Enhancing LiDAR Products: Quality Assessment, Optimisation, and Innovative Approaches

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Key words: LiDAR, Elevation, Queensland, DTM, DEM, Canopy Height Model, surface

SUMMARY

This article presents a case study on enhancing LiDAR products through quality assessment (QA), optimisation, and innovative approaches. Over the past two years, more than 312,000 square kilometres of LiDAR data were captured in Queensland, Australia. These datasets have been thoroughly checked, converted into various derivative products, optimised for cloud storage, and made accessible through different online and offline platforms.

As part of the QA process, a new in-house method was developed, leading to the creation of products including digital height models (DHM), canopy height models (CHM), and building outlines.

In this article, we will demonstrate how the datasets were validated, the types of products generated, and how different organisations have utilised these datasets for various purposes.

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1. INTRODUCTION

LiDAR (Light Detection and Ranging) is a remote sensing technology that uses laser pulses to measure distances from the sensor to objects on the ground, creating highly accurate 3D models of surface features. It is primarily used for generating elevation products, terrain analysis, vegetation modelling, infrastructure planning, and disaster management.

Queensland Government departments rely on LiDAR data to support multiple critical applications, including:

- **Flood modelling and risk management:** High-resolution elevation models help predict and mitigate flood risks, especially in remote area.
- **Environmental and vegetation monitoring:** LiDAR helps monitor deforestation, vegetation growth, coastal and riverbank erosion, and land-use changes.
- **Infrastructure development:** Accurate elevation data derived from high-accuracy LiDAR supports planning for roads, culverts, and bridges in both urban and rural expansion.
- **Agriculture and water management:** Elevation models assist in optimising irrigation, drainage, and land conservation.

The Queensland Government's future planning relies on high-quality elevation data to support sustainable development and climate resilience.
The Department of Natural Resources and Mines, Manufacturing, and Regional and Rural Development (NRMMRRD), in collaboration with other government agencies, including the Queensland Reconstruction Authority (QRA) and the Department of Environment, Tourism, Science, and Innovation (DETSI), is responsible for the coordination and acquisition of foundational spatial data, including LiDAR and elevation data.

Key initiatives include:

- **Queensland Spatial Strategy:** Improving digital mapping infrastructure, including LiDAR-based elevation models, to support decision-making across industries.
- **Disaster Preparedness:** Using LiDAR-derived elevation products to enhance early warning systems for cyclones, floods, and bushfires.
- **Smart Cities and Infrastructure:** Integrating LiDAR data into digital twins for urban planning and transport network optimization.
- **Coastal and Environmental Protection:** Enhancing coastal mapping to manage sea-level rise and protect biodiversity.

By continuing to invest in LiDAR and elevation datasets, Queensland ensures better-informed policies and sustainable growth for the future.

2. LiDAR quality assessment and ICSM LiDAR specification

A significant investment in LiDAR and elevation data acquisition across Queensland and Australia has led to a review of the national LiDAR specifications originally published in 2010.

This review was conducted by the Intergovernmental Committee on Surveying and Mapping (ICSM) through the Elevation, Depth, and Imagery Working Group (EDIWG). It provided an opportunity for existing users and vendors to maximise the use and future functionality of LiDAR collections.

Below are the key updates in the upcoming LiDAR specification:

- Planning guidance
- LiDAR collection specification
- LiDAR and derivative product processing and handling
- Deliverables specifications
- Quality assurance guidance
- Metadata template

As part of the updated LiDAR specification, all LiDAR products must be assessed and checked before being archived and published on various platforms.

Below are the key requirements in the new LiDAR specification for Queensland, which all projects must adhere to:

- **LiDAR point density:** 8 points per square metre (ppsm)
- **Horizontal and vertical accuracy:** +/- 60 cm and +/-20 cm respectively
- **Projection and datum:** GDA2020 MGA Zone, AusGeoid2020
- **LiDAR classification level:** (as per Specification)

3. Initial and deep quality checking

There are two main steps to ensure LiDAR data quality. The first step is an initial check, which ensures that the data is free from major issues and helps save time. The second step is a detailed LiDAR check, which consists of multiple steps that will be described later.

3.1 LiDAR (point cloud) and elevation (derived product) initial check

The verification process covers three different file formats: point cloud data in LAS format, raster Digital Terrain Model (DTM) in GeoTIFF format, and vector contour data in ESRI shapefile (SHP) format. A Python script utilising the open source LAStools software (Rapidlasso, 2025) has been developed to check these files for the items listed in Table 1. The output is an .xlsx file containing the results for all three formats. See Figures 1, 2 & 3 for examples of output.

Table 1: *Items that are checked for each of the three file formats.*

Initial check	**Point Cloud**	**DTM (GeoTIFF)**	**Contour (vector shapefile)**
Verify projection	X	X	X
File format	X	X	X
Naming convention	X	X	X
Point cloud version & format	X		
File is not compressed		X	
Correct cell size		X	
Min & max X, Y & Z values	X	X	X

file_path	..//pointcloud_las_tiles_ahd/SW_453000_7906000_1k_class_AHD.las
crs	GDA2020 / MGA zone 54
version	1.4
point_data_format	7
x_min	453417.184
x_max	453999.999
y_min	7906000.461
y_max	7906999.999
z_min	-22.339
z_max	102.334
x_file_name	453000
y_file_name	7906000
check_name	Mismatch

Figure 1: *Results from point cloud check.*

file_path	..//dtm_tif_tiles/SW_453000_7906000_1k_50cm_DTM.tif
crs	GDA2020 / MGA zone 54
compression	None
cell_size_x	0.5
cell_size_y	0.5
x_min	480000
x_max	481000
y_min	7863000
y_max	7864000
x_file_name	453000
y_file_name	7906000
check_name	Mismatch

Figure 2: *Results from DTM check.*

file_path	..//contour_shp_tiles/SW_453000_7906000_1k_25cm_contour.shp
crs	GDA2020 / MGA zone 54
x_min	453417.3159
x_max	454000
y_min	7906047.543
y_max	7907000
x_file_name	453000
y_file_name	7906000
check_name	Mismatch

Figure 3: *Results from contour check.*

3.2 LiDAR detailed check

Once the point cloud passes the initial check, the next step is a detailed verification of the point cloud and its derivative products. This process includes both manual and automatic checks. For the automatic check, an in-house script has been developed to validate the files. Compared to the initial check, the detailed check takes longer to complete.

The second step involves a manual review for aspects that cannot be verified automatically, such as point cloud classification and accuracy assessment. Below is a list of each step along with detailed descriptions.

3.2.1 Project coverage and trajectories

This check includes:

- number of files is correct, and file names match specification naming convention
- data provides full coverage of the area of interest (see Figure 4)
- tile index has been provided and the attribute table fields meet specification
- flightlines have been provided and the attribute table details meet specification

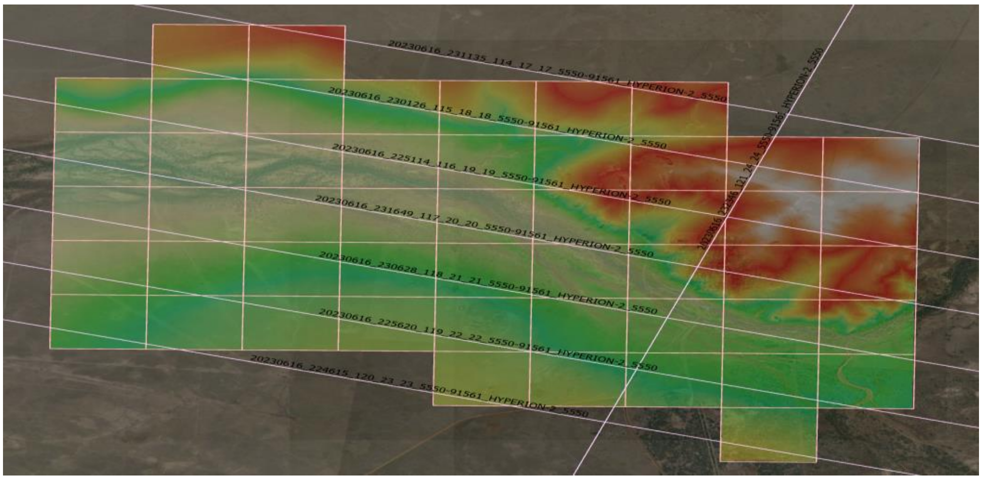
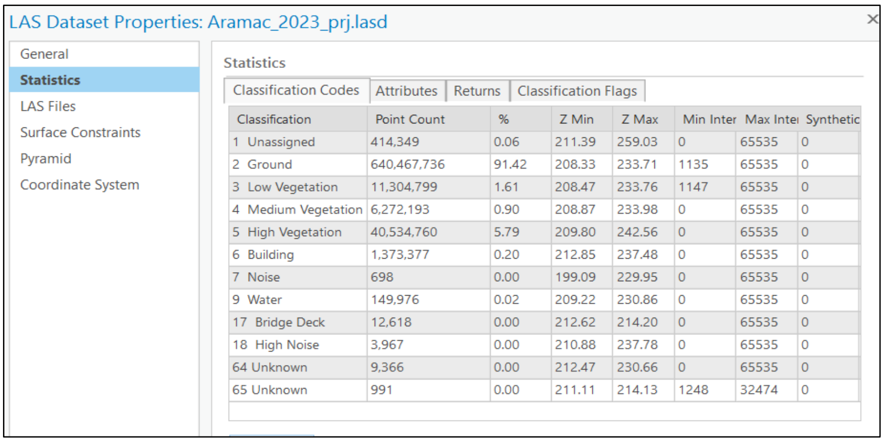


Figure 4: *In the snip above, the area of interest is completely covered by LiDAR.*

3.2.2 Checking point cloud LAS properties for both Australian Height Datum (AHD) and/or Ellipsoid (ELL) heights

This check includes:

- coordinate system checks for both AHD and ELL files
- point cloud properties check including classification codes, attributes, returns and classification flag (see Figure 5)



LAS Dataset Properties: Aramac_2023_prj.lasd

General
Statistics
LAS Files
Surface Constraints
Pyramid
Coordinate System

Statistics

Classification Codes | Attributes | Returns | Classification Flags

Classification	Point Count	%	Z Min	Z Max	Min Inter	Max Inte	Synthetic
1 Unassigned	414,349	0.06	211.39	259.03	0	65535	0
2 Ground	640,467,736	91.42	208.33	233.71	1135	65535	0
3 Low Vegetation	11,304,799	1.61	208.47	233.76	1147	65535	0
4 Medium Vegetation	6,272,193	0.90	208.87	233.98	0	65535	0
5 High Vegetation	40,534,760	5.79	209.80	242.56	0	65535	0
6 Building	1,373,377	0.20	212.85	237.48	0	65535	0
7 Noise	698	0.00	199.09	229.95	0	65535	0
9 Water	149,976	0.02	209.22	230.86	0	65535	0
17 Bridge Deck	12,618	0.00	212.62	214.20	0	65535	0
18 High Noise	3,967	0.00	210.88	237.78	0	65535	0
64 Unknown	9,366	0.00	212.47	230.66	0	65535	0
65 Unknown	991	0.00	211.11	214.13	1248	32474	0

Figure 5: *The snip above shows the point cloud properties in ESRI ArcGIS Pro.*

- point density

In this step, the point density across the entire project will be checked to ensure that the point cloud meets the required standard (see Figure 6). If the point density does not meet the specifications, it will be recorded in the final metadata report.

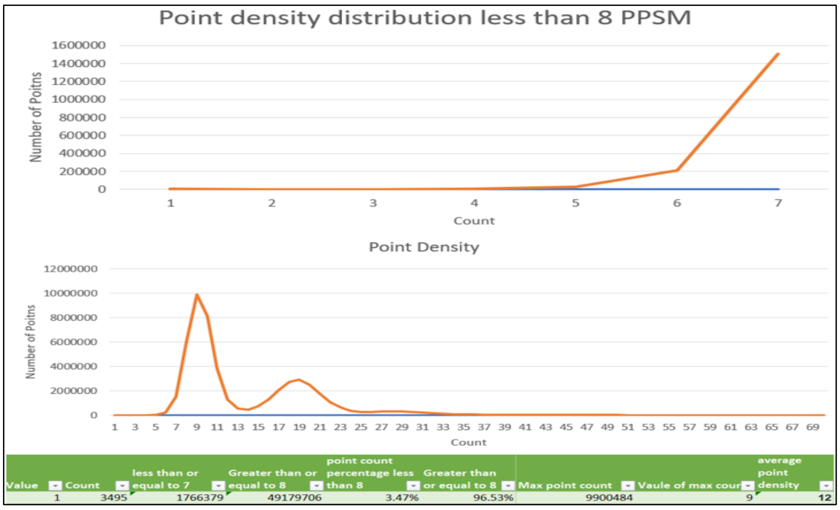


Figure 6: *The above results show that the average point density for this project is 12 ppsm, which exceeds the required 8 ppsm.*

3.2.3 Point cloud classification check

This is a time-consuming step that requires manual checking. In this phase, six main classifications will be randomly reviewed to ensure that the point clouds are free from major misclassification issues. The primary classification levels include: ground, vegetation, building, water, noise, and, in Queensland, Australia, bridges and culverts. See Figures 7 and 8 for examples.

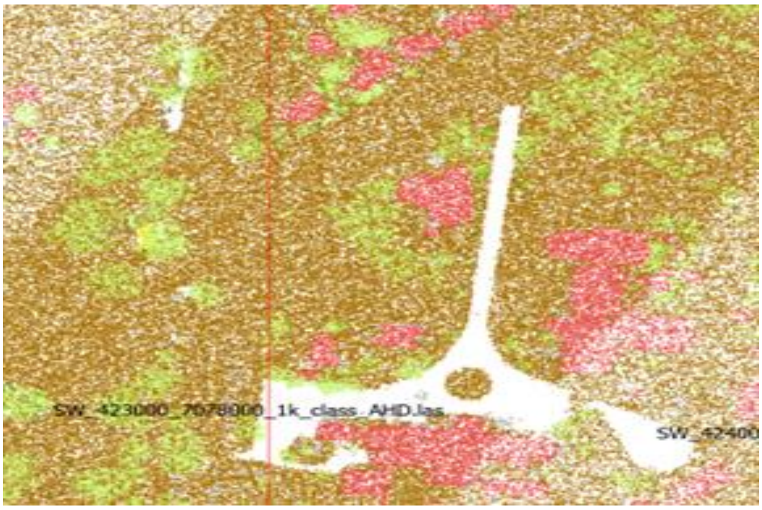


Figure 7: *Area of missing point cloud – appears to be over roads. Contractor confirmed that there were no returns from an area of freshly laid bitumen road.*

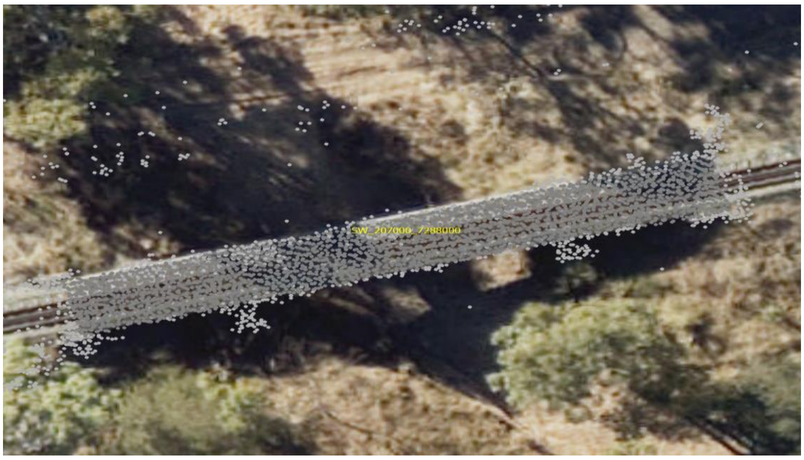


Figure 8: *There are Unassigned (light grey – class 1) points which should be classified as bridge.*

3.2.4 Checking DTM

Similar to the point cloud check, this verification for DTM should be done manually to ensure that the raster DTMs are free from any major anomalies including hydro-flattening (U.S. Geological Survey, 2024; Crawford, 2022). Figures 9, 10 and 11 below show examples of issues that the final products should be free of.

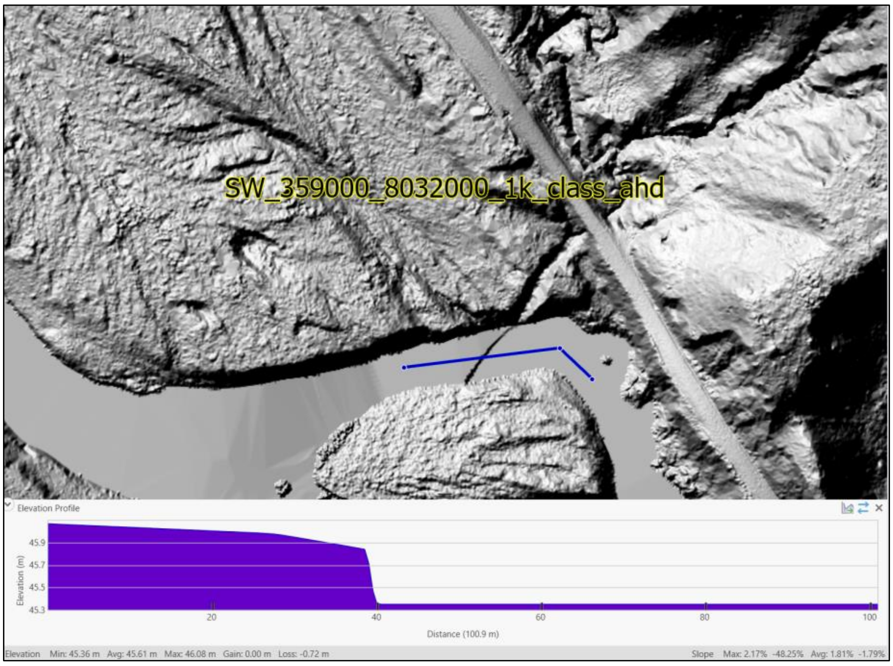


Figure 9: *Hydro-flattening issue: A 1 metre drop in the area caused an artificial fall, which is incorrect.*

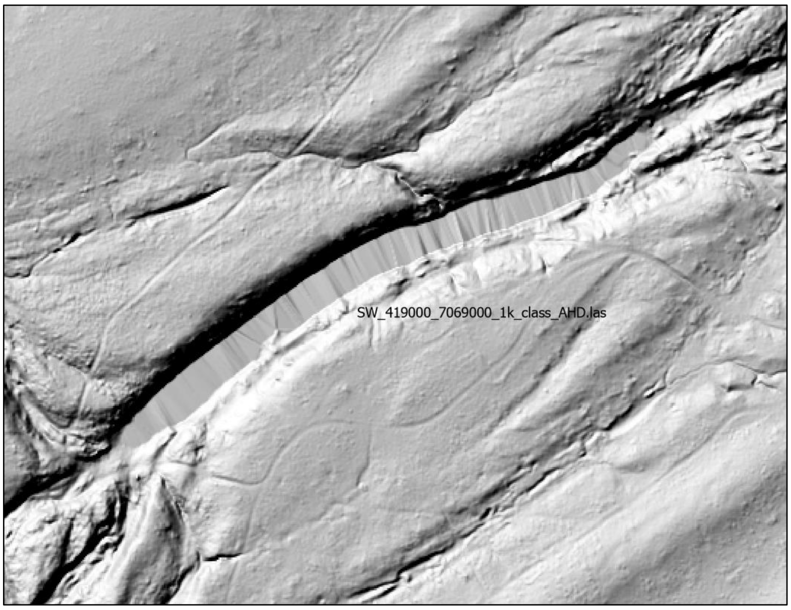


Figure 10: *Water body (as indicated by point cloud) has not been hydro-flattened.*

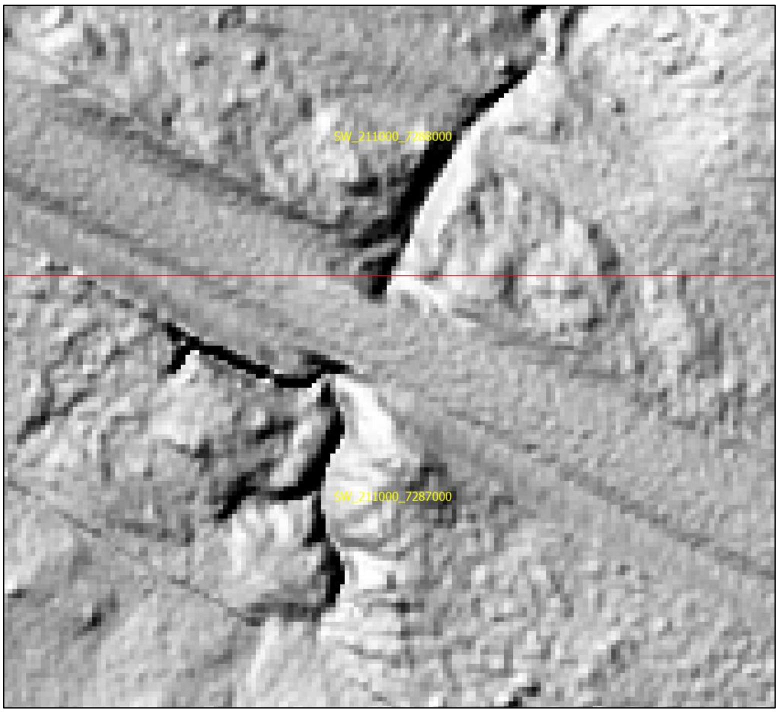


Figure 11: *Bridge is included in DTM but should be excluded (misclassification).*

3.2.5 Checking contours

Compared to other elevation products, contours have a different format. The vector contours should be checked alongside point clouds and DTMs to ensure they are free from anomalies such as overshoots, undershoots, and mismatches at tile edges. Below are some examples of issues that should be corrected before archiving and using the contours for any purpose (Figures 12 and 13).

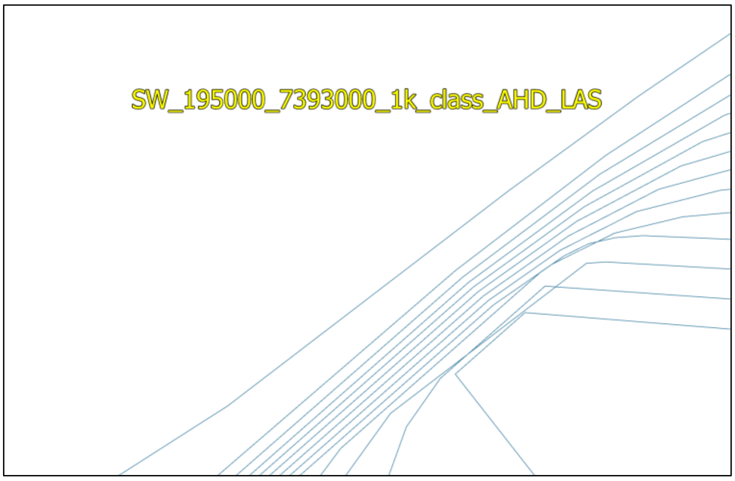


Figure 12: *An example of contours crossing over each other.*

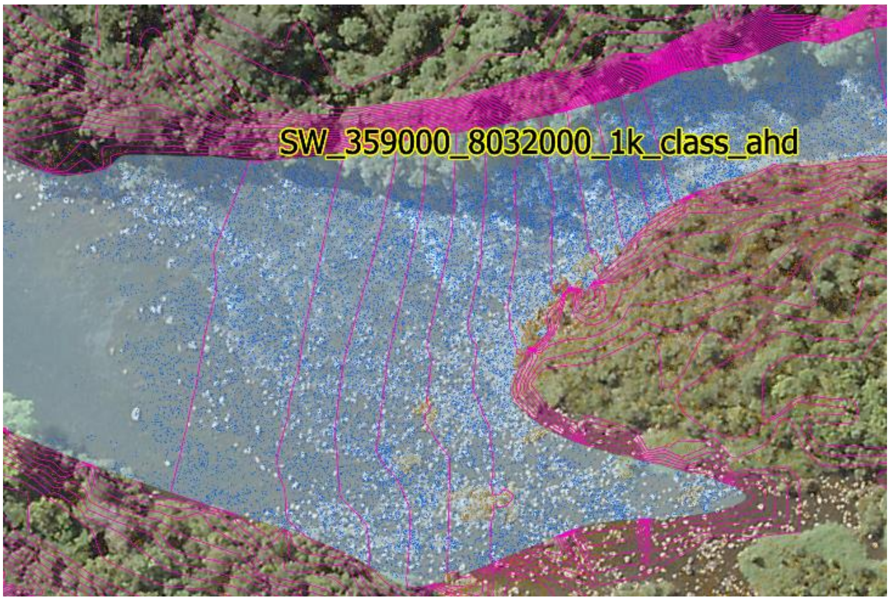


Figure 13: *An example where slope over this area has resulted in numerous contours and should be checked for the possibility of erosion.*

3.2.6 Checking image intensity

The image intensity derived from the point cloud is used to assess horizontal accuracy by comparing identifiable features in the intensity image with available imagery (Figure 14). On the other hand, all files in ECW format should be checked to ensure they are correctly projected and delivered in grayscale format, not RGB.

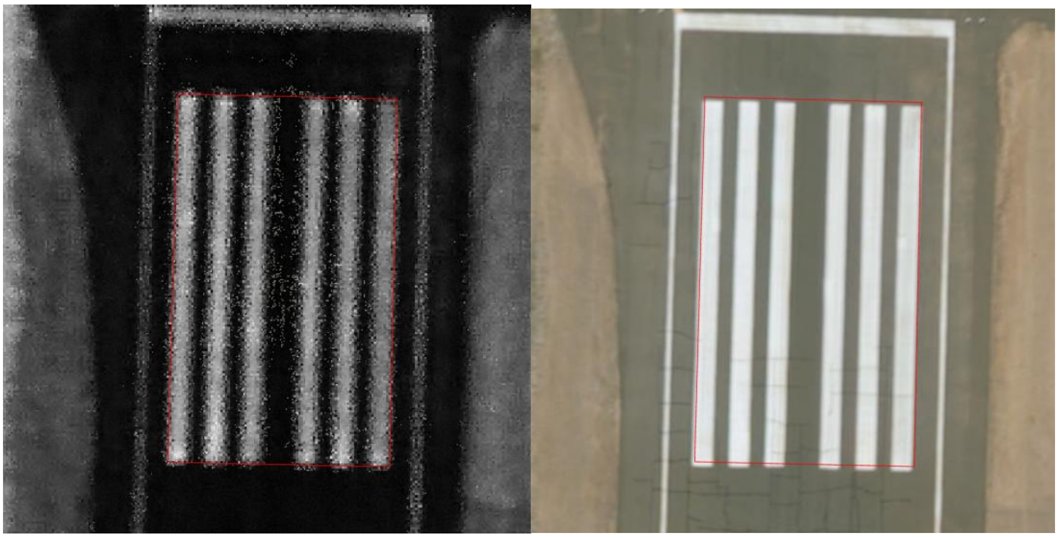


Figure 14: *An example of horizontal accuracy check, comparing an on-ground feature in the intensity image (left) with the same feature in available imagery.*

3.2.7 Horizontal and vertical accuracy check

Checking the vertical and horizontal position of the point cloud and its derivative products is another manual task. The overall positional accuracy of LiDAR projects is verified using existing ground control points that were not used in LiDAR processing. These ground control points are part of an internal database used for cadastral purposes. Below is an example of a Root Mean Square Error (RMSE) check on a LiDAR project that meets the required LiDAR accuracy standards (Figure 15).

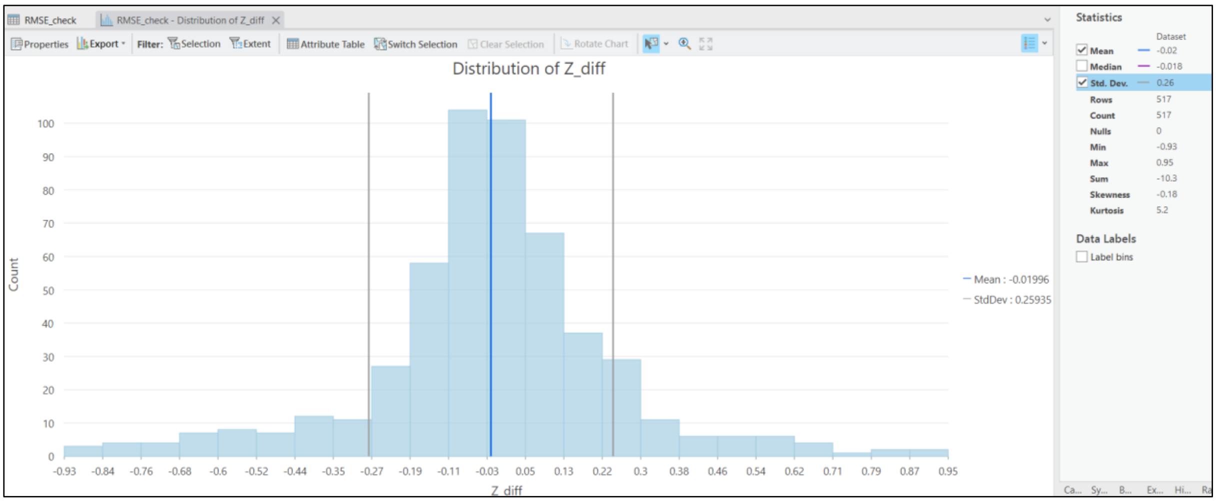


Figure 15: *An example where the calculated RMSE is 0.276 for this project. 517 Ground Control Points were used to calculate the RMSE. This does not meet the required vertical accuracy of ≤ ±20cm.*

3.2.8 Metadata check

The Queensland Spatial Catalogue (QSC) (Queensland Government, 2024) website is the platform for publishing and storing all LiDAR metadata records captured across Queensland, Australia. As part of the LiDAR product verification process, the metadata report provided by the contractor must be reviewed to ensure it is free from typos and includes all necessary information. Any important additions or major updates should be made before publishing the record in the QSC.

The following link leads to an example of a LiDAR metadata record in QSC: https://qldspatial.information.qld.gov.au/catalogue/custom/detail.page?fid=%22Queensland%20LiDAR%20Data%20-%20Moonie%20South%202023%20Project%22

4. LiDAR derived products

Derivative LiDAR products are one of the main reasons for conducting any LiDAR project. Depending on the intended use of elevation data, there are different types of LiDAR products. To generate these products, the point cloud must first be classified. Based on ICSM standards, Figure 16 shows a list of point classes and their corresponding classification levels, with Figure 17 providing a simplified description of the classification quality levels.

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

Figure 16: *List of point classifications and their corresponding classification levels.*

Level	Description
0	Undefined
1	Automated and Semi-Automated Classification
2	Ground surface improvement
3	Manual Ground Correction
4	Full Classification

Figure 17: *Simplified description of classification levels.*

One of the main LiDAR products is the Digital Terrain Model (DTM), which represents the bare earth surface. It is derived from the ground and culvert point classes. The DTM should be hydro-flattened and free from any water effects. However, some users prefer to create non-hydro-flattened DTMs for specific applications and usage. Another popular LiDAR product is the Digital Surface Model (DSM), which includes ground, vegetation, buildings, culverts, and bridges.

A key part of creating a smooth and error-free DTM is the use of hydro-enforced or hydro-flattened elevation products. In these products, all water bodies—including lakes, reservoirs, and bank-to-bank rivers—are flattened to ensure consistency. This process eliminates anomalies caused by point clouds classified as water. As part of the LiDAR QA check, all water bodies should be hydro-flattened, and the final DTM products intended for archiving and application use should be hydro-enforced (Figure 18).

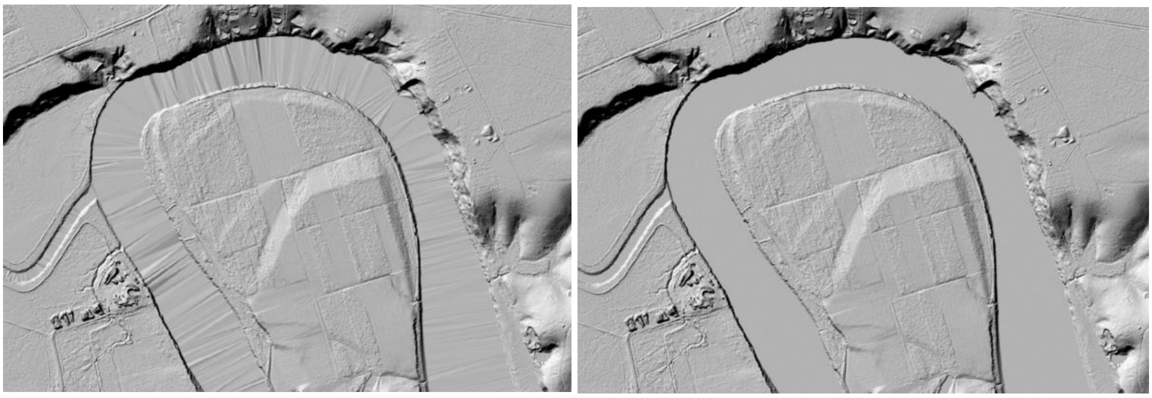


Figure 18: *An example of non-hydro-flattened (left) and hydro-flattened (right) DTM.*

Contours are traditional elevation products derived from DTM in LiDAR projects. The contours processed and used in Queensland GEO Resources applications, such as Queensland Globe (Queensland Government, 2025) and the Queensland Spatial Catalogue (Queensland Government, 2024), are cartographic contours. Compared to engineering and raw contours, cartographic contours have fewer vertices, resulting in a smoother representation ideal for display purposes (Figure 19). However, they are not recommended for GIS analysis or critical elevation-based decision-making. For accurate height measurements and GIS processing, the most suitable elevation products are point clouds and/or DTM.

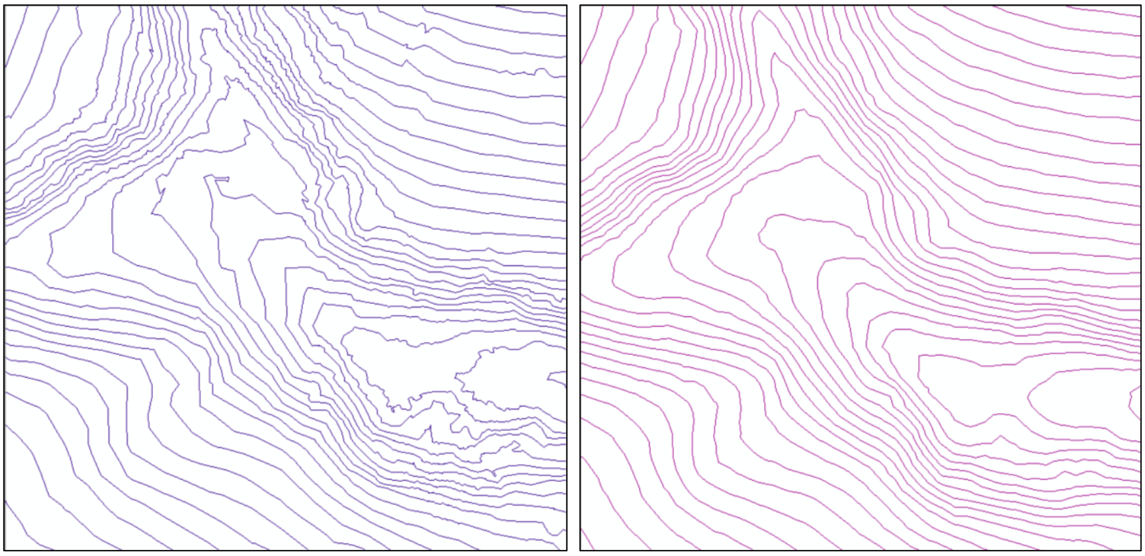


Figure 19: *An example of raw contours (Left) and cartography contours (right)*

The Canopy Height Model (CHM) is a widely used LiDAR product derived from classified point clouds. To generate this product, the point cloud must be classified for both ground and vegetation. According to ICSM standards, vegetation is categorised into three levels: low, medium, and high. The high vegetation (and in some cases, medium vegetation) classes are used to create an interim Digital Vegetation Model (DVM). The CHM is then calculated by subtracting the DTM from the DVM, following the formula: CHM = DVM – DTM (Figure 20). The primary reason for not using points classified as low vegetation to create the CHM product is the high percentage of noise in this class. According to the ICSM LiDAR specifications, class 3 (low vegetation) includes noise, meaning not all points in this category accurately represent vegetation.

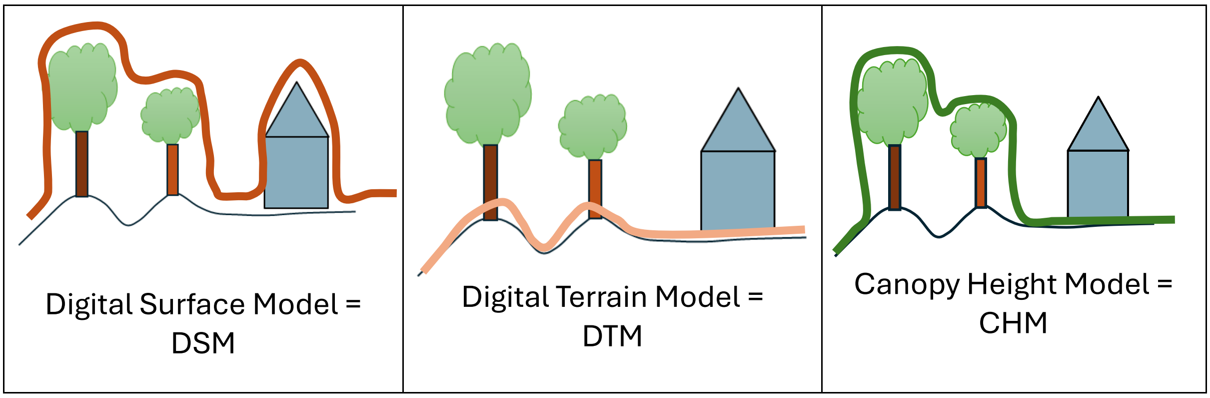
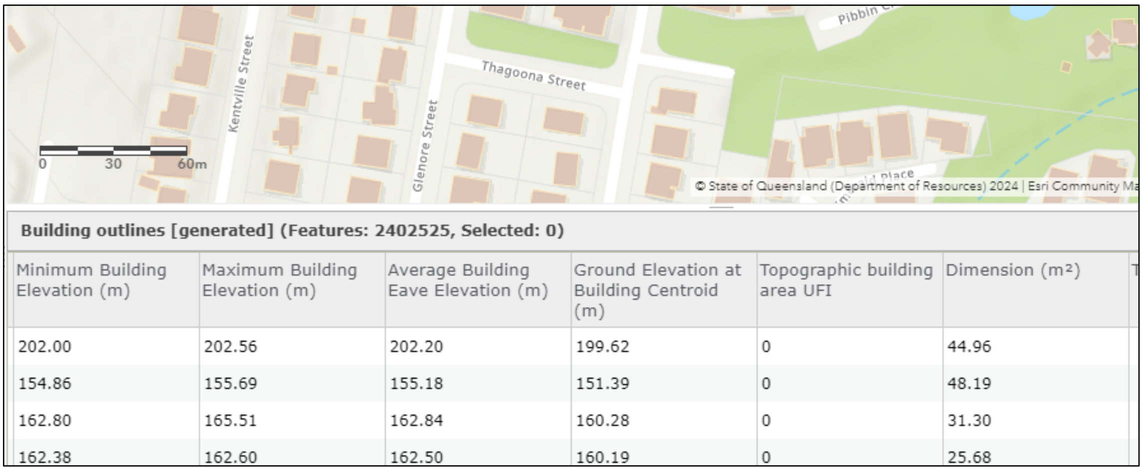


Figure 20: *A pictogram explaining calculation of a CHM.*

The building outline derived from LiDAR is one of the new products developed and published on the Queensland Government department website. This product is generated from the point cloud building class and is further refined using additional information, such as cadastral boundaries and other available resources.

One of the main challenges in creating this product is the limitations of LiDAR. In some cases, black-coloured roofs do not reflect LiDAR pulses and instead absorb the laser, resulting in a sparse point cloud that is insufficient for generating accurate building polygons. Some manual editing is required to complete the dataset. However, extracting building heights and other valuable attributes, such as building dimensions and minimum/maximum elevations, enhances the product’s usefulness (Figure 21).

As part of the QA process, generating this product helps validate building classifications and allows for the identification and reporting of major issues before publishing the final dataset on GIS platforms.



Minimum Building Elevation (m)	Maximum Building Elevation (m)	Average Building Eave Elevation (m)	Ground Elevation at Building Centroid (m)	Topographic building area UFI	Dimension (m²)
202.00	202.56	202.20	199.62	0	44.96
154.86	155.69	155.18	151.39	0	48.19
162.80	165.51	162.84	160.28	0	31.30
162.38	162.60	162.50	160.19	0	25.68

Figure 21: *An example of available attributes for the derived building outline product.*

By capturing LiDAR at a higher point density, such as 8 ppsm, and manually classifying point clouds for features like bridges and culverts, we can enhance the value of elevation products. Bridges and culverts are two key features used from LiDAR capture to improve DTM products for flood modelling and to accurately represent the bare earth surface. In recent LiDAR projects, these features have been manually classified (Classification Quality Level 3) and incorporated into DTM products to support flood modelling and analysis.

5. Archiving and distributing elevation products

After completing the quality assessment and generating LiDAR derived products, the next step is to archive the data in the department-approved storage. Different departments and organisations follow varying policies for data archiving. In Queensland, the Department of Natural Resources and Mines, Manufacturing, and Regional and Rural Development manages spatial data through the Spatial Information Resources (SIR) platform, which serves as the primary system for storing, managing, and delivering data. To ensure accessibility via this platform, all LiDAR datasets are archived in Amazon Web Services (AWS) cloud storage. In addition to cloud storage, a local copy is also maintained on a hard disk drive (HDD). This local archive provides an additional level of security, ensuring that data can be recovered and restored if needed. For archiving data in AWS cloud storage, the department follows a standardised naming convention for both files and folders, as specified in the LiDAR Specification. Below is an example of the naming convention used for LiDAR project archives stored in the AWS cloud.

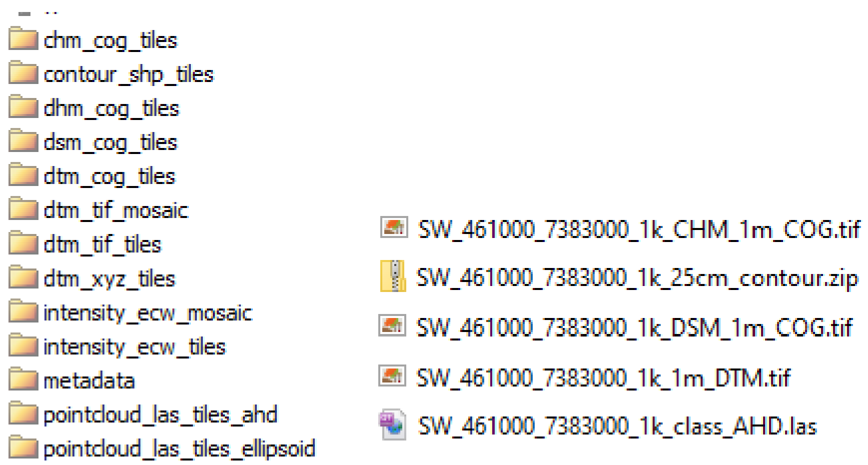


Figure 22: *An example of folder and file naming convention in AWS cloud storage.*

To access data via AWS cloud storage, internal customers and the public can submit a request to the department's Open Data Team using an online form. The request process depends on the number and size of the datasets required. Once a request is submitted, the Open Data Team provides the data in the requested format and type. Traditionally, downloading and copying raw LiDAR files to local storage for processing has been the standard approach. However, this method is becoming outdated for GIS data processing. At the Department of Natural Resources and Mines, Manufacturing, and Regional and Rural Development, based on experience and data usage patterns, various elevation services have been developed and published on the ESRI platform as raster services. These elevation raster services include LiDAR projects in raster DTM format, which can be integrated into both ESRI and non-ESRI applications.

The other popular elevation service is the CHM. This product represents vegetation classified points as their height above ground, in a raster image service on the ESRI platform.

The CHM service is used for various applications, including forestry, environmental monitoring, and urban and rural planning.

— **Urban and Environmental Planning**: Supports green zone infrastructure planning, wind and shade analysis near public areas such as schools and hospitals, and erosion and flood risk assessment.

— **Forestry**: Helps measure vegetation height, calculate vegetation area, monitor vegetation changes, and identify suitable habitats for wildlife.

— **Disaster Management**: Assists in wildfire risk assessment and cyclone/storm damage assessment.

Building outline web map service is another derived product from classified point cloud data. According to the ICSM standard, any man-made structure, such as residential and commercial buildings, storage towers, and silos should be classified as a building with a classification value of 6. By capturing point cloud data at a high density (greater than 8 ppsm), it is possible to generate good quality building polygons and create building outline products. Since the points have height values, GIS applications or scripts can be used to generate 3D building outline polygons. These 3D features can then be converted into a web map service with an associated attribute table.

Figure 23 shows the list of available products that are derived from classified point cloud.

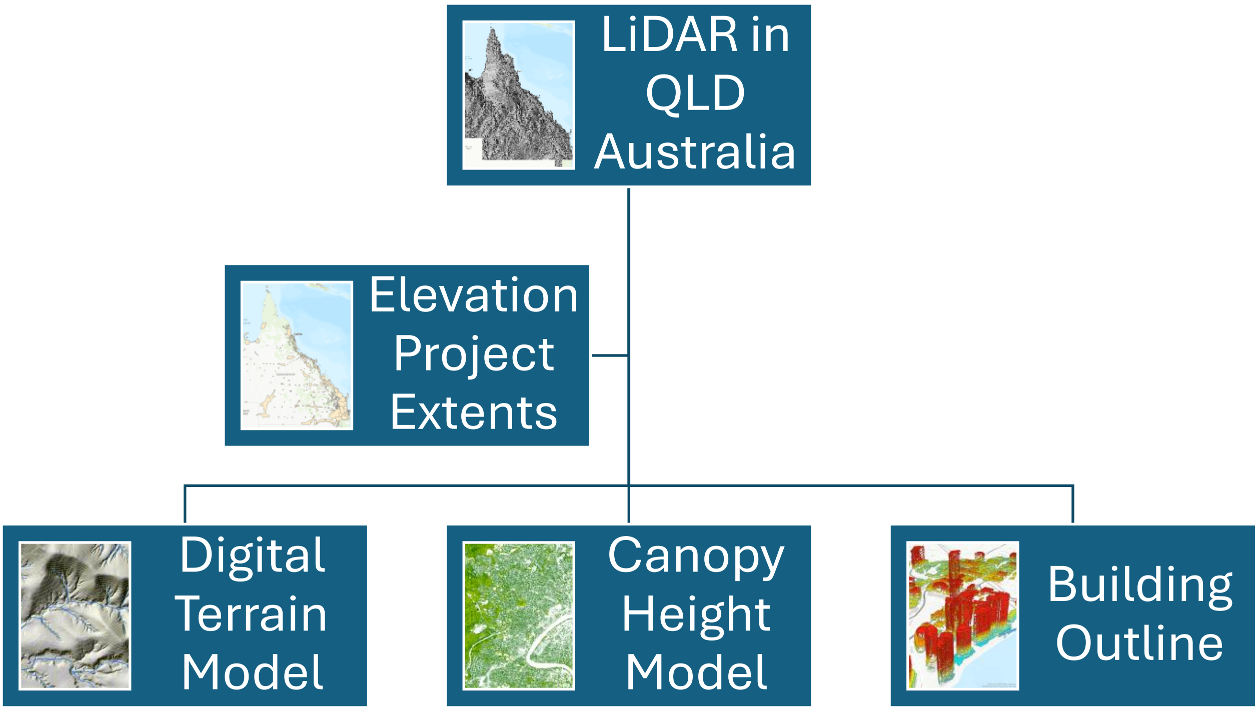


Figure 23: *Available products that are derived from the classified point cloud.*

The following links provide access to the above products in the ESRI platform:

DTM, Elevation time series web service:

https://spatial-img.information.qld.gov.au/arcgis/rest/services/Elevation/DEM_TimeSeries_AllUsers/ImageServer

Canopy Height Model (vegetation height above 2 meters) (restricted service):

https://spatial-img.information.qld.gov.au/arcgis/rest/services/Elevation/CanopyHeightModel/ImageServer

Building and settlements outline webmap service:

https://spatial-gis.information.qld.gov.au/arcgis/rest/services/Structure/BuildingsAndSettlements/MapServer

Elevation project extents:

https://spatial-gis.information.qld.gov.au/arcgis/rest/services/Elevation

Contours (1 metre):

https://qldspatial.information.qld.gov.au/catalogue/custom/detail.page?fid={5471036F-0ED8-41EE-BDBE-14EA846FC81E}

ELVIS:

Those classified point clouds in las format and DTMs in raster GeoTIFF format that are more than three years old are freely available in the Elevation Information System (ELVIS) (Geoscience Australia, 2021).

ELVIS is an online portal developed and managed by Geoscience Australia that provides free access to a wide range of elevation and terrain data across Australia. It enables users to explore, visualise, and download DEMs, DTMs, LiDAR, bathymetric data, and other terrain datasets for various applications, including flood modelling, environmental management, infrastructure planning, and landform analysis.

Key Features of ELVIS:

— **Access to Elevation Data**: Offers datasets such as LiDAR, SRTM, DEMs or DTMs and bathymetric data.

— **User-Friendly Interface:** Allows users to search, preview, and download elevation datasets by location or project area.

— **Free and Open Data:** Most datasets are available under open-access licenses.

— **Supports Various Formats:** Data can be downloaded in formats such as GeoTIFF, LAS, or LAZ.

— **Coverage:** Includes nationwide datasets as well as high-resolution LiDAR in selected areas.

Below is the link to access and download the elevation data across Australia and Queensland:

https://elevation.fsdf.org.au/

Metadata

To learn more about elevation datasets in Queensland the QSC, developed by NRMMRRD, provides essential details about each dataset, including its source, accuracy, format, coverage, and collection methods. This information helps users assess whether the data is suitable for their specific needs. Below is a link to Logan 2023 LiDAR metadata record in QSC:

Queensland LiDAR Data - Logan 2023 LGA

REFERENCES

Crawford, C. (2022) Hydro-Flattening of River Shorelines in Lidar Based DEM Production, United States of America, ESRI, https://www.esri.com/arcgis-blog/products/arcgis-pro/3d-gis/hydro-flattening-of-river-shorelines-in-lidar-based-dem-production/.

Geoscience Australia (2021) Elvis - Elevation and Depth - Foundation Spatial Data, Canberra, Commonwealth of Australia (Geoscience Australia), https://elevation.fsdf.org.au/.

Queensland Government (2024) Queensland Spatial Catalogue – QSpatial, Brisbane, Department of Natural Resources and Mines, Manufacturing and Regional and Rural Development, https://qldspatial.information.qld.gov.au/catalogue/custom/index.page.

Queensland Government (2025) Queensland Globe, Brisbane, Department of Natural Resources and Mines, Manufacturing and Regional and Rural Development, **https://qldglobe.information.qld.gov.au/.**

Rapidlasso (2025) LAStools, Germany, rapidlasso GmbH, https://rapidlasso.de/product-overview/.

U.S. Geological Survey (2024) Lidar Base Specification Appendix 2: Hydro-flattening Reference, Lidar Base Specification 2024 rev. A, originally included in Lidar Base

Specification v. 1.3., United States of America, USGS, https://www.usgs.gov/ngp-standards-and-specifications/lidar-base-specification-appendix-2-hydro-flattening-reference.

BIOGRAPHICAL NOTES

Mehdi Etemadi is an experienced geospatial professional with over 30 years of expertise in GIS, photogrammetry, and elevation data management. He has spent the last 18 years contributing to the Spatial Information (SI) team in the Department of Natural Resources and Mines, Manufacturing, and Regional and Rural Development, bringing extensive knowledge from both private and public sector roles overseas. Holding a Masters degree in Photogrammetry/GIS and a Bachelor's degree in Surveying, Mehdi specialises in elevation project management, data validation, and the development of efficient workflows for DTMs and LiDAR processing.

His work involves research into improving elevation data management, storage, and distribution, along with publishing elevation datasets and providing training and documentation support. Mehdi is recognised as a key contact for LiDAR data within the Queensland Government.

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