and using the cells within each polygon as sample values: – *Minimum difference in the sample area (numeric)* – *Maximum difference in the sample area (numeric)* – *RMSD of the sample area (numeric)*

3.6 Check points

- Check points must be an independent set of points used for the sole purpose of assessing the vertical and horizontal accuracy of the project.
- Control points used in the calibration process for data acquisition must not be used as check points.
- The vendor is expected to apply best practice selecting and surveying check sites (see Section 2.3).

3.6.1 Check point distribution

- Check points must be distributed extensively and evenly throughout each project area.
- Within each assessment type, check points will be distributed among all constituent land cover types in approximate proportion to the areas of those land cover types.
- The Contracting Authority may permit the distribution of check points more densely in the vicinity of important features and more sparsely in areas that are less consequential.

3.6.2 Check point locations

- Check points for FSDF Elevation LiDAR collections must be established in areas of bare, open ground and with a clear view of the sky where there is a very high probability that the sensor will have detected the ground surface.
- All tested locations will be photographed showing the position of the survey tripod (if used) and the ground condition of the surrounding area.
- The check point should be placed on the ground in clear, flat, open terrain where:
  - *the slope is less than 10 degrees*
  - *the ground has not been ploughed or disturbed*
  - *there are no obstructions by artefacts such as buildings, vegetation, boulders and vehicles (e.g., where the check point would be overshadowed by the vertical artefact.)*

3.6.3 Check point locations for horizontal accuracy

- For horizontal accuracy testing of the point cloud, wherever practical, a vendor-determined portion of the check points should be located at the ends of paint stripes or other point features visible on the LiDAR intensity image, allowing them to double as horizontal check points.

The ends of paint stripes on concrete or asphalt surfaces are normally visible on LiDAR intensity images of 10cm or better resolution, as are 90-degree corners of different reflectivity, e.g., a footpath corner adjoining a grass surface.

3.6.4 Number of check points

- The minimum number of required check points are based on the total area of the project as agreed by the vendor and Contracting Authority.
- The number will vary depending on the area of interest and accessibility to appropriate check point locations:

Project Size	Minimum number of check points
Less than 100 km^2	5
Between 100 km^2 and 400 km^2	20
Between 400 km^2 and 2500 km^2	20 plus 1 per 50km^2 where the coverage exceeds 400km^2
Greater than 2500 km^2	62 plus 5 per 500km^2 where the coverage exceeds 2500km^2

- Clusters of check points at the one location are considered as one check point in any criteria assessment.
- The Contracting Authority may adjust the number of check points required in locations of concern or due to challenging areas of access.

3.6.5 Use of historic check points

- In addition to newly acquired survey check points, historical points may be used, provided they were acquired within a relevant time period and not used in calibration or data acquisition of the current project.
- Historical check points must meet all the check point requirements and surface conditions at the check point location.
- The Contracting Authority must be advised in advance if historical points will be used and reserves the right to reject any or all points.

3.7 Supplemental vertical accuracy validation

- The requirement to assess Supplemental Vertical Accuracies (SVA) may be specified by the Contracting Authority where information is required on the vertical accuracy achieved within land cover categories outside of bare open ground.
- In this instance, each landcover type representing 10% or more of the total project area, and additional landcover categories specified by the Contracting Authority must be tested and reported as an SVA.
- For supplemental and consolidated accuracy tests, the 95th percentile method shall be employed to determine accuracy.
- The methodology for establishing check points, testing, and reporting must be consistent with the Fundamental Spatial Accuracy Validation (Section 3.4) and approved by the Contracting Authority.

3.8 Spatial distribution and point density validation

3.8.1 Spatial distribution of points

- The uniformity of the spatial distribution and regularity of pulses distribution shall be assessed through a distribution raster covering the entire project with the first return pulses within the geometrically usable centre part of each swath (typically 95% of the centre portion of the swath width) and excluding acceptable data voids.
- The resolution of the distribution raster should be twice the project Aggregate Nominal Pulse Spacing (ANPS x 2).
- At least 90% of the grid cells shall have at least 1 LiDAR point.
- The vendor is expected to apply best practice in assessing the project accuracy and achieving compliance with this specification.
- The supplied rasters must be:
  - *Provided in specified Datum and Coordinate Reference System (see Section 3.3 and 4.1.2).*
  - *Supplied in agreed raster format with the Contracting Authority.*

3.8.2 Point density

- The density of points shall be assessed through the provision of point density rasters to demonstrate complete coverage and achievement of minimum ANPD across the project area.
- These rasters include:
  - *Individual swath raster - validate swath overlap and minimum ANPD has been achieved on an individual swath basis.*
  - *Whole project area raster - validate that the project area has been completely covered and minimum ANPD has been sufficiently achieved across the whole project area.*
- Mosaic of a capture polygon must be created by first generating point density rasters for each individual swath (all returns) and then mosaicking these using the maximum pixel value where swaths overlap.
- Point density shall be calculated using all returns to derive a raster mosaic with a pixel size of 1m x 1m.
- Pixel values must represent the density of points within their respective cell area (i.e., points/m^2) and have a pixel data type of floating point.
- 95% of pixels in the project area (excluding pixels covering water bodies or areas of low near infra-red reflectivity) must meet the ANPD requirement.

- Excessive volumes of sensor noise should not be considered when assessing whether the dataset conforms to minimum point density requirements.
- The supplied rasters must be:
  - *Provided in specified Datum and Coordinate Reference System (see Section 3.3 and 4.1.2).*
  - *Supplied in agreed raster format with the Contracting Authority.*

3.9 Post-survey spatial accuracy report

The Contracting Authority may request a Post-Survey Spatial Accuracy Report. Acceptance of the Post-Survey Spatial Accuracy Report and related information is required by the Contracting Authority before point classification and other product derivation is to proceed (typically a contract milestone).

Description	Specification
The Post-Survey Spatial Accuracy Report	1. Details of system calibration checks. 2. Results of relative (flight run) matching and details of any adjustments made. 3. Source of primary ellipsoidal height control. 4. Details of ellipsoid to orthometric corrections applied including any final adjustment to local AHD supplemental to the standard Geoid correction. 5. Results of vertical and horizontal accuracy validation including Supplemental Vertical Accuracies. 6. Results of Positional Accuracy Validation.
The Post-Survey Spatial Accuracy Report Attachments	1. Project extent, shapefile (.shp) or geopackage (.gpkg) format – see Section 4.5.1 2. Flight trajectories (flight lines) – *shapefile (.shp) or geopackage (.gpkg) polyline format.* – *All flight trajectories used for the capture of the delivered LiDAR data must be supplied.* – *Flight trajectories will need to include the date of capture, start time, end time and which reference station was used for each trajectory – see Section 4.5.2.* 3. Check point comparison table (supplied as separate table), Microsoft Excel spreadsheet read-only format (.xlsx) with attribute details including Point ID, Published Easting, Northing, Height (E,N,H), Check Point Values (E,N,H), Residuals (E,N,H), and comments. 4. Survey Control and check point locations, shapefile (.shp) or geopackage (.gpkg) point format as per the attribute structure in Section 3.9. 5. Digital photographs of all survey and check sites, with the Site ID included in the filename. The bearing of the photo direction should also be included. 6. Intraswath Precision, shapefile (.shp) or geopackage (.gpkg) format delineating the sample areas checked and attributed with the following and using the cells within each polygon as sample values: – *Minimum slope-corrected range (numeric)* – *Maximum slope-corrected range (numeric)* – *RMSDz of the slope-corrected range (numeric)* 7. Overlap Consistency, shapefile (.shp) or geopackage (.gpkg) format delineating the sample areas checked and attributed with the following and using the cells within each polygon as sample values: – *Minimum difference in the sample area (numeric)* – *Maximum difference in the sample area (numeric)* – *RMSD of the sample area (numeric)* 8. Laser scanning equipment calibration report, PDF format (.pdf) 9. Spatial distribution of points raster (Section 3.8.1), supplied in the format specified by the Contracting Authority. 10. Point density for all returns raster (Section 3.8.2), supplied in the format specified by the Contracting Authority.

- All spatial data deliverables are to be supplied with the various datums and coordinate reference system as specified in Section 4.1.2.
- Ancillary files associated with the Survey Control, or any other Survey Control-related information or files as determined by the vendor or Contracting Authority must also be supplied. This may include photos and other documents describing control point locations, or survey control capture reports.

3.9.1 Ground control and check point shapefile

Ground control and check point shapefiles must be supplied with the attributes:

Field name	Field data type	Description
Name	Text	Name of control / check point
Easting	Double	Easting (X) coordinate of point
Northing	Double	Northing (Y) coordinate of point
Elevation	Double	Elevation (Z coordinate) of point
Comment	Text	Any additional comments about the point, e.g., positional accuracy, description of ground feature, control source.

3.9.2 Non-compliance

- If any requirement within the Post-Survey Spatial Accuracy Report does not comply with the required accuracies, specifications, or expectations, it must be proactively investigated and reported by the vendor and discussed with the Contracting Authority before further classification and processing is carried out.
- Unless determined otherwise by the Contracting Authority, acceptance of the Post-Survey Spatial Accuracy Report by the Contracting Authority does not remove the vendor's responsibility to have achieved the original spatial accuracy requirements – particularly if later instances of non-compliance are identified following the supply of processed contract deliverables.

3.10 Use of the LAS withheld bit flag

- Outliers, noise points, geometrically unreliable points near the extreme edge of the swath, aerosol backscatter, laser multipath, airborne objects, sensor anomalies, and other points that cannot be reasonably interpreted as valid surface returns or the vendor deems unusable must be identified using the Withheld flag (as defined in LAS 1.4 specification) and not deleted.
- All data collected must be delivered in the classified point cloud.
- During manual or automated classification processes, these points are to be identified and assigned the appropriate standard LAS classification values for noise—class 7 for low noise and class 18 for high noise (see Section 3.12).

Noise classes are primarily used to denote points that are valid but not earth-bound (for example, birds) or spurious (for example, artificially induced deviations in elevation at or near land/water interfaces).

The use of the Withheld flag ensures that the Contracting Authority receives all data collected (rather than the vendor deleting the points they consider "unusable"), while allowing the vendor to apply their best judgement in what to use for further classification.

3.11 Use of the LAS overage bit flag

- Identifying overage points is not required, however if they are explicitly identified they must be identified using the Overlap bit 3 flag as defined in the LAS 1.4 specification for Record Format 6.
- Points flagged as overlap must still be delivered in the classified point cloud, and they must be classified per the project classification requirements unless also flagged as Withheld.
- This ensures classification of all points that are not flagged as Withheld.

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.

Identification of overage points allows their simple exclusion from subsequent processes where the increased density and elevation variability they introduce is unwanted (i.e., DTM generation).

3.12 Point cloud classification

- The classification of all returns must be strictly undertaken in accordance with the Standard LiDAR Point Cloud Classes as per Section 3.12.1.
- Additional classes may be used on specific projects as determined by the Contracting Authority as per Section 3.12.2
- Automated classification and manual editing must be performed as required to achieve the Classification Quality Level accuracy specified for each required class (see Section 3.12.3) and any additional classes determined by the Contracting Authority. This includes the incorporation of hydro-flattening and clean-up of poor automated classification results such as vegetation incorrectly classified as ground or ground points classified as vegetation.
- Classification of returns shall be complete as is feasible and without avoidable return misclassification.
- All points not identified as withheld must be processed for classification including returns identified as overlap (overage).
- Classified overlap points must also retain their overage bit flag status.
- Model key points may be identified using class 8 at the discretion of the Contracting Authority and created as a separate product.
- No points are to be assigned a classification value of 0. This classification value is only included to maintain compatibility with certain software and legacy LAS specifications.
- The Unclassified class (classification value 1) must include points that have been subject to a classification process and emerged in an undefined state.
- The percentage of points assigned a classification value of 1 must be less than 1% of the total number of returns in each capture polygon.
- Points with spuriously high or low Z values are to be classified as Low Noise (classification value 7) or High Noise (classification value 18).
- Assessing and verifying the accuracy of point classification into classes beyond the LiDAR Point Cloud Classification Scheme (Section 3.12.1) is the responsibility of the Contracting Authority.

3.12.1 Standard LiDAR point cloud classification classes

All classified point cloud data must adhere to the following Standard LiDAR Point Cloud classification scheme adapted from the LAS 1.4 specifications and ASPRS guidelines to the Australian geographic context:

Number	Point class	Description
0	Created	Created, never classified
1	Unclassified	Processed, but unclassified
2	Ground	Bare ground
3	Low Vegetation	0-0.3m above ground (essentially sensor noise)
4	Medium Vegetation	0.3-2m above ground
5	High Vegetation	>2m above ground
6	Buildings	Permanent or semi-permanent residential, commercial, or industrial buildings. This includes houses, sheds, silos, etc.
7	Low Noise	Spurious low point returns (unusable)
9	Water	Any point in water
17	Bridges and permanent jetties	Any structure or overpass erected over a depression or obstacle (such as a water body) to carry traffic, rail transport, pedestrians, or some utility such as a pipeline. Excludes bridge furniture, e.g., guard rails, handrails, supporting structures, etc.
18	High Noise	Spurious high point returns (unusable)

3.12.2 Additional LiDAR point cloud classification classes

Additional classes may be used for specific projects or to meet specific industry standards as determined by the Contracting Authority with examples as follows:

Number	Point class	Description
10	Rail	
11	Road Surface	
13	Wire - Guard	
14	Wire - Conductor	
15	Transmission Tower	
16	Wire-Structure connector	
19	Overhead Structure	e.g., conveyors, mining equipment, traffic lights
21	Snow	If present and identifiable
22	Temporal Exclusion	Features excluded due to changes over time between data sources – e.g., water levels, landslides
64	Culvert	A tunnel carrying a stream or open drainage under a road or railroad or through another type of obstruction to natural drainage
65	Bridge furniture	Guard rails, handrails, supporting structures

3.12.3 ICSM Point Cloud Classification Quality Levels

The minimum number of classified point cloud classes to be delivered for a particular project, the completeness and data processing effort required, and the classification accuracy required must adhere to the following *Classification Quality Level* scheme:

Level	Description
0	**Undefined** • All points allocated a 1 (default) by LiDAR processing software with no classification algorithms applied • Classification Accuracy Required is unspecified
1	**Automated and Semi-Automated Classification** • Data is subjected to fully or semi-automated, batch processing or algorithms which, as a minimum will classify the points into the following classes: 2 (ground), 3-5 (vegetation), 6 (buildings/ structures), 7 & 18 (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 is 95% for Ground points within any 1km-by-1km area (minimum), and other classes as specified by the Contracting Authority.
2	**Surface improvement** • Level 1 classified data is further enhanced, using automated and manual methods, by the removal of significant anomalies which remain in the ground class (2). • Typically, this editing will re-classify points into classes 3-5 (vegetation), class 9 (water), class 7 (low points/noise) or class 18 (high points/ noise). • The overall intent here is to create a ground surface suitable for orthorectification of imagery, with a minimum of effort. • Classification Accuracy Required is 98% for Ground points within any 1km-by-1km area (minimum), and other classes as specified.
3	**Manual Correction** • Level 2 is further enhanced; whereby significant and highly supervised (often manual or semi-automated) effort is generally required for this level to ensure that points are assigned to the correct class – particularly that only actual ground points are assigned to class 2. • Typically, this editing will both remove and add points to the specified classes derived using the automated algorithms. • Full manual line scan editing of batch output may be required in highly complex environments. • Features which may require special attention include water and areas where the ground surface may be obscured including buildings, densely vegetated water courses, rainforest, dense coastal vegetation or grass, rocky outcrops/boulders, contour/levee banks, wood/rubbish piles and islands. • Any points observed in water are to be re-classified into class 9. • All points regardless of classification should be reviewed. • Any point that is measuring a ground height should be classified 2 (ground). • If points have been classified 2 (ground), but are not measuring a ground height, they should be reclassified to the appropriate LAS classification. • Ideally, to assist with the creation of hydrologically sound data, 'bridge-like' structures will be identified at this level and classified accordingly. This manual task is best undertaken with reference to associated imagery or feature datasets provided by the Contracting Authority. • Classification Accuracy Required is 99% for ground points within any 1km-by-1km area (minimum), and other classes 95% within any 1km-by-1km area (minimum) or as specified by the Contracting Authority.

Level	Description
4	**Full Classification** • Detailed classification and correction of all specified classes unless otherwise determined by the Contracting Authority. • Typically, this level of classification would only be undertaken to meet highly specific project requirements over localised areas. • When specified, each class must achieve the required classification accuracy. • Development of a hydrologically conditioned DTM will generally require a higher level of editing to remove man-made structures such as buildings, bridges, and culverts. • Classification Accuracy Required is 99% for all specified classes within any 1km-by-1km area.

3.12.4 FSDF Point Cloud Classification Quality Levels

For FSDF Elevation LiDAR collections the following Classification Quality Levels are recommended as the minimum standard to be achieved for each of the following Standard LiDAR Point Cloud Classes:

Number	Point class	Classification Quality Level
0	Created	Level 1
1	Unclassified	Level 1
2	Ground	Level 3
3	Low vegetation	Level 2
4	Medium Vegetation	Level 2
5	High Vegetation	Level 3
6	Buildings	Level 3
7	Low Noise	Level 1
9	Water	Level 3
17	Bridges and permanent jetties	Level 3
18	High Noise	Level 1
64	Culvert	Level 3
65	Bridge Furniture	Level 3

- Point classification must be consistent across the entire project area.
- Where a classification level is specified for a non-ground class, equivalent effort and methods (i.e., automated, semi-automated, manual) should be applied to this class as if it were ground.

The increase in the minimum classification quality level requirements for several classes and the inclusion of additional infrastructure classes compared to the 2010 ICSM LiDAR specifications is reflective of the recent expansion of the FSDF to include several additional built infrastructure themes and the role that airborne LiDAR acquisition can play in improving those datasets.

3.12.5 Assessment of point cloud classification accuracy

Description	Specification
Point Cloud Classification Accuracy Assessment	1. The assessment of Classification Accuracy should be tested by using ancillary information including high resolution ortho imagery or other relevant geospatial datasets. 2. Sampling should be well distributed across the AOI. 3. A minimum of 5 random locations per 1km x 1km area should be sampled, with the total number of areas sampled at the discretion of the Contracting Authority. 4. In most circumstances detailed visual inspections of the DTM and individual classified scan line profiles and use of high-quality reference imagery will be sufficient to independently demonstrate if classification standards have been achieved for the specified classes. 5. For certain items (e.g., bridges and culverts) additional spatial datasets may be required for appropriate validation. 6. The vendor must report on classification methods used and on how classification accuracy is checked and assured. 7. Point Cloud Classification Accuracy may be relaxed by the Contracting Authority in localised circumstances for challenging areas.
Point Cloud Classification Consistency	1. Point classification is to be consistent across the entire project. 2. Noticeable variations in the character, texture, or quality of the classification between tiles, swaths, lifts, or other non-natural divisions are grounds for rejection. 3. Areas showing inconsistency in ground points due to uneven terrain are grounds for rejection. 4. Duplicate points (2 points with the same XYZ coordinates and timestamp) within the project is not acceptable and will be rejected. 5. Near duplication (that is, a group of points duplicated but with a slight but consistent spatial offset) will be regarded as duplication.

3.13 Manual classification guidance notes

Description	Specification
Vegetation	1. Although class 2 is specified as 'bare ground', it is accepted that return signals from low ground covers such as grass etc. are included, and indeed necessary in many circumstances to obtain sufficient data for elevation modelling. 2. Where there is a clear delineation in the data between bare earth and ground cover, then such vegetation must be attributed as class 3 (low vegetation). 3. Where dense vegetation prevents survey of any actual ground points it can be very difficult to classify the points with 100% certainty, however this remains the greatest challenge for LiDAR processing and exactly the reason why the Classification Quality Levels were introduced – in particular, Level 3. 4. It is accepted that this lack of actual ground points may result in significant voids and therefore production of a DTM will require interpolation across such areas. 5. There should not be widespread occurrences of points with a classification value of 3 (Low Vegetation) occurring on roads and other flat, artificial surfaces, water, or buildings.
Temporary or Mobile Objects	1. Where the automated algorithms have determined return signals obtained from 'temporary' objects such as motor vehicles, shipping containers, haystacks, wood piles etc. to be ground (class 2), those data points must be re-attributed as class 1 (unclassified). 2. Similarly, where it is obvious amongst quarries, construction sites or other areas that mounds or piles of ground material, gravel etc. are temporary and remain in the ground class, then those data points must be re-attributed as class 1 (unclassified).

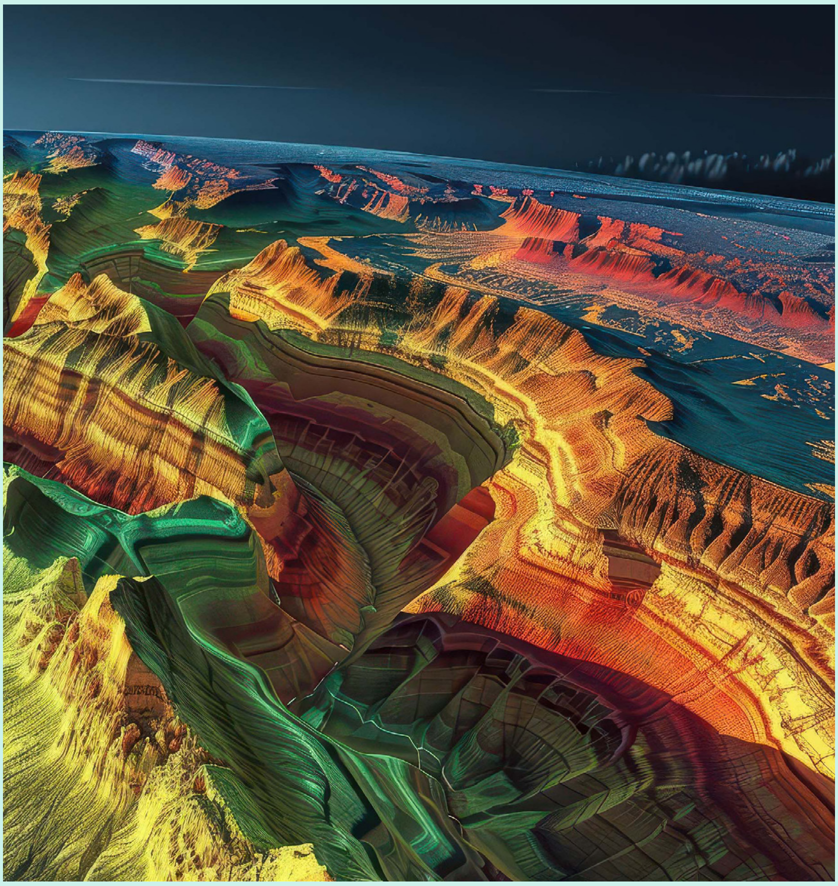
Description	Specification
Bridges	1. Where return signals are obtained from a bridge (being a structure erected over a depression or obstacle to carry traffic, pedestrians, or some utility such as a pipeline, including permanent jetties), those data points must be attributed as class 17 (bridge). 2. This classification will apply only to the aerial component of the structure and not embankments or other support features that impede the flow of water – which must be attributed as class 2 (ground). 3. All data points that are part of the bridge structure are required to be identified as such regardless of their initial classification being ground, vegetation, buildings or other. 4. This class could exclude bridge furniture in specific project acquisitions, e.g., guard rails, handrails, supporting structures, etc. where a specific class 65 (bridge furniture) is utilised.
Culverts	1. Where return signals are obtained from the surface above a culvert, those data points must be attributed as class 2 (ground). 2. This requirement is excluded where a specific class 64 (culverts) is utilised.
Water	1. Where return signals are obtained from water (due to turbidity, sediment etc.), those data points must be attributed as class 9 (water). 2. If, due to the presence of water, spurious data points are computed (above or below the surface), those points must be attributed as class 7 (noise, not usable). 3. There are no minimum extents for water bodies specified. 4. Where it is possible to identify water (or floating vegetation) in the data, it should be classified as such, including non-perennial waterways and dams. 5. As the temporary extents of water from coastal inundation are difficult to avoid, any such area should be identified by the vendor and dealt with on a case-by-case basis if necessary. 6. Definition of the actual edge of water bodies is always subjective and will be treated as such where the available imagery and data profiles are vague with respect to the extent of the water. 7. In addition, and under the following circumstances related to water bodies, editing of other point classes must be undertaken as described here: – *Vegetation in water* • *Where return signals are obtained from vegetation standing in water (reed beds, mangroves etc.), those data points must be attributed as class 3, 4 or 5 (vegetation).* • *Where it is obvious that the vegetation is at water level (lily pads, floating weed etc.), those points must be attributed as class 9 (water).* – *Objects or structures in water* • *Where return signals are obtained from objects or structures standing in water (rock outcrops, jetties, pontoons, boats, debris etc.), those data points must be attributed into an appropriate class.* • *Rocky outcrops and islands must be class 2 (ground). Structures, including permanent jetties to be classified as class 17 (bridge deck). Boats and other random or temporary features to be classified as class 1 (unclassified).* – *Ocean and large water bodies* • *Definition of the water line along beaches requires profiling to obtain the best result for ground classification.* • *Due to the motion of the water, there may also be data incorrectly classified as vegetation in the ocean or water body which must be re-classified as class 9 (water).*

3.14 Hydro-flattening

- Hydro-flattening is the processing of water bodies so that the surface of the feature is level and enables water to flow downhill.

Description	Specification
3.14.1 Hydro-flattening methodology	1. If hydro-flattening is undertaken, the methodology used for hydro-flattening is at the discretion of the vendor and is not intended to satisfy detailed hydrological or hydraulic modelling applications.
3.14.2 Hydro-flattening must be undertaken for non-tidal natural and artificial water bodies and watercourses	1. Inland ponds and lakes (water bodies) with a surface area of 625m² or greater (approximately equal to a 25m x 25m pond) at the time of collection must be flattened. – *Flattened water bodies must present a flat and level water surface (a single elevation for every bank vertex defining the water body's perimeter, in the vertical datum used for hydro-flattening).* – *The entire water-surface edge must be at or below the immediately surrounding terrain (bottom of bank level or just above water strike).* – *Long impoundments such as reservoirs, inlets, and fjords, whose water-surface elevations decrease with downstream travel must be treated as streams or rivers.* 2. Inland streams or rivers (watercourses) 30m or greater nominal width at the time of collection must be flattened. – *This should not unnecessarily break a stream or river into multiple segments. At times it may squeeze slightly below 30m for short segments. vendors should use their best professional judgment.* – *Flattened streams and rivers must present a flat and level water surface bank-to-bank (perpendicular to the apparent flow centreline).* – *Flattened streams and rivers must present a gradient downhill water surface, following the immediately surrounding terrain.* – *In cases of sharp turns of rapidly moving water, where the natural water surface is notably not level bank-to-bank, the water surface will be represented as it exists while maintaining an aesthetic cartographic appearance.* – *The entire water-surface edge must be at or below the immediately surrounding terrain.* – *Watercourses must break at level road crossings (culverts) leaving the roadway over the culvert intact.* – *Watercourses must be continuous (not break) at bridges, overpasses, and other above-ground features.* – *When the identification of a structure as a bridge or culvert cannot be made definitively, the feature must be regarded as a culvert.* – *Sinks must not be filled.* 3. Boundary waterbodies, regardless of size, where the collection does not include the opposite shore must be flattened. – *They shall be represented as a polygon that follows the shore throughout the project and is then closed using arbitrary line segments as needed across the waterbody.* – *All landward water surface edges shall be at or below the immediately surrounding terrain.* – *The water-surface elevation must be consistent throughout the project.* – *The water surface must be flat and level, as appropriate for the type of water body (level for lakes, a gradient for streams and rivers).* – *Any unusual changes in the water-surface elevation over the course of the collection (such as changes in upstream dam discharge) must be documented in the project metadata.* – *In the event of an unusual change in water-surface elevation, the water body shall be handled as described in Hydro-Flattening Tidal Features (Section 3.14.3).* 4. The hydro-flattening methodology used for a capture polygon must be detailed in the Project Report deliverable (Section 4.2).

Description	Specification
3.14.3 Hydro-flattening tidal features	1. The water surface within a Tidal Waterbody (defined as any waterbody that is affected by tidal variations, including oceans, seas, gulfs, bays, inlets, salt marshes, and large lakes) shall be flat and level for each different water surface elevation. 2. Vertical discontinuities within a waterbody resulting from tidal variations during the collection are considered normal and shall be retained in the final DTM. 3. Horizontal discontinuities along the shoreline of a waterbody resulting from tidal variations during the collection are considered normal and shall be retained in the final DTM. 4. Long tidal waterbodies that also exhibit downhill flow can present unusual challenges; vendors are to exercise their best professional judgment in determining the appropriate approach solution to meet the overall goal of hydro-flattening as described in this section. 5. The hydro-flattening methodology used for tidal waterbodies must be detailed in the Project Report deliverable (Section 4.2).
3.14.4 Hydro-flattening products	1. Any additional data layers created for the purposes of hydro-flattening, such as masks and breaklines, must be supplied to the Contracting Authority. 2. The format and file naming of these data layers will be discussed and agreed to by both the vendor and Contracting Authority. 3. In combination with methodology provided in the Project Report (Section 4.2), the Contracting Authority should have all necessary data to be able to re-produce the hydro-flattened DTM from the point cloud.



4

Deliverables Specifications

4. Deliverables Specifications

The comprehensive delivery of all datasets and ancillary products collected under the contract provides transparency of assumptions and processing lineage supporting increased data utility. This section defines standardised delivery specifications that facilitate the ability to conduct detailed Quality Assurance processes, enable end-user assessment of fitness of purpose, and maintains capacity to reprocess the data at a point in the future into alternative formats. This is the final phase in ensuring LiDAR data can contribute to the national Foundation Spatial Data Framework (FSDF) and fully deliver on its diverse possibilities.

4.1 Mandatory deliverables (FSDF Elevation LiDAR collections)

For FSDF Elevation LiDAR collections the following data and reports are required to be supplied to the Contracting Authority for Quality Assurance checks, this includes delivery of all ancillary products collected under the contract that support the processing of the LiDAR dataset:

- Project Report, PDF format (.pdf) (Section 4.2)
- Metadata statement submitted in the specified format (see Section 4.1.3)
- Tiled classified point cloud, LAS v1.4 format (.las) – orthometric heights
- Tiled 1m (or better resolution) DTM, GeoTIFF format (.tif) – orthometric heights
- Tiled LiDAR intensity image, GeoTIFF format (.tif) or alternative as specified by the Contracting Authority.
- Tile indexes for each tiled deliverable, as per requested vector format e.g., geopackage or ESRI Shapefile
- All additional data layers used for hydro-flattening including breaklines for hydro-flattened features, delivered as per requested vector format e.g., geopackage or ESRI Shapefile
- The items previously delivered as part of the Post-Survey Spatial Accuracy Report including the report in pdf format and all file attachments listed under Section 3.9.
- GNSS data for all base station occupations in excess of 6 hours for possible inclusion in the Contracting Authority's state survey control infrastructure.
  - *GNSS observation log sheets which include the following details:*
    - *Survey Mark ID*
    - *Occupation time & date*
    - *Antenna height measurements*
    - *Instrument /antenna types & serial numbers*
  - *The GNSS observation log sheets should be provided in pdf format or Excel spreadsheet if data is captured digitally.*
- The Contracting Authority can nominate to substitute LAS deliverable requirements with the compressed lossless LAZ (LAS zip) format as an alternative supply version of LAS files to reduce data transfer volumes.
- The Contracting Authority can nominate to complement GeoTiff deliverable requirements with the Cloud Optimised GeoTiff (COG) to support user discovery and access efficiencies.
- The Contracting Authority can nominate to complement LAS deliverable requirements with the Cloud Optimised Point Cloud (COPC) to support user discovery and access efficiencies.

While conversion to LAZ format may reduce vendor data transfer volumes for supply, consideration should be given to whether the Contracting Authority holds spatial software capable of directly reading the LAZ format, or whether an additional data processing step is required to uncompress the data to perform necessary Quality Assurance checks on receipt.

Once in COG and COPC formats, data cannot be reprocessed back into the original GeoTIFF and LAS formats without loss of information. It is recommended not to rely on COG and COPC formats to meet archival requirements.

4.1.1 Optional deliverables

The Contracting Authority may wish to include additional requirements and deliverables in the contract including:

- Tiled 1m resolution non-DTM models as requested by the Contracting Authority.
- Tiled cartographic contours as per Contracting Authority requirements.
- Tiled engineering contours as per Contracting Authority requirements.
- Tiled RGB or RGBN colourised point cloud LAS v1.4 format (.las).
- Tiled classified point cloud LAS v1.4 format (.las) – ellipsoidal heights.
- Tiled concurrent imagery, GeoTIFF format (.tif).
- Higher/lower resolution DTM.
- River flow or tidal collection restrictions.
- Treatment of DTM generation in specific situations when dense low crop e.g., sugarcane prevents reliable ground points.

4.1.2 Datum and coordinate reference system

- All spatial data deliverables are to be supplied in the various datums and coordinate reference system as specified in Section 3.3.
- Each project spatial dataset deliverable shall be processed and delivered in a single CRS (MGA Zone), except in cases where a project area covers multiple CRSs such that processing in a single CRS would introduce unacceptable distortions. In this instance the Contracting Authority will advise whether to either:
  - *Deliver the project in a single CRS where the project centroid or majority of coverage exists, or*
  - *Split the project into multiple CRSs with the buffered extent extending out to the full GDA2020 tile key boundary.*

4.1.3 Metadata

- For each supplied data product, a complete metadata record consistent with the current version of metadata standard AS/NZS ISO 19115 must be provided. AS/NZS ISO 19115:2015 is the current version at the time of publishing. Further guidance on upcoming metadata version changes is available from the ICSM Metadata Working Group.
- Metadata must be provided with every delivery including interim, partial, and final deliveries.
- The delivery of metadata details is required in both a standard report format (e.g., PDF) and machine-readable format (JSON, XML) for use in automated processes and metadata catalogue solutions.
- In general, the metadata record should contain key information about the LiDAR product to support context, discovery, and re-use.
- This includes the standardised reporting of accuracy.

The ISO19115 records are most useful for working in a common standards-based catalogue where core details (name, dates, extent) can easily be queried to support discovery alongside imagery and vector data.

4.1.4 Intellectual Property ownership

- To maintain maximum forward flexibility the vendor must deliver the Contracting Authority all the data created or developed in performing the contract with unrestricted copyright (customer-owned intellectual property) or with intellectual property shared equally with the vendor if improved value for money can be achieved.

4.2 Project report

A project report must be supplied including the following items as a minimum:

- **Introduction:** including a statement of consistency with any specified standards and any extra-ordinary details that may have affected the nature or delivery of the project.
- **Collection report:** detailing mission planning and flight logs, including dates of collection, and sensor information including details on how each collection specification (Section 2) has been met.
- **Survey report:** with details on control and adjustments as per the Post-Survey Spatial Accuracy Report (Section 3.9). Duplication of original version is permitted if no changes were made post supply.
- **Processing report:** detailing calibration, classification, and product generation procedures including manual and automated classification methods used, hydro-flattening methodology, DTM creation including interpolation method, percentage of points in each class and methods for other derived product deliverables.
- **Quality Assurance report:** detailing analysis methodology, accuracy assessment and validation of the following:
  - *Vertical and horizontal local accuracy, including a table of the product data compared to each check site.*
  - *Point cloud data, including a summary of relative (smooth surface repeatability and overlap consistency), non-vegetated vertical and horizontal local accuracy, and classification accuracy.*
  - *Approach for achieving and verifying accuracy for each major land cover type in the project area (representing > 10% or more of the total project area).*
  - *DTM, including a summary of checks for artefacts and hydro-flattening quality.*
  - *Other optional deliverables as relevant.*
  - *Any additional information on quality assurance performed for classification.*
- **Conclusion**

Elevation data (including point clouds and derivative products) must be validated and corrected for systematic errors to ensure accuracy specifications are met. The Project Report must describe how this was achieved.

4.3 LiDAR point cloud products

Description	Specification
4.3.1 Unclassified Point Cloud	1. Raw project source data, such as native format LiDAR files are not required for delivery. 2. The vendor must hold a back-up copy of all relevant unclassified project data for a minimum period of time as specified in Section 4.7.
4.3.2 Classified Point Cloud Tiles	Classified point cloud tile deliverables must include or conform to the following: 1. Fully compliant with the Data File Format specifications (Section 3.1). 2. Provided in specified Datum and Coordinate Reference System (Section 3.3). 3. Include data from all project swaths, returns, and collected points, fully calibrated, adjusted to ground, and classified. Project swaths exclude calibration swaths, crossties, and other swaths not used in product generation. 4. Fully compliant with Point Cloud classification specifications (Section 3.12) including classification classes and achievement of the required ICSM Classification Quality Levels (Section 3.12.3) as determined by the Contracting Authority. 5. Tiled Delivery as per Section 4.6 Data Supply. Tiles should be supplied with all classifications in a single file. 6. Files named as per Section 4.6 Data Supply. 7. The vendor must hold a back-up copy of all relevant classified project data for a minimum period of time as specified in Section 4.7.

Description	Specification
4.3.3 Colourised Point Cloud Tiles	Colourised point cloud tile deliverables must include or conform to the following: 1. Fully compliant with the Data File Format specifications (Section 3.1). 2. Provided in specified Datum and Coordinate Reference System (Section 3.3). 3. Include data from all project swaths, returns, and collected points, fully calibrated, adjusted to ground, and classified. Project swaths exclude calibration swaths, crossties, and other swaths not used in product generation. 4. Colourised using RGB or RGBN photogrammetry data as specified by the Contracting Authority. 5. Tiled Delivery as per Section 4.6 Data Supply. 6. Files named as per Section 4.6 Data Supply.

During this period, additional quality control and assurance testing may be conducted as needed and determined by the Contracting Authority. If any deficiencies are found in the deliverables, content, and data (i.e., not meeting the specifications), the Contracting Authority may reject the data, requiring completion of the deliverables or reprocessing or re-flying of deficient areas.

As part of the contract management process, it is best practice for the Contracting Author to carry out independent checks to verify that the delivered data meets project specifications.

4.4 Derived products

Description	Specification
4.4.1 Intensity Image	1. An intensity image must be generated using the intensity values from first returns of LiDAR strikes only. 2. Intensity image generation must employ a binning method to interpolate the average intensity value within each pixel with the Natural Nearest Neighbour algorithm being used to interpolate void areas. 3. The pixel size of the intensity image should permit horizontal accuracy checking of the FHA of the survey as per requirements of the Quality Level (QL) of the project. 4. As Quality Level 1 (QL1) must be attained for FSDF Elevation LiDAR collections, a minimum intensity image pixel size of 10cm is required or alternative as advised by the Contracting Authority noting vendor processing requirements and data volumes. 5. Intensity image tiles must be complete with data except for areas covered by a tidal waterbody (this does not include tidal ground exposed at the time of capture). 6. Where ECW (.ecw) is the specified delivery format: – *Intensity images must be supplied as a single band raster in ECW version 2 format with pixel data type 8-bit unsigned integer and correct spatial reference system information embedded in the ECW file.* – *All ECW files must be created with a target compression ratio of 10:1.* – *All ECW files must be supplied with ERS and TAB world reference files.* 7. Where Cloud-Optimised GeoTIFF (COG) (.tif) is the specified delivery format: – *Intensity images must be supplied as a linear single band raster with pixel data type 8-bit unsigned integer and correct spatial reference system information embedded in the COG header including calculated min/max statistics.* – *All COG files must be created with LZW compression.* – *Provided in specified Datum and Coordinate Reference System (Section 3.3).* – *Tiled Delivery as per Section 4.6 Data Supply.* – *Files named as per Section 4.6 Data Supply.* 8. For FSDF Elevation LiDAR collections an image intensity pixel size of 10cm is considered current best practice for projects with a point density of 8 points per square metre or greater.

Description	Specification
4.4.2 Digital Surface Model (DSM)	1. The Digital Surface Model (DSM) should be generated from the "first return" LiDAR mass point data after removal of noise. This will include ground and non-ground points such as vegetation and buildings. 2. The DSM generation should employ a Point to TIN and TIN to Raster process with Nearest Neighbour interpolation. 3. The minimum grid cell size must be guided by the Quality Level of the survey, refer to Section 2.2 Quality level e.g., QL1 is 1m. 4. All DSM deliverables must be supplied with elevation values as 32-bit float data type in either of the following formats: – *ASCII XYZ (.xyz)* – *Uncompressed, 1-band 32-bit GeoTIFF (.tif), or* – *Compressed (LZW compression), 1-band 32 bit GeoTIFF (.tif)* 5. ASCII XYZ files must have the X, Y and Z values delimited by a single tab character. 6. The X and Y values in ASCII XYZ files must be on the half-pixel value. 7. GeoTIFF files must be supplied with the correct spatial reference system information embedded in the GeoTIFF file header. 8. Provided in specified Datum and Coordinate Reference System (Section 3.3). 9. Tiled Delivery as per Section 4.6 Data Supply. 10. Files named as per Section 4.6 Data Supply.
4.4.3 Digital Terrain Model (DTM)	1. A Digital Terrain Model (DTM) must be generated using elevation information from the classified point clouds so that it defines the 'bare earth' ground surface. 2. Only points with a classification value of 2 or 64 (ground and culvert classes (where the culvert was specified by the Contracting Authority)) will be used to generate the DTM. 3. The DTM must include all significant, visible, constructed features if they appear to sit on the earth or at ground level, e.g., road embankments. 4. Small structures and all structures built above the ground must be excluded from the DTM. This includes buildings, bridges, and solid concrete dividers. All vegetation must be excluded from the DTM as well. 5. DTM generation must employ a Point to TIN and TIN to Raster process using the Nearest Neighbour algorithm for interpolation. 6. DTM tiles must be complete with data except for areas covered by a tidal water body (this does not include tidal ground exposed at the time of capture). 7. The minimum grid cell size must be guided by the Quality Level of the survey, refer to Section 2.2 Quality level e.g., QL1 is 1m. 8. All DTM deliverables must be supplied with elevation values as 32-bit float data type in either of the following formats: – *ASCII XYZ (.xyz)* – *Uncompressed, 1-band 32-bit GeoTIFF (.tif), or* – *Compressed (LZW compression), 1-band 32 bit GeoTIFF (.tif)* 9. ASCII XYZ files must have the X, Y and Z values delimited by a single tab character. 10. The X and Y values in ASCII XYZ files must be on the half-pixel value. 11. GeoTIFF files must be supplied with the correct spatial reference system information embedded in the GeoTIFF file header. 12. Provided in specified Datum and Coordinate Reference System (Section 3.3). 13. Tiled Delivery as per Section 4.6 Data Supply. 14. Files named as per Section 4.6 Data Supply.

<table>
<tr><th>Description</th><th>Specification</th></tr>
<tr><td>4.4.4 Digital Height Model (DHM)</td><td>1. The Digital Height Model (DHM) is generated by subtracting the DTM from the DSM
2. The minimum grid cell size must be guided by the Quality Level of the survey, refer to Section 2.2 Quality level e.g., QL1 is 1m.
3. Elevation values supplied as 32-bit float data type in either of the following formats:
– ASCII XYZ (.xyz)
– Uncompressed, 1-band 32-bit GeoTIFF (.tif), or
– Compressed (LZW compression), 1-band 32 bit GeoTIFF (.tif)
4. ASCII XYZ files must have the X, Y and Z values delimited by a single tab character.
5. The X and Y values in ASCII XYZ files must be on the half-pixel value.
6. GeoTIFF files must be supplied with the correct spatial reference system information embedded in the GeoTIFF file header.
7. Provided in specified Datum and Coordinate Reference System (Section 3.3).
8. Tiled Delivery as per Section 4.6 Data Supply.
9. Files named as per Section 4.6 Data Supply.</td></tr>
<tr><td>4.4.5 Canopy Height Model (CHM)</td><td>1. Canopy height is defined as the height of the foliage source above ground for any point of the canopy.
2. Unless specified by the Contracting Authority, the Canopy Height Model (CHM) represents the height of all vegetation features under class 4 (Medium Vegetation), and class 5 (High Vegetation) only and does not include other classes includes ground, water, buildings, or bridges and permanent jetties etc.
3. The CHM is obtained by subtracting the interpolated ground-classified hits (DTM) from the interpolated vegetation-classified hits in the DSM.
4. The CHM gives the interpolated height of all points in the canopy in the form of a regularly spaced raster.
5. Maximum values should not exceed 110 metres.
6. Values should not be negative.
7. Minimum heights in the CHM may depend on the vegetation communities present in a given project area.
8. The CHM must have a pixel size of 1m x 1m unless alternatively specified by the Contracting Authority.
9. All CHM deliverables must be supplied with height values as 32-bit float data type in either of the following formats:
– Uncompressed, 1-band 32-bit GeoTIFF (.tif), or
– Compressed (LZW compression), 1-band 32 bit GeoTIFF (.tif)
10. GeoTIFF files must be supplied with the correct spatial reference system information embedded in the GeoTIFF file header.
11. Provided in specified Datum and Coordinate Reference System (Section 3.3).
12. Tiled Delivery as per Section 4.6 Data Supply.
13. Files named as per Section 4.6 Data Supply.

Low vegetation (class 3) is excluded from the CHM as this class does not contribute to canopy and generally contains significant noise not accommodated for in other noise categories.</td></tr>
</table>

<table>
<tr><th>Description</th><th>Specification</th></tr>
<tr><td>4.4.6 Foliage Cover Model (FCM)</td><td>

A Foliage Cover Model (FCM) is used as a measure of vegetation density below the canopy level and is measured by the number of returns that strike vegetation features before striking the ground.
FCM is calculated as one minus the gap fraction probability as defined by the proportion of counts from all vegetation returns at least 2m above the ground for each 2m bin expressed as a percentage (%).
The FCM must have a pixel size of 10m x 10m unless alternatively specified by the Contracting Authority.
All FCM deliverables must be supplied in either of the following formats:

Uncompressed, 1-band 8-bit GeoTIFF (.tif), or
Compressed (LZW compression), 1-band 32 bit GeoTIFF (.tif)

GeoTIFF files must be supplied with the correct spatial reference system information embedded in the GeoTIFF file header.
Provided in specified Datum and Coordinate Reference System (Section 3.3).
Tiled Delivery as per Section 4.6 Data Supply.
Files named as per Section 4.6 Data Supply.

</td></tr>
<tr><td>4.4.7 Contours</td><td>

Cartographic contours must be generated from the DTM. Contours must not be generated directly from point cloud data.
The contour interval should be guided by the Quality Level of the survey unless alternatively specified by the Contracting Authority, refer to Section 2.2 Quality level e.g., QL1 is 0.5m.
Contours must adhere to the following topology rules:

Contours must not intersect.
Contour features that cross tile boundaries must smoothly join at the tile edge to ensure a seamless contours dataset across each capture polygon.
Contours must not have dangles unless at the edge of a project area.
Contours must be visually cartographic style (rounded) and not engineering style contours (jagged and angular in appearance).
Contour lines are to be long continuous line strings rather than separate lengths.

Cartographic contours must be supplied as 3D polylines in the shapefile (.shp) or geopackage (.gpkg) format.
Contour Shapefiles must include a field named “ELEVATION” with the field data type of Double. This field must contain the elevation value for each contour feature.
Contours Shapefiles must include a field named “TYPE” with the field data type of String. This field must contain a ‘type’ value for each contour feature in accordance with the following:

<table>
<tr><th>Field Value</th><th>Description of included contours</th><th>Example contour elevation values</th></tr>
<tr><td>“Index”</td><td>Contours with elevation values that are a multiple of 2.5.</td><td>2.5, 0, 2.5, 5</td></tr>
<tr><td>“Intermediate”</td><td>Contours with elevation values that are a multiple of 0.5 and not already classified as Index contours.</td><td>-0.5, 0.5, 1, 1.5, 2, 3</td></tr>
<tr><td>“Supplementary”</td><td>Remaining contours not already classified as Index or Intermediate.</td><td>-0.25, 0.25, 0.75</td></tr>
</table>
</td></tr>
</table>

Description	Specification
4.4.8 Building Outlines	1. Vectorised horizontal extent of classified buildings within LiDAR point cloud. 2. Roof outlines with maximum elevation or height above ground as an attribute. 3. Minimum building size of $10m^2$.

4.5 Ancillary products

4.5.1 Project extent

The project extent is a geo-referenced spatial representation of the detailed extent of each delivered dataset and must be provided to the following requirements:

- The extents must be those of the actual LiDAR source or derived product data, exclusive of TIN artefacts or raster void areas.
- A union of tile boundaries or minimum bounding rectangles is not acceptable unless these are identical to the dataset extents.
- The project extent must be supplied as shapefile (.shp) or geopackage (.gpkg) format.
- Provided in specified Datum and Coordinate Reference System (Section 3.3).
- Files named as per Section 4.6 Data Supply.

4.5.2 Flight trajectories (flight lines)

The trajectory file (flight line) should be a single file, line (not point or polygon) and projected file in shapefile (.shp) or geopackage (.gpkg) format. All flight lines should be merged into a single file.

- Flight trajectories will need to include the date of capture, start time (local time), end time (local time) and which reference station was used for each trajectory.

Field name	Alias	Data type	Example
FIS	FID		
Shape*	shape		
Prj_name	Project Name	text	Capricornia 2023 Project
Cap_start	Capture Start date/time (AEST)	text	8/06/2022 11:56
Cap_end	Capture End date/time (AEST)	text	8/06/2022 11:04
Altitude	Flying Height (meter)	double	1234.56
PSID	Point Source ID	long	1234
Station	Station	text	DALB,YLRB,WEEM,4MRN,4GW2

- Each flight trajectory 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 flight trajectories must be supplied as shapefile (.shp) or geopackage (.gpkg) polyline format.
- Provided in specified Datum and Coordinate Reference System (Section 3.3).
- Files named as per Section 4.6 Data Supply.

4.5.3 Tile key/index

- A tile index must be supplied for each spatial data deliverable specified as 'tiled'.
- The tile index must be derived from the geometry of the deliverable it represents and not copied from a generic 1km x 1km tile grid.
- Tile indexes must include a field named "Tile" with field data type String. The "Tile" field must contain the name of the data tile it represents using the naming convention defined in Section 4.6.
- No gaps or regions of NoData are to be present between or within tiles.
- Tiles must fit together to form a seamless dataset for each tiled deliverable and be free of any artefacts that delineate the edges of tiles (e.g., artificial elevation 'stepping' between tiles).
- Each tile index must be supplied as shapefile (.shp) or geopackage (.gpkg) format.
- Provided in specified Datum and Coordinate Reference System (Section 3.3).
- Files named as per Section 4.6 Data Supply.

4.6 Data supply

4.6.1 File structure

- Deliverables for each capture polygon in a project must be supplied in a separate directory.

4.6.2 File naming

- Whilst achieving national consistency in file naming is highly desirable, it is recognised that over the last decade many jurisdictions have amassed significant archival LiDAR data volumes and have developed bespoke naming approaches.
- Prescribing a single mandatory file naming requirement risks the introduction of inefficiencies to established data management processes (particularly automated processes) and misalignment of data.

4.6.3 ELVIS portal file name convention

- As the primary mechanism to access openly available elevation and depth foundation spatial data, the ELVIS application applies its own unique file naming approach to data supply and provides the end user with a means of national consistency.
- If the data is to be shared on the ELVIS Portal (https://elevation.fsdf.org.au/) the following file naming conventions must be adhered to:

Point cloud data		
ProjectNameYYYY-CL-Datum-PPM_East-North_Zone_Width_Height.ext		
Project Name	Kempsey	A meaningful description of the total survey area of interest. Do not use "_" as part of the Project Name
YYYY	2009	Year of survey
CL	-C3	Classification level (C0-4)
Datum	-ELL or AHD	Specified vertical datums. Ellipsoidal (ELL) or Orthometric (AHD)
PPM	-8ppm	Points per square metre
East-North	_480000-6558000	Easting and northing value (whole or half kilometre) of the south- west corner of the tile (e.g., 480,000mE 6558,000mN)
Zone	_56	MGA zone of the file
Width	_1km	Width of the tile as whole number with units (km or m if tile width less than 1km)
Height	_1km	Height of the tile as whole number with units (km or m if tile width less than 1km)
ext	.las or .laz	File extension e.g., las or laz
Examples: Kempsey2009-C3-AHD-4ppm_480000-6558000_56_1km_1km.las, BlueLake2023-C3-AHD-8ppm_480000-6558000_56_500m_500m.las		

Elevation raster tiles		
ProjectNameYYYY-ModelType-Datum-Resolution_East-North_Zone_Width_Height.ext		
Project Name	Kempsey	A meaningful description of the total survey area of interest. Do not use "_" as part of the Project Name
YYYY	2009	Year of survey
Model Type	-DTM	DSM – Digital Surface Model DEM – Digital Elevation Model DTM – Digital Terrain Model DHM – Digital Height Model CHM - Canopy Height Model FCM – Foliage Cover Model
Datum	-ELL or -AHD	Specified vertical datums. Ellipsoidal (ELL) or Orthometric (AHD)
Resolution	-10cm	Resolution of raster tile with units (e.g., cm, m)
East-North	_480000-6558000	Easting and northing value (whole or half kilometre) of the south- west corner of the tile (e.g., 480,000mE 6558,000mN)
Zone	_56	MGA zone of the file
Width	_1km	Width of the tile as whole number with units (km or m if tile width less than 1km)
Height	_1km	Height of the tile as whole number with units (km or m if tile width less than 1km)
ext	.tif	File extension e.g., tif
Examples: Kempsey2009-DTM-AHD-1m_480000-6558000_56_1km_1km.tif, BlueLake2023-DTM-AHD-10cm_480000-6558000_56_500m_500m.tif		

4.6.4 Tiling sizes

All spatial data deliverables specified as 'tiled' must be supplied as default 1km x 1km tiles using a 1km x 1km grid in the appropriate GDA2020 MGA zone projection unless otherwise specified by the Contracting Authority.

- In this instance the origin (southwest corner) of each tile must align with a whole 1000-metre value for easting and northing coordinates in the appropriate GDA2020 MGA zone projection, e.g., 426000m E 7243000m N.

For point densities higher than 8 points per square metre it may be appropriate to reduce the grid to 500m x 500m, 100m x 100m, or some other ratio of the 1km x 1km grid to reduce individual tile data volumes and support compute capacity.

4.7 Back-up storage period (vendor)

The vendor must hold a back-up copy of all project data, for a minimum period of 12 months (1 year) beyond the final delivery of the project deliverables or an agreed alternative duration as determined by the Contracting Authority.

- On request by the Contracting Authority, the vendor must provide the resupply of all project data with the same intellectual property rights as per the original contract requirement.
- The vendor may charge a reasonable data access and distribution charge in such instances.
- The vendor must take all reasonable steps to ensure integrity of the back-up data during the agreed period including storing the information in multiple locations that are secure and environmentally stable to reduce the risk of loss.

The vendor back-up period is not intended to be a substitute for optimal information management archival practices, and these should be undertaken by the Contracting Authority on original supply of the project deliverables to minimise risk of loss.

5. References

ASPRS Guidelines on Geometric Inter-Swath Accuracy and Quality of LiDAR Data, Photogrammetric Engineering and Remote Sensing Vol 84(3), (2018). Available at LIDAR Standards And Guidelines Public Review Process

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Elevation Data Product Specification and Description (LiDAR), Spatial Services, Department of Customer Service, New South Wales Government (2020). Available at Information sheets - Spatial Services

Federal Airborne LiDAR Data Acquisition Guideline version 3.1, Natural Resources Canada (2022). Available at GEOSCAN Search Results: Fastlink

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LAS Specification 1.4 – R15, American Society for Photogrammetry and Remote Sensing (2019). Available at LASer (LAS) File Format Exchange Activities

LiDAR Base Specification version 1.3, United States Geological Survey (2018). Available at Lidar Base Specification Online | U.S. Geological Survey

LiDAR for ecology and conservation WWF Conservation Technology Series 1(3), World Wildlife Fund UK (2017). Available at Remote sensing with Lidar | WWF

New Zealand National Aerial LiDAR Base Specification version 1.2, Toitū Te Whenua Land Information New Zealand (2022). Available at New Zealand National Aerial LiDAR Base Specification

Specifications for Airborne LiDAR for the Province of British Columbia version 5.1, Ministry of Forests, Lands, Natural Resource Operations and Rural Development, British Columbia, Canada (2020). Available at Home

6. Glossary

Accuracy: The degree of conformity of a measured or calculated value compared to the actual value.

- Absolute accuracy: A measure that accounts for all systematic and random errors in a dataset. Absolute accuracy is stated with respect to a defined datum or reference system.
- Positional accuracy: The accuracy at the 95% confidence level of the position of features, including horizontal and vertical positions, with respect to horizontal and vertical datums.
- Relative accuracy: A measure of variation in point-to-point accuracy in a dataset. In light detection and ranging (LiDAR), this term may also specifically mean the positional agreement between points within a swath, adjacent swaths within a lift, adjacent lifts within a project, or between adjacent projects.

Aggregate Nominal Pulse Density (ANPD): 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.

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.

Bare Earth (Bare-earth): This refers to the digital elevation data of the terrain, free from vegetation, buildings and other man-made structures (elevations of the ground).

Break line: A linear feature that describes a change in the smoothness or continuity of a surface (for example to define streams, rivers, shorelines, and dams).

Check Point: A check point is a surveyed point used to estimate the positional accuracy of a geospatial dataset against an independent source of greater accuracy. Check points are independent from control points and may never be used as control points on the same project.

Classification: This refers to 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 future differentiation between bare-earth terrain points, water, noise, vegetation, buildings, other man-made features, and objects of interest.

Control Point: A control point is 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 check points and may never be used as check points on the same project.

Data Void: In LiDAR, a data void is 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 a data void.

Digital Terrain Model (DTM): A DTM is a digital representation of relief composed of an array of elevation values referenced to a common vertical datum and corresponding to a regular grid of points on the earth's surface. A DTM is a representation of the bare ground surface without any objects such as vegetation and buildings.

Digital Surface Model (DSM): A DSM is a representation of the earth's surface including vegetation and man-made structures. The Digital Surface Model (DSM) provides the height of the vegetation, canopies, and structures above the vertical datum.

Discrete Return: This is a 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 can capture multiple discrete returns from each emitted laser pulse.

First Return: This is the first important measurable part of a returned LiDAR pulse. First returns also include single returns.

Flight plan: A flight plan shows the planning process for LiDAR capture. It is used as a check by the Contracting Authority to confirm the plan design meets project specifications and identify if restricted airspace access may be an issue.

Intensity: 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.

Last Return: The last important measurable part of a return LiDAR pulse.

Overlap: This is the % of overlap associated with two adjacent flight lines (swaths) that happens as a result of the plane flying back and forth through the project area to achieve desired uniform data density and optimal ground cover under canopy

Flight plan: A flight plan shows the planning process for LiDAR/Imagery capture. It used to check to confirm meets project specifications and confirm airspace access is not limited.

Overage: Overage corresponds to 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. They are the non-tenderloin parts of a swath. 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.

Point: A point is defined in the guideline as LiDAR pulse that has been collected, validated, and classified.

Point Cloud: Often referred to as the "raw point cloud", this is the primary data product of a LiDAR instrument. In its crudest form, a LiDAR raw point cloud is a collection of range measurements and sensor orientation parameters. After initial processing, the range and orientation associated with each laser pulse is converted to a position in a three-dimensional frame of reference and this spatially coherent cloud of points is the base for further processing and analysis. The raw point cloud typically includes first, last, and intermediate returns for each emitted laser pulse. In addition to spatial information, LiDAR intensity returns provide texture or colour information.

Pulse: A laser pulse is the transmission of electromagnetic energy from a coherent light source using a laser at a specific wavelength.

Pulse Repetition Frequency (PRF): PRF is the frequency of transmitted laser pulses. High PRF enables dense point-spacing on the ground providing higher-resolution descriptions of the landscape. However, since PRF is inversely related to pulse energy, high PRF might reduce the probability of foliage penetration in densely vegetated areas.

Raster: is a matrix of rows and columns of pixels that contain a value and can represent a surface.

Triangulated Irregular Network (TIN): A TIN is 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.

Waveform Data (Full-waveform): This is a 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.

Withheld Points: A withheld points is marked by 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 pre-processing or using automatic classification routines.