

Managing Big Data in a Small Office: How Can We Best Utilise LiDAR and Aerial Photography?

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ABSTRACT

For the survey industry, 'big data' is exemplified through LiDAR (Light Detection and Ranging) data. This could have been captured via terrestrial or airborne laser scanning (or both combined). Each project can constitute hundreds of thousands or even millions of 3-dimensional points, creating files that are hundreds of megabytes to gigabytes of data. This, in conjunction with aerial photography, combines into 'big (survey) data'. Land and Property Information (LPI) maintains a large database of LiDAR and aerial photography data, negating the need to capture the data in the first instant and being available at a very reasonable cost. This paper explores how surveyors can efficiently and economically lever useful information from this library of data and what usable deliverables this data can provide, apart from pretty pictures and contours. For the surveyor, the first hurdle to using the data is the fact that the majority of survey software packages cannot handle the scale of data involved, or if the software can process the data, the processing power, time and memory required is prohibitive to many of the smaller survey offices. The answer lies in embracing Geographic Information System (GIS) software, along with a rethink of how to utilise the suite of existing survey software packages. GIS software allows us to manipulate big data in a much more efficient manner, integrate other GIS mapping (e.g. vegetation mapping and heritage sites) and opens up the possibility of extracting data for a variety of applications. Using this approach, site investigation, feasibility studies, infrastructure corridor assessment, slope analysis, flood risks, and many other aspects of land development and administration can be managed in a desktop environment efficiently and economically, allowing the targeted application of survey resources to either ground-truth or increase the resolution of the LiDAR data to progress a project to detailed design.

KEYWORDS: LiDAR, aerial photography, GIS, big data, feasibility.

1 INTRODUCTION

Light Detection and Ranging (LiDAR) and aerial photography (in this paper referred to as imaging or imagery) in combination can provide a powerful tool for both the public and private sectors involved in the management and development of the built and natural environments. Until recently, this information has required costly investment in data capture, infrastructure and processing of this powerful data. For example, in 2008 the cost of capturing aerial LiDAR data and imagery for 50 ha cost upwards of \$70,000 in a non-metropolitan area whereby multi-stage mobilisation of the survey aircraft was required to reach the survey area. This cost did not allow for the investment in more powerful computers and memory, along with the high-end Geographic Information System (GIS) software required to be able to manage the size and complexity of the deliverables from the LiDAR and imagery or the

additional training time of staff required to be able to get the final deliverables from the GIS software. This has, to a large extent, limited the utilisation of this data to large organisations and large projects where the funding, skills and infrastructure are in place to economically and efficiently utilise the data.

Land and Property Information (LPI), a division of the Office of Finance and Services within the NSW government, has been collating digital imagery and aerial surveys to define topography using LiDAR and other technologies over significant areas of NSW since 2008. This data is available for purchase by registered LPI users within both the public and private sectors (with certain licencing requirements). This, in conjunction with the range of 'simplified' GIS software packages and the dramatic reduction in the cost of data storage, has brought the substantial deliverables of this data within reach of small survey practices and smaller projects.

This paper explores the process of establishing the nature and quality of the data, the range of deliverables, limitations and integration of the deliverables with other survey software and archiving and backing up of the data for future reference through example data and project case studies.

2 LPI LiDAR AND IMAGERY DATA

2.1 LiDAR Data and Specifications

LiDAR survey data is produced in a spatially accurate point cloud and a 1 m resolution bare earth Digital Elevation Model (DEM). All elevation data is processed to achieve 'Category 1' DEM products as described by the ICSM Guidelines for Digital Elevation Data (ICSM, 2008), which specifies accuracies not exceeding 30 cm RMSE (2 sigma or 95% confidence). The general specifications of LPI LiDAR data are listed in Table 1.

It is important to understand what datum the LiDAR data was captured in as this will often not be automatically imported into the GIS software and will need to be manually entered in some cases. This is vital when integrating the LiDAR data with other third party GIS data (as discussed later in this paper).

Table 1: General specifications of LPI LiDAR data.

Horizontal Datum	GDA94
Vertical Datum	(Orthometric) AHD71
Vertical Datum	(Ellipsoidal) GDA94
Projection	MGA Zones 54-57
Geoid	AUSGeoid09
Point Density	Minimum 1 point per metre at nadir (lowest return point of laser scan)

2.2 LiDAR Accuracy

In assessing the suitability of the LiDAR data for a desired purpose, the quality of the LiDAR data must be assessed. In most cases, the accuracy obtained for LPI will be *lower* than that obtained via a commissioned project-specific LiDAR data capture process, but is still of a useable order for feasibility, early design and assessments. Fitness for purpose will be addressed throughout this paper.

The applied determination of accuracy methodology, stated below, is taken from LPI's LiDAR Product Specifications (LPI, 2013). Table 2 lists the ICSM accuracy requirements.

“Vertical accuracy is assessed by comparing LiDAR point returns against survey check points in bare open ground. It is calculated at the 95% confidence level as a function of vertical MSE (as per ICSM Guidelines for Digital Elevation Data, 2008). This is undertaken after the standard relative and absolute adjustment of the point cloud has taken place (i.e. flight line matching and shift/transformation to local AHD). A mean value will also be reported for accuracy which is expected to be close to zero.

Horizontal accuracy is checked by comparing the LiDAR intensity data viewed as a ‘TIN’ surface against surveyed ground features such as existing photo point targets. To date our analysis of ground comparisons shows that although the vertical accuracy achieved on bare open ground is well within the requirements for Category 1 DEM products as specified in the ICSM Guidelines for Digital Elevation Data, local geoid and height control anomalies may degrade the accuracy on large coastal projects.”

Table 2: ICSM accuracy requirements (Category 1) from ICSM (2008).

Vertical accuracy	± 30 cm at 95% confidence (1.96 x RMSE)
Horizontal accuracy	± 80 cm at 95% confidence (1.73 x RMSE)

2.3 LiDAR Deliverables and Formats

LPI provides its LiDAR data in multiple formats that can provide for a specific end-use (Table 3).

Table 3: Deliverables of LPI LiDAR data.

Product	File Format	Description
1 Classified point cloud	LAS 1.2	Attributed in accordance with designated classification level (2 km x 2 km tiles)
2 Model key points (MKP)	LAS 1.2	‘Thinned’ ground points (2 km x 2 km tiles)
3 DEM (1m, 5m or 10m)	ESRI ASCII Grid	‘Bare earth’ (artefact free) DEM (2 km x 2 km tiles)
4 Intensity image	Compressed ECW	0.5 m resolution laser intensity image (single file mosaic – tiles combined) – only available when entire project area is purchased

2.3.1 Classified Point Cloud

Classified point clouds refer to the class membership of a LiDAR point return. All points begin as ‘default’, i.e. have no classification and are then allocated a meaningful value (i.e. ground, vegetation, building, etc.) by either automated or manual methods or a mix of both. The classification of each point is held in the LAS file and is read into the GIS software, which can interpret this through colourisation (Figure 1). This can be used as a visualisation tool when no aerial imagery is available to aid in the interpretation of the point cloud.

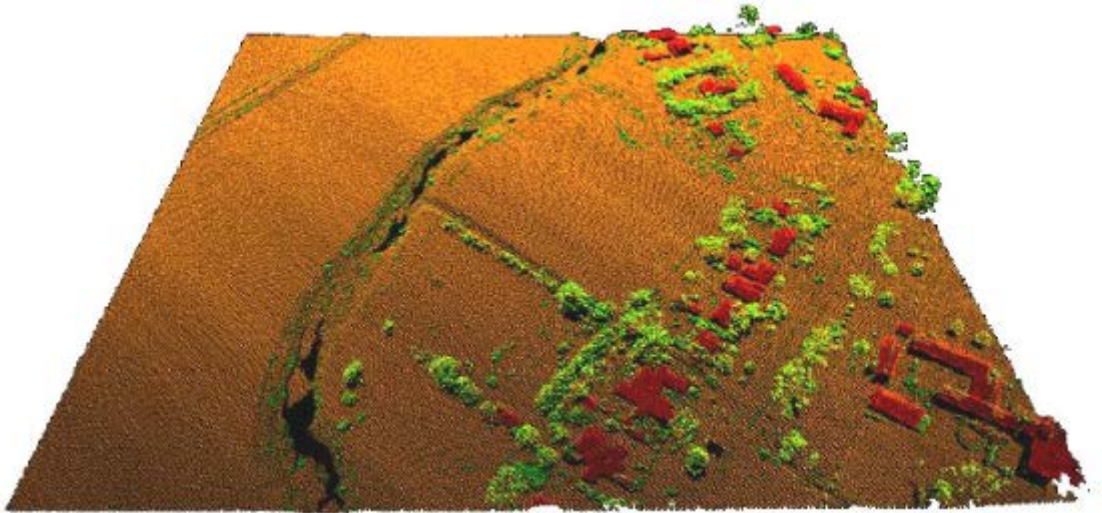


Figure 1: Coloured classified point cloud example (LPI, 2013).

2.3.2 Model Key Points (MKP)

Model Key Points (MKP) are a generalised subset of the original mass points and represent the minimum number of points required to determine the shape of the ground. Experience has indicated that this represents the optimal dataset and should be used in preference to 5 m, or 10 m grid interval point grids as it better represents the surface and is of a considerably smaller file size than the 1 m grid dataset (Figure 2). It should be noted that the minimal point interval is maintained at 1 point per 10 m² as can be seen over the paddock areas.

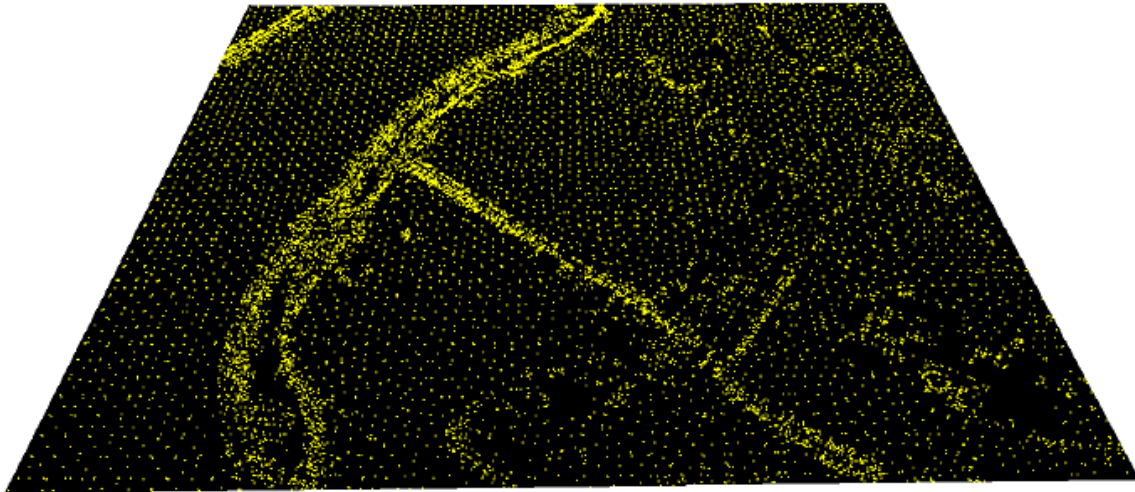


Figure 2: Model key points example (LPI, 2013).

2.3.3 Digital Elevation Model (DEM)

The DEM specifies elevations of the terrain (bare earth z-values) void of vegetation and manmade features. It may incorporate a range of data models such as mass point, TIN, grid or contours and may also include break lines to better represent discontinuous features, thereby improving the overall quality of the DEM (Figure 3).

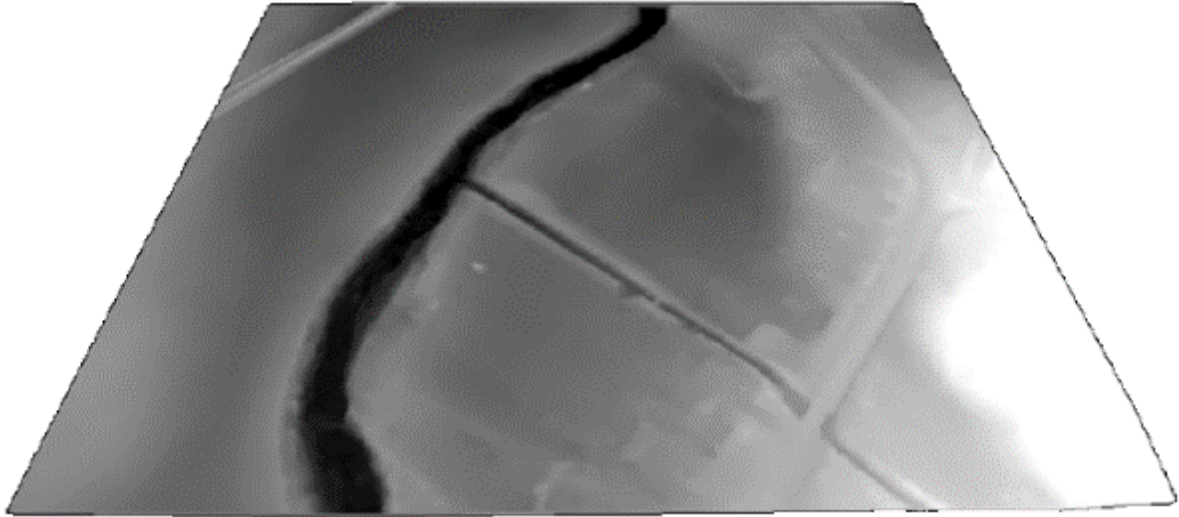


Figure 3: DEM example – shading by elevation (LPI, 2013).

2.3.4 Intensity Image

The intensity image is based on the intensity of the laser pulse return from the LiDAR instrument. This relates to the brightness of the object struck by the infrared laser pulse. Dark grey represents high reflectiveness (e.g. roads and buildings), lighter grey represents low reflectiveness (e.g. grass or other high infrared absorbent surfaces) and white represents nil reflectance (Figure 4). This is a useful tool when no aerial imagery is available. However, it should be noted that these images should *not* be interpreted as black and white images as this would provide false indication of the true contrasts.



Figure 4: Example of intensity image (LPI, 2013).

2.3.5 LiDAR Deliverable Data Sizes

This is where the ‘big data’ label comes from! Table 4 indicates the data sizes for the Bathurst project area – this has been nominated as it includes urban areas, agricultural areas, hills and plains and thus represents an average of the data sizes that can be expected. This clearly illustrates the large differences in dataset size depending on which dataset is chosen for a particular purpose. This also supports the use of the MKP format where possible as the optimal dataset for size and surface representation.

Table 4: Deliverable nominal file sizes of LPI LiDAR data.

Deliverable	Nominal file size (averages)		
	Bathurst		
	Data Size	Single Tile	Multiple (20)
Classified Point Cloud	± 5 million	220 Mb	4.4 Gb
Model Key Points	± 250 thousand	4 Mb	80 Mb
Ground DEM 1 m Grid	± 4 million	35 Mb	700 Mb
Ground DEM 5 m Grid	± 160 thousand	2 Mb	40 Mb
Ground DEM 10 m Grid	± 40 thousand	500 Kb	10 Mb
Total		261.5 Mb	5.23 Gb

It should be clearly understood that the data size can vary considerably from this average and is relative to the nature of the terrain in the project area. The greater the undulation and number of structures, the greater the file size. Conversely, flat areas with minimal structures will have significantly smaller datasets. This will be most evident in the Model Key Points format.

These data sizes also preclude the suitability of the majority of dedicated survey packages in manipulating this data. From personal experience, CivilCAD would take over 5 minutes to load 45,000 points, whereas the GIS software takes only 4 seconds.

2.3.6 Currency of LiDAR Data

The LiDAR data currently available ranges in date from 2009 through to 2014. It is important that the currency of the LiDAR data be taken into consideration with regard to the end use of the data. In areas with recent significant land development or changes in the natural environment through natural disaster or erosion, the available data may not be appropriate to use and provide false representation of the land use and topography.

2.4 LPI LiDAR Coverage

The LiDAR data coverage does not cover the entirety of NSW. LPI has used a targeted approach whereby the majority of the coastal fringe and most significant towns and their surrounding areas have been included to date. Figure 5 indicates the current coverage as of January 2015 via KMZ file supplied by LPI. This file is available upon request from LPI and allows interrogation of each project area for currency of data and data available. Figure 6 provides an example of the metadata for each project area.

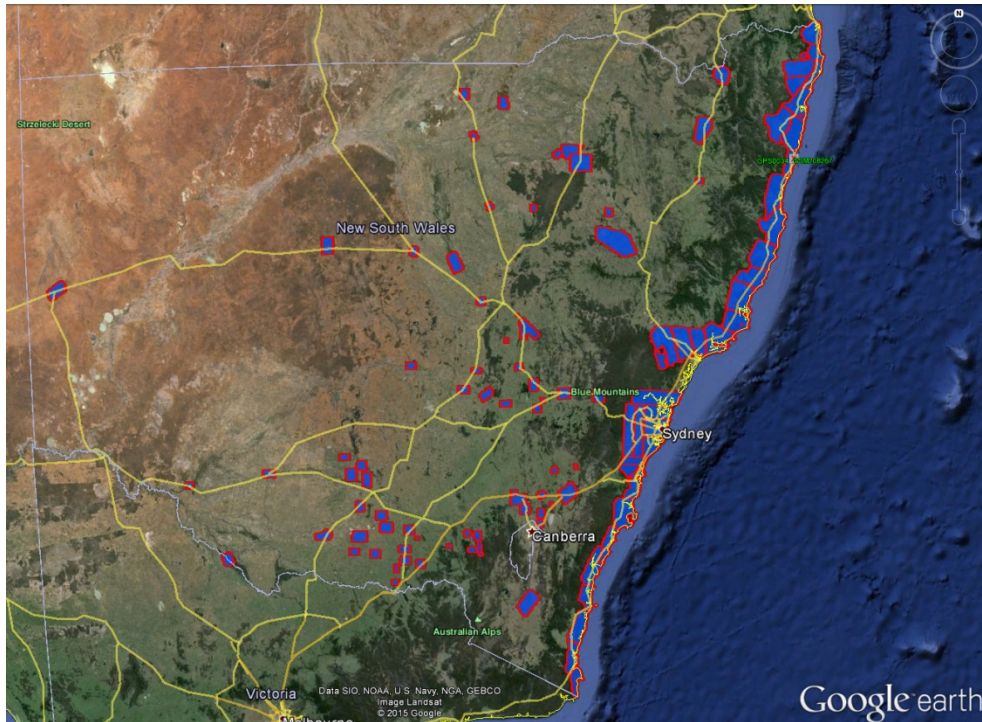


Figure 5: Areas provided with LPI LiDAR data (current as of January 2015).

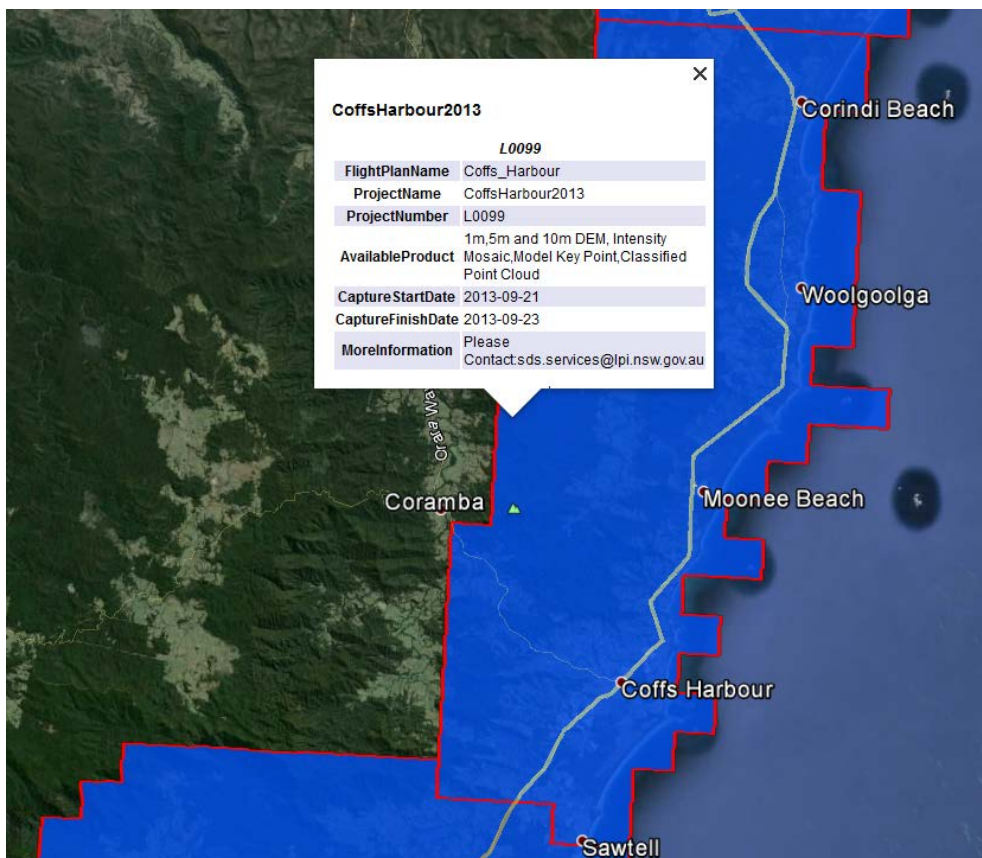


Figure 6: Example of project area LiDAR metadata.

The LPI website (LPI, 2015a) also provides monthly updates via downloadable PDF maps (Figure 7).

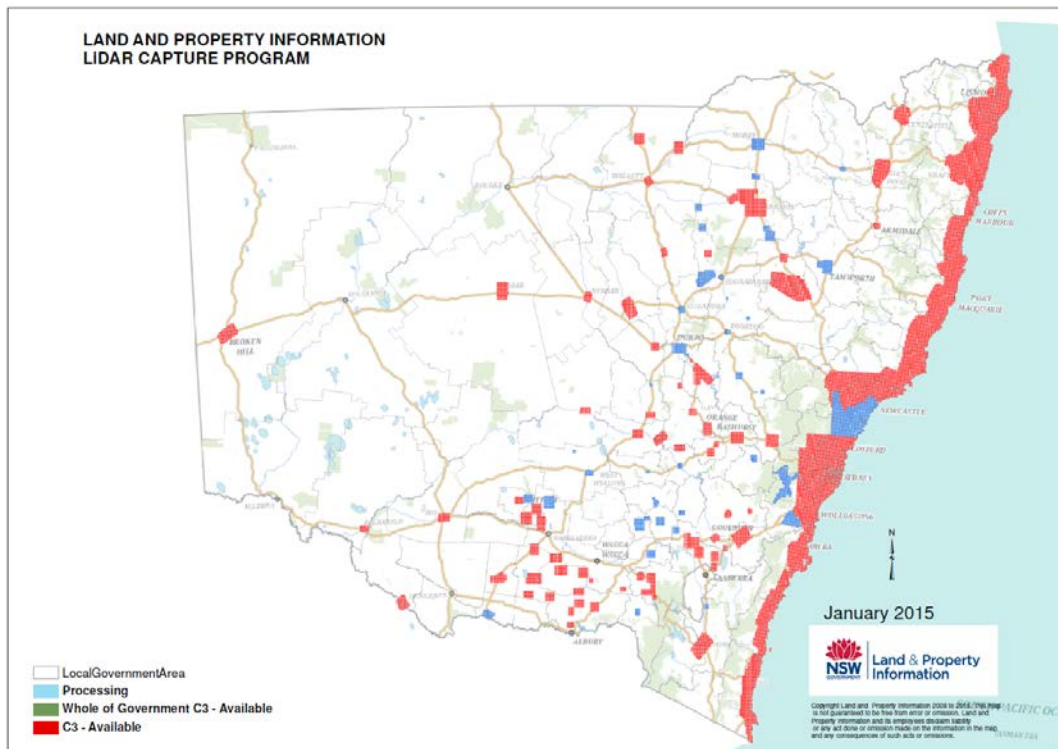


Figure 7: LPI LiDAR capture program as of January 2015 (LPI, 2015).

2.5 Aerial Imagery

2.5.1 What is Available?

LPI's orthorectified aerial photography covers a considerable area of NSW with only some western areas without coverage (Figure 8). This KMZ dataset is provided in the same context as for the LiDAR data and is also imbedded with area-specific imagery data (Figure 9).

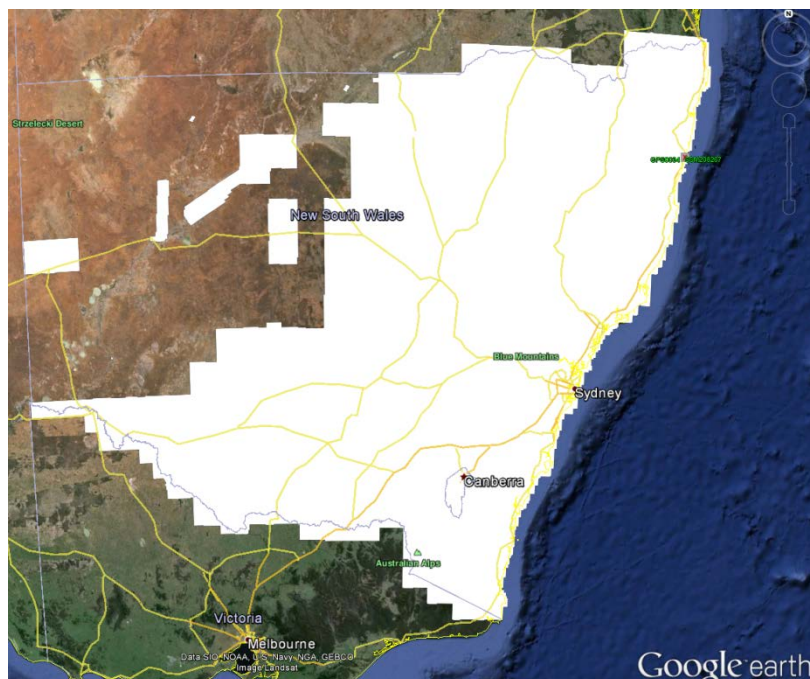


Figure 8: Areas provided with LPI aerial imaging data (current as of January 2015).

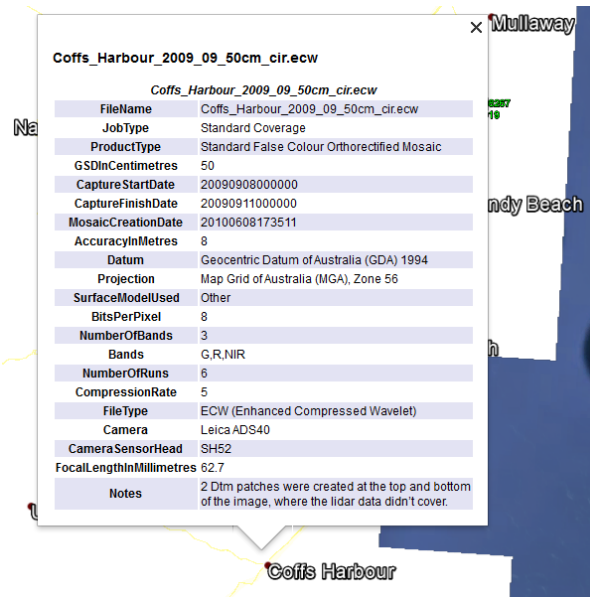


Figure 9: Example of project area aerial imaging data (current as of January 2015).

2.5.2 Imagery Data Specifications

As for LiDAR, it is important to understand the datum the imagery was captured in, as this will often not be automatically imported into the GIS software and will need to be manually entered. This is vital when integrating the imagery with LiDAR data and other third party GIS data. Table 5 outlines the general specifications of LPI aerial imagery data.

Table 5: General specification of LPI aerial imagery data.

Horizontal Datum	GDA94
Vertical Datum	(Orthometric) AHD71
Vertical Datum	(Ellipsoidal) GDA94
Projection	MGA Zones 54-57
Geoid	AUSGeoid09
Survey Control	The primary ground control surveys are referenced to AHD as specified above comprising state survey control marks with 'established' GDA94 coordinates and/or 'accurate AHD' heights as defined in the Surveying and Spatial Information Regulation 2012 (NSW Legislation, 2014).

For further information, the reader is referred to the NSW LPI Orthorectified Aerial Imagery and Derived Product Capture and Processing Specifications for Standard Program Acquisitions document (LPI, 2015b).

2.5.3 Resolution of Imagery

The resolution of the imagery is based on the ground sampling distance. This represents the distance between pixel centres measured on the ground and is referred to as the GSD. Table 6 indicates the resolutions for the differing image products.

Table 6: Image resolutions by product type.

Resolution	Product Type
10 cm – 20 cm GSD	Town coverage
50 cm GSD	Standard 1:100,000 mosaics
10 cm – 50 cm GSD	Special projects (e.g. emergency services)

2.5.4 Spectrums Available

Various light spectrums are available (Table 7), but not all spectrums are available on every image. Investigation with LPI will determine the spectrums available for the subject area. Although RGB is the most commonly used format due to its visible light spectrum banding, the infra-red images are useful for vegetation mapping. Vegetation absorbs infra-red light differently depending upon the species and health of the plant. This is highlighted in the infra-red spectrum images allowing for a more detailed vegetation analysis.

Table 7: Image colour spectrums available.

RGB	Red Blue Green
RBGn	Red Blue Green and Near Infra-Red
CIR	Coloured Infra-Red
NIR	Near Infra-Red

2.5.5 Areas Available

Table 8 lists the image areas available. It should be noted that 1:100,000 mosaics cover approximately 50 km by 55 km. This does vary from area to area as does the level of overlap between mosaics.

Table 8: Image areas available.

Image Area	Resolution
Whole of town	10-20 cm GSD
1:100,000 map area equivalent (mosaic)	50 cm GSD
Nominated areas (10 km x 10 km) cropped from 1:100,000 mosaic images	50 cm GSD

2.5.6 Image Data Sizes and Formats

Early image capture tends to be in JPG2000 format with later images in ECW (Enhanced Compression Wavelet) format. Approximate sizes for each format for 1:100,000 mosaics are indicated in Table 9. Data size for whole of town and special (emergency) coverage varies due to the size of the capture and can amount to between 500 Mb and 2 Gb, with a few unique cases in excess of 6 Gb. Town coverage file types vary as per the standard coverage sizes (ECW, JP2).

Table 9: Image format and nominal file sizes.

Format (Spectrum)	Data Size
JPG2000 (NIR)	3.5-7.5 Gb
ECW (CIR)	1.5-5.0 Gb
ECW (RGB)	1.0-5.0 Gb

2.5.7 Image Accuracy

Fundamental spatial accuracy of orthorectified aerial imagery conforms to the ICSM Category 1 standard, i.e. Fundamental Horizontal Accuracy (FHA) is better than or equal to $\pm 2.5 \times$ Ground Sample Distance (GSD) at the 95% confidence interval ($1.73 \times$ RMSE). This results in an accuracy of ± 1.25 m on 50 cm GSD imaging at the 95% confidence interval (LPI, 2015b).

2.6 Data Delivery and Cost

The different forms of transmittal for data are listed in Table 10.

Table 10: Transmittal formats.

Form of Transmittal	Notes
FTP site	up to 20 Gb – download through internet
DVD	
External HDD	purchased from LPI
External HDD	sent in from user, uploaded and returned to user

The low cost of data is one of the leading reasons to investigate how this data can provide project deliverables. For this example, cost is based on a single LiDAR project area and associated cropped 50 cm GSD image. Table 11 provides a breakdown of a typical data acquisition. It should be noted that the project area can vary considerably and should be checked for coverage via the LPI coverage KMZ file in Google Earth.

Table 11: Typical data acquisition cost.

Product	Cost excl. GST
LiDAR full package for project area	\$715
10 km x 10 km 50 cm resolution image	\$117
Total	\$832

3 DATA UTILISATION

Owing to the size of the datasets, it is apparent that most survey software will have significant issues or not be able to import the data at all. Some of the higher-end survey software is now able to manage the point clouds but comes at significant cost. This is where investigation of some of the smaller GIS packages is required. It is possible to use software that only costs \$100s rather than the \$1,000s usually associated with GIS software. These ‘simplified’ packages can efficiently handle the large datasets and in most cases provide all of the deliverables indicated in this paper.

It should be understood that these GIS software packages are not detailed hydrological modelling packages, and further analysis will be needed by specialists to determine finite outcomes for detailed design. Care should be taken using the settings associated with each of the outputs as this can dramatically alter the outputs. Bad settings equal bad outputs, equals erroneous feasibility studies, equals expensive mistake!

The data derived from using the methodology described in this paper is best applied to the master planning and feasibility stages of projects to help in determining the focused approach only where it is needed, thus minimising the costs of detailed data capture, processing and analysis. The following sections provide examples of what can be generated from the LPI data using a Model Key Point (MKP) file and a 10 cm resolution image.

3.1 Contours and Terrain Models

Contours and terrain models (triangle files) are the simplest and most common output from LiDAR data (Figure 10). However, it should be noted that due the large number of points utilised to create the contour and terrain model, these surfaces can be of considerable size in themselves. Options are usually available within the GIS software that will ‘simplify’ the contours to some extent, thus reducing the file sizes, care should be taken with this as excessive simplification will cause the representational accuracy of contours to be degraded.

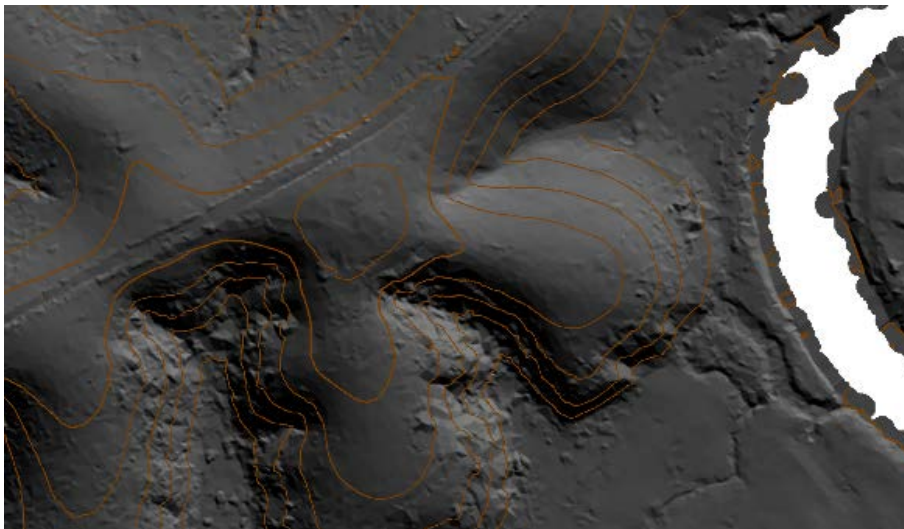


Figure 10: 5 m contour interval over daylight shaded DEM.

3.2 Coloured DEMs

Colourisation of the DEM can provide an insight into the survey area that conventional survey methods would never hope to attain. Definition of natural drainage channels, tracks and roads, erosion areas and a whole variety of natural and built environment features can be teased out of the data. This section provides some examples of what can be achieved. These deliverables are best exported from the GIS software as raster (image) files and inserted into other software in a similar manner to normal background imagery.

3.2.1 Daylight Shading

Daylight shading can be useful in determining what areas will be in sun and what areas will be in shade during the day. Examples of lighting conditions in the early morning and late afternoon are shown in Figures 11 & 12, illustrating that the effect on the rendering can be quite dramatic.

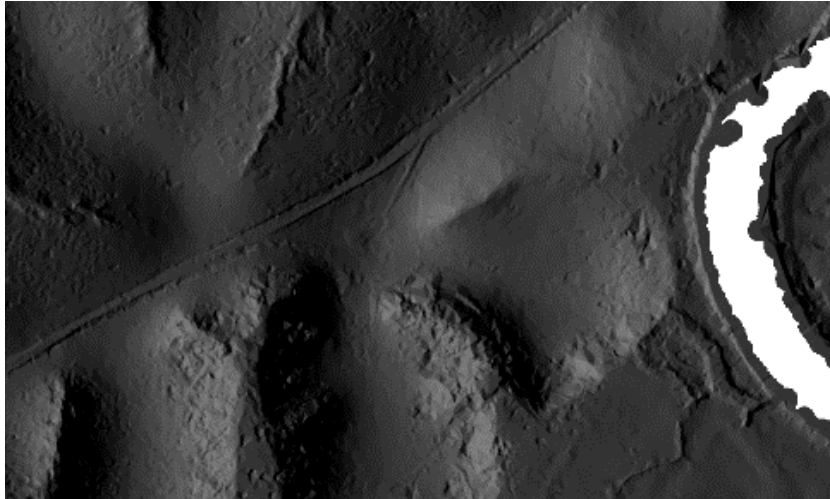


Figure 11: Early morning daylight shading.

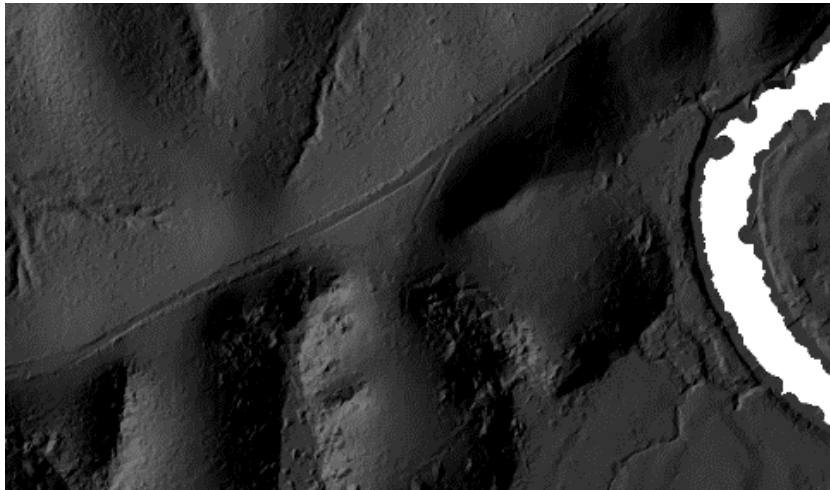


Figure 12: Late afternoon daylight shading.

3.2.2 Colour by Elevation

Colour by elevation can provide easily interpreted relative heights of the DEM. This can be very useful when providing interpretation of drainage over gently sloping areas where contours are less indicative (Figure 13).

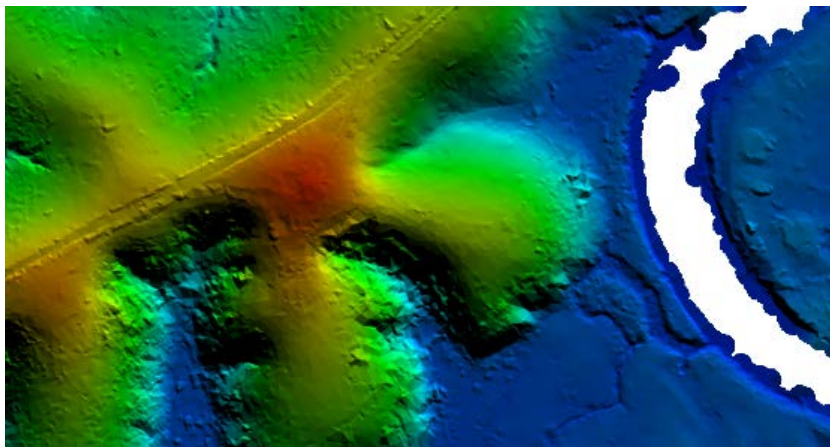


Figure 13: Colour by elevation shading.

3.2.3 Shade by Slope Direction

Shading by slope direction can provide insights into subtle changes in terrain that may not be readily visible in daylight or height by elevation shading. This can be seen in Figures 14 & 15, illustrating 'atlas' shading (general colour representation that you would find on large scale topographical maps) and shading by slope direction, respectively. Historical banks of the waterway become apparent and therefore of assistance in understanding the geomorphology of the subject area. This data is also of interest to farmers and other growers as it indicates areas that are best targeted for planting through identification of desirable aspects.

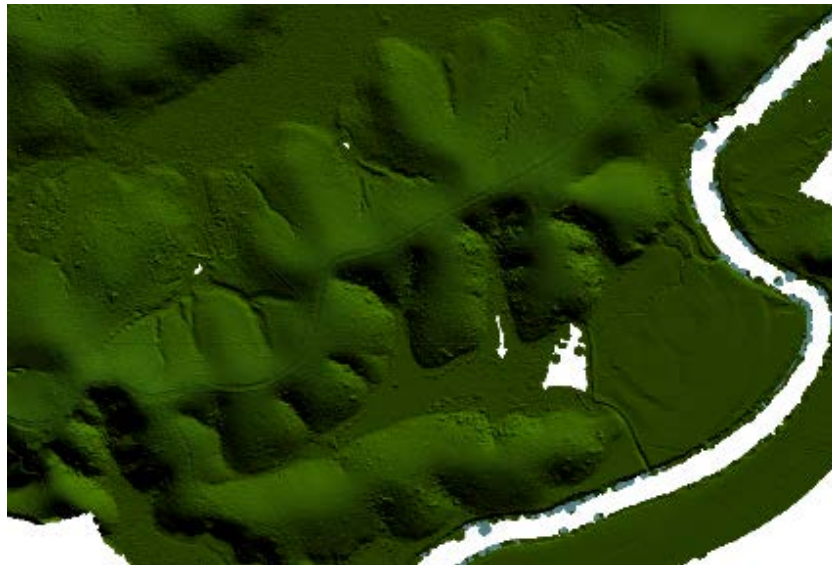


Figure 14: 'Atlas' shading.

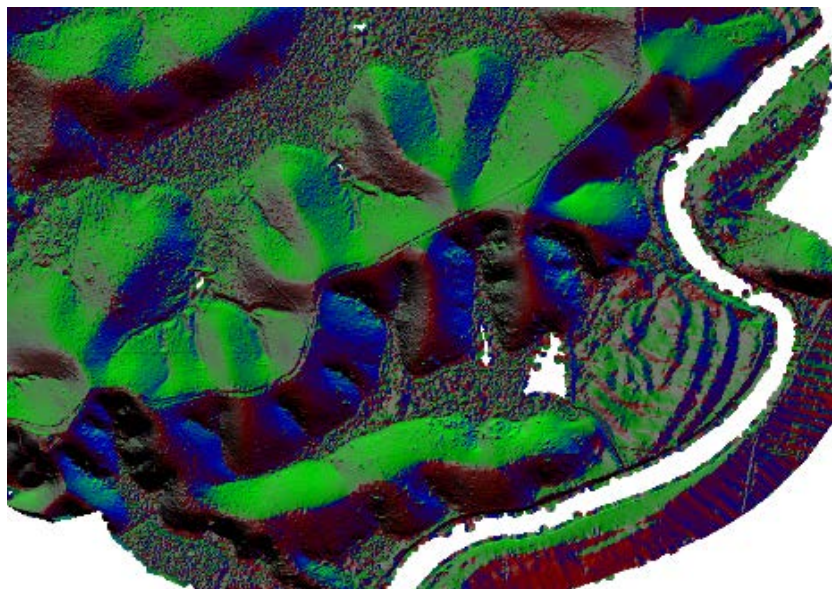


Figure 15: Shade by slope direction.

3.3 Definition of Drainage Channels, Waterways and Catchments

Understanding how an area sheds itself of rainfall is of significant interest to parties involved in all forms of land development and management. Digitisation of published topographic

mapping may not accurately represent the true extent or location of drainage channels and waterways thus limiting the quality of the data for planning purposes. Many of the GIS packages are capable of analysing the surface models and determining the catchment areas, and consequently the alignment of drainage channels and waterways over the project area.

There will often be considerable customisation associated with the level of detail that can be produced. Care must be taken in this area to choose settings that represent waterways in a realistic manner, e.g. telling the software to ignore any drainage channel less than 30 m in length. An example of drainage channel analysis is given in Figure 16, with coloured graphical representation of the catchment areas shown in Figure 17. As previously mentioned, these GIS packages are not capable of full hydrological analysis or categorisation of drainage channels or waterways. This data is indicative and is to be used to determine where further study by hydrological professionals may be required.

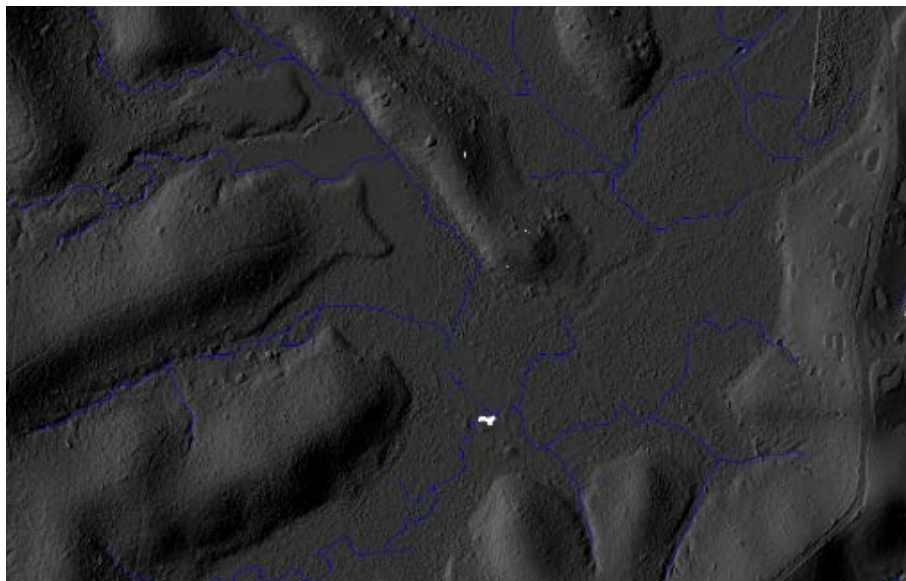


Figure 16: Drainage channels generated from catchment analysis.

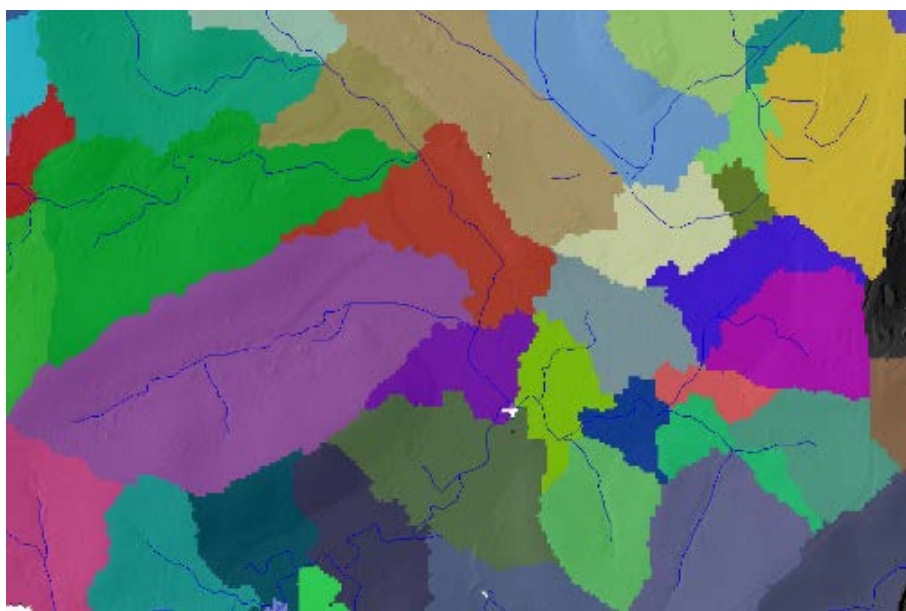


Figure 17: Indication of individual catchments through colourisation.

3.4 Modelling of Flood Scenarios from Rain Events, Storm Surges and Sea Level Rise

Australia is the land of fire and flood. Adding sea level rise, storm surges and in rare cases tsunamis, it is clear that the analysis, understanding and mitigation of risks to life and assets from these events is vital in the future planning of our built environments. Again, the GIS data can assist in assessing these threats. Modelling tools are available that can illustrate sea level rise and impacts of storm surge and flood events (Figure 18). This figure models a 0.25 m water level above a nominated level associated with the waterway. Floodwater inundation is indicated in pink. It is apparent that some buildings were built on pads that mitigate for this and some were not.



Figure 18: Flood event modelling.

3.5 Slope Analysis

Understanding the range of slope over a project area can be useful for many aspects of assessment and design, e.g. the determination of road alignments to avoid gradients over a particular angle. Figure 19 indicates a colourised assessment of gradient: 0-10° = green, 10-15° = yellow, and over 15° = red.

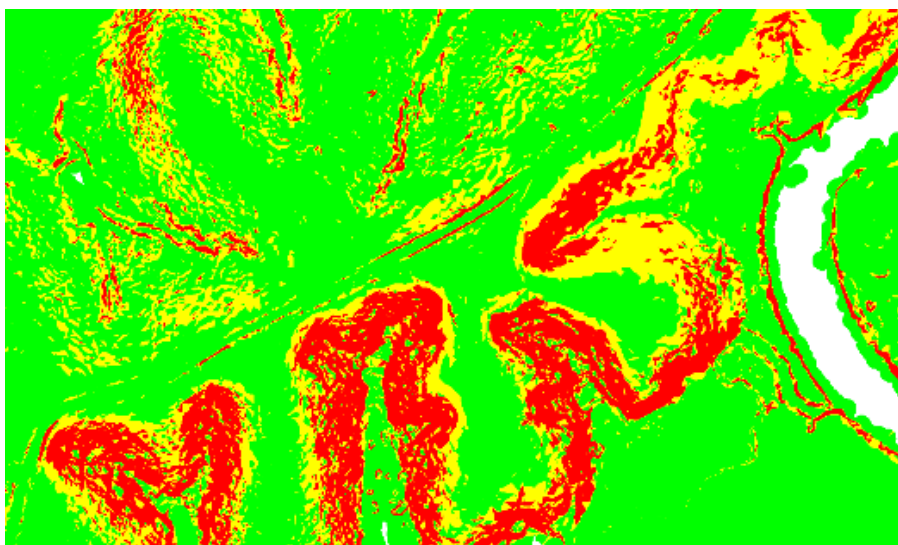


Figure 19: Slope analysis.

3.6 Bushfire Risk Analysis

Continuing with the earlier theme of planning for natural disasters, fire presents as significant or greater a threat than that of flooding. When carrying out a bushfire risk assessment, vegetation and slope are of paramount importance. By combining imagery, slope analysis shaded DEMs and, where possible, LGA detailed vegetation (see section 4 regarding the integration of third party GIS data) analysis, reasonable desktop assessments can be made in establishing Asset Protection Zones (APZ) and determining the level of risk of assets within a project area. Determination of appropriate constraints and criteria should be made by suitably qualified persons in the area of bushfire assessment, given the risk to life and assets bushfires in Australia represent. Figure 20 indicates what can be represented using the above techniques (although LGA vegetation mapping data is not displayed here).

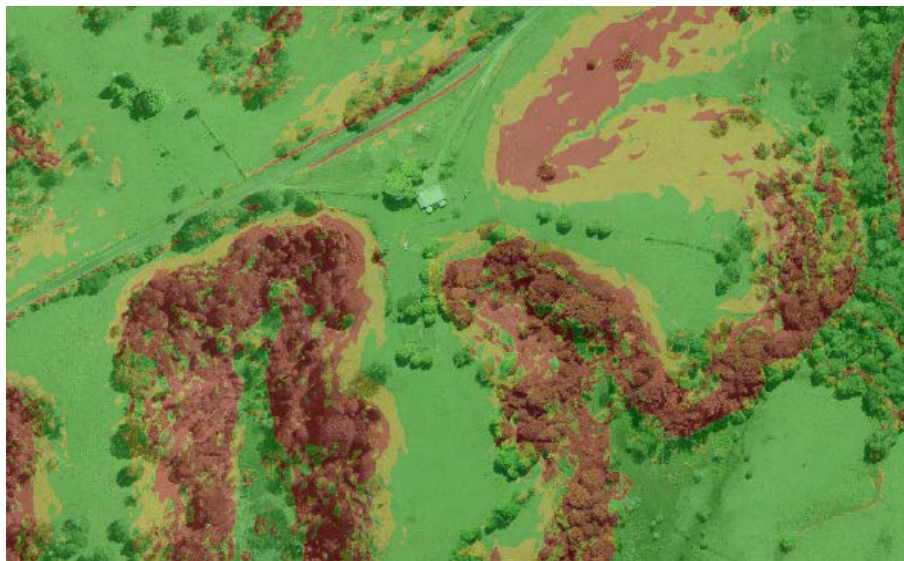


Figure 20: Bushfire risk modelling.

3.7 Visualisation using 'Draped' Images over DEMs

Public consultation associated with land development can be a challenging exercise. Providing realistic imagery of proposals can greatly aid in ensuring the public interpret what is being proposed in an accurate and intuitive manner. Again, the utilisation of GIS data can augment LPI's aerial imagery and proposed designs through integration of DEMs. As an example, Figure 21 shows the original image, while Figure 22 shows the integration with the DEM, introducing natural terrain shading. Figure 23 indicates what can be achieved with 3D perspectives of the existing topography. Finally, Figure 24 introduces the natural constraints of the subject area in terms of slopes, contours, fire and flood.



Figure 21: Standard image.



Figure 22: Opaque standard image draped over DEM to indicate terrain.

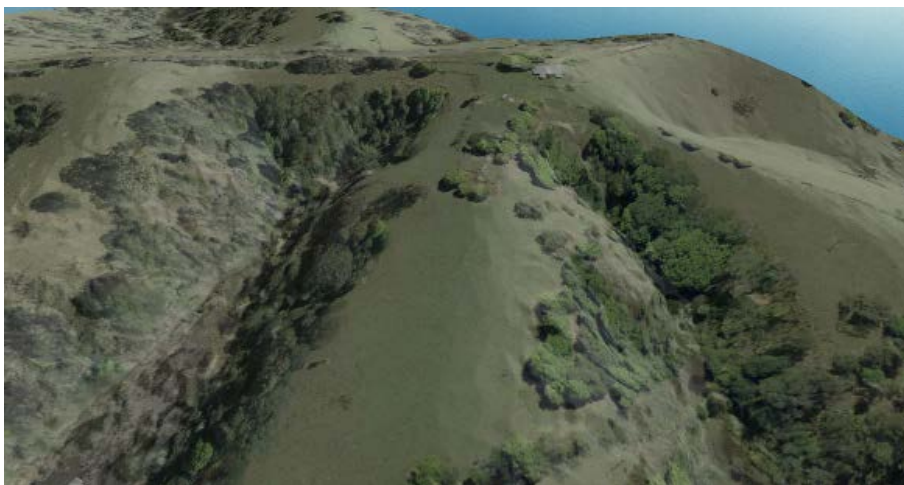


Figure 23: 3D visualisation.

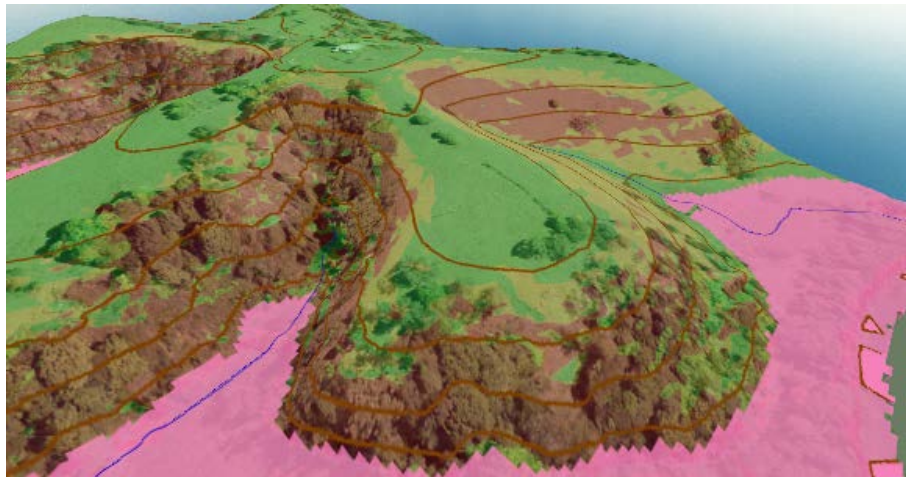


Figure 24: 3D visualisation of a combined constraint plan.

4 DATA INTEGRATION

4.1 Integration of Third Party GIS Data

As GIS software is being utilised to augment LiDAR and image data, it allows for the importation and integration of third party GIS data. For example, most local councils will have a GIS department managing database that can cover all aspects of town planning, council assets, detailed vegetation mapping, contaminated lands, etc. Many councils are prepared to issue this data for a fee thus allowing the integration of high-value data when determining service corridors, assessing feasibility studies and strategic planning that accurately take into consideration local authority constraints. Figure 25 provides an example of typical detailed vegetation, flooding and property boundary data courtesy of Coffs Harbour City Council's online mapping portal (Coffs Harbour City Council, 2015).

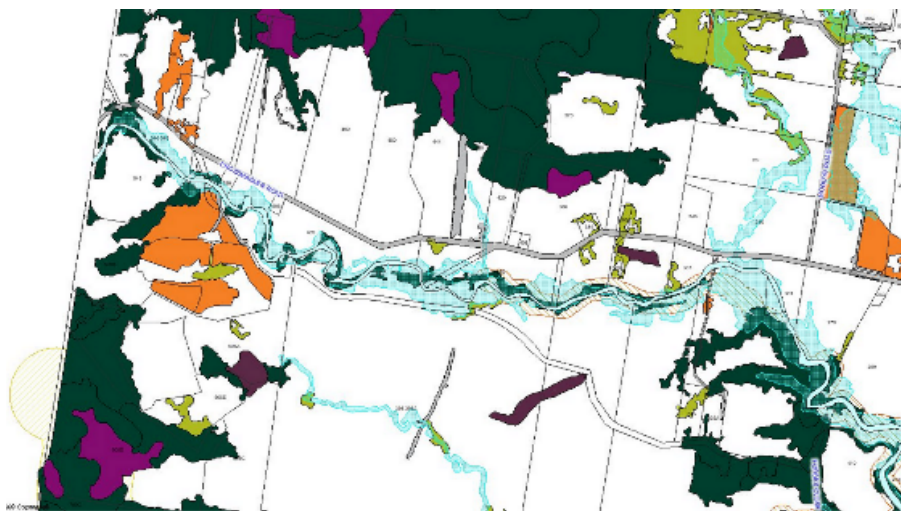


Figure 25: Example of Local Authority GIS Local Environment Plan mapping.

4.2 Integration with Survey or CAD Software

Most of the GIS packages will provide numerous options regarding the export of vector (CAD) and raster (image) data. Experimentation will be needed to determine the best formats

and export settings that provide the optimal resolution, detail and file size to be integrated into the survey software packages or other CAD packages. Once these have been determined, they should be integrated into standard procedures and applied consistently.

4.3 Management of Datasets

With data being exported from GIS datasets into CAD and third party GIS data being imported into LiDAR data along with information from the survey software, it is vital that procedures are developed and enforced that manage the origin and currency of data. This can be achieved in any manner of ways and is best developed by each individual practice to integrate with their current quality assurance and document control systems. If these processes are not adhered to, there is great risk of superseded data being used along with confusion as to where particular data should be held in the GIS database or in the survey software.

5 STORAGE, MANAGEMENT AND BACKUP OF LiDAR AND IMAGE DATA

Consideration should be given as to how to store, access, backup and archive LiDAR and aerial imagery. Each practice will have its own current data storage solution, thus storage and backup solutions of LiDAR and image data will be just as individual. The findings and recommendations stated below are based around a small business server solution that can be found in many small practices. It is recommended that consultation with an IT specialist be undertaken to determine what would be the most suitable solution for individual practices.

5.1 Storage of Data

Where only very intermittent small projects are envisaged, the standard protocols used for conventional survey data are still the best solution. However, if multiple smaller projects are envisaged (or even one or two large projects), standard server storage solutions will struggle, causing the slowing of all data transfer between servers and workstations. If the latter scenario is expected, then it is recommended that dedicated hard drives be allocated to the existing server to specifically manage these large datasets, stored in a similar file structure as the original project drive. This will then avoid the issue of compromising current project drive storage and access speeds. Most small business servers will have capacity for several hard drives, so the cost of implementing this process would be in the order of \$400 for each additional 2TB hard drive and around \$100 for installation.

5.2 Management of Data

It is recommended that the existing GIS software is utilised to manage the collation of the LiDAR, imaging and any third party GIS data – these can be saved in the same location as the LiDAR and aerial imagery datasets. This will avoid most issues where data gets moved independent of the project database and thus needs rebuilding. The GIS database will usually hold the correct order of data, configuration associated with DEM shading, image transparency settings, etc. This will save considerable time reloading data when revisiting a project in the future.

5.3 Backup and Archiving of Data

As noted in regards to storage, the practice's standard backup and archiving protocols should cope with a few small projects. However, if the move to independent hard drives is made on

the server, this should also be replicated in the backup solution. In most cases, this can be via external multi-TB hard drives that are rotated into fireproof offsite storage. These drives can be purchased for about \$200-300.

5.4 Cloud Storage

At this time cloud storage is not recommended as a storage solution. The sheer size of the datasets preclude this as a solution for small to medium practices. However, with the continued expansion of online storage, data transfer speed and (hopefully) improved encryption and security, this situation may change in the future.

6 CONCLUDING REMARKS

Utilisation of LPI's LiDAR and aerial imagery datasets through GIS is possible for even the smallest of survey practices. Cost of data, equipment and software have drastically reduced in recent years, enabling a broad range of deliverables to be provided at a reasonable cost. However, the data's limitations must not be underestimated. Basing detailed design on these outputs is highly dangerous due to the resolution, accuracy and currency of the LPI data. Where possible, it is recommended that ground truthing of the data be carried out on sample areas over the extent of the project area. This will provide some 'dead reckoning' of the data and lends confidence to stated relative accuracies of the data.

The data's utilisation lies in the early stage feasibility and planning studies, where broad decisions can be made along with targeted detailed surveys of key areas to allow for detailed design and assessments via conventional terrestrial surveys, Global Navigation Satellite System (GNSS) surveys or further LiDAR surveys.

Recent investigations into current costs of aerial LiDAR and image capture have indicated that high-resolution capture (30 cm horizontal, 15 cm vertical, and 5-10 cm resolution imagery) can be captured at reasonable cost, provided capture can be planned far enough ahead. A 50 ha project area within the coastal fringe of NSW would cost in the order of \$7,000 excl. GST (January 2015).

This paper provides no recommendations with regard to the integration of terrestrial laser scanning data, solid modelling or particular GIS packages to achieve the examples given. It is for the individual practice to determine the 'best fit' of software and infrastructure to integrate with the practice's budget and current processes.

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