INTERGOVERNMENTAL COMMITTEE ON SURVEYING & MAPPING

ICSM Guidelines for Digital Elevation Data

VERSION 1.0

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Preface

The purpose of this document is to provide investors, providers and users of elevation data with guidelines and recommendations for acquiring elevation data depicting the earth's surface based on current best practice.

The Guidelines for Digital Elevation Data were prepared by the Intergovernmental Committee on Surveying and Mapping Elevation Working Group under the auspices of the National Elevation Data Framework (NEDF) initiative currently under development. The Working Group involves experts from State and Federal mapping agencies, industry and academia.

The purpose of the NEDF initiative is to develop a collaborative framework that can be used to increase the quality of elevation data and derived products such as digital elevation models (DEMs) describing Australia's landform and seabed. The aim is to optimise investment in existing and future data collections and provide access to a wide range of digital elevation data and derived products to those who need them.

The guidelines represent a first cut in the preparation of 'best practice' guidelines for Australia and have been prepared as an outcome of a review of existing available material from around Australia and selected countries. These guidelines are considered a living document. If you have any questions or comments on the guidelines please email icsm@ga.gov.au.

For further information on the NEDF or these guidelines please visit the ANZLIC site at http://www.anzlic.org.au/nedf.html and the ICSM site at http://www.icsm.gov.au/icsm/elevation/index.html.

1. Introduction

1.1 Objectives

Elevation data and products such as Digital Elevation Models derived from these data comprise an essential layer within the National Spatial Data Infrastructure. Historically the creation of these datasets has been the domain of National and State mapping agencies. However, in recent years the rapid development of survey technologies and industry capability, the need for high resolution elevation data to meet a range of purposes, and the nature of government funding arrangements has resulted in significant project-based investment.

The need for standards and guidelines were highlighted at a series workshops held around Australia under the auspices of the National Elevation Data Framework (further described below). Attendees cited a range of issues including:

- Difficulties in integrating data from previous data acquisitions due to a wide variety of specifications, formats, quality and metadata into state and national datasets;
- High transaction costs for both purchasers and providers preparing and responding to varying tender specifications;
- The use of inappropriate specifications for intended purposes which as resulted in acquisitions costing more than necessary, or not satisfying users needs;
- Evolving requirements and continuous improvements in technology that make it difficult for purchasers to maintain "best practice" knowledge.

The purpose of this document is to provide investors, providers and users of elevation data with guidelines and recommendations for acquiring elevation data depicting the earth's surface based on current best practice. The objectives of these guidelines are to:

- Learn from current best practice and reduce the chance of repeating mistakes across agencies
- Help purchasers acquire "fit-for-purpose" data as painlessly as possible
- Minimise compliance costs for providers
- Align multiple users needs where possible
- Facilitate interoperability and data integration
- Future Proof our investment in data.

1.2 The National Elevation Data Framework (NEDF)

The purpose of the NEDF initiative is to develop a collaborative framework that can be used to increase the quality of elevation data and derived products such as digital elevation models (DEMs) describing Australia's landform and seabed. The aim is to optimise investment in existing and future data collections and provide access to a wide range of digital elevation data and derived products to those who need them.

Impetus for a national approach to digital elevation data is coming from a range of sources. This support is driven by:

- Calls for a national framework approach from the Council of Australian Governments (COAG) for the National Climate Change Framework and multi-jurisdictional bodies such as the National Spatial Information Management (NSIM) Committee in its Spatial Strategic Plan 2007-2010 for counter-terrorism and emergency management needs;
- The urgent data needs of the National Water Security Plan;
- The very wide range of applications using elevation data and products;
- A universal need for increased accuracy of elevation data to meet this wide range of applications (and exploit growing availability of high-resolution sources);
- Need for better access to both existing and future elevation data sets by a wide range of users;
- Ability to use data derived from various sources to create new products, such as 3D visualisation for urban and infrastructure design and for communication with the general community.
- Current needs in key areas such as climate change, water management, wetland and coastal management, disaster mitigation, infrastructure planning and management, local planning and city management and industries such as insurance and mining.

ANZLIC – the Spatial Information Council, with the support of the Australian Department of Climate Change (DCC), Geoscience Australia (GA) and the Cooperative Research Centre for Spatial Information (CRCSI) is coordinating the development of a National Elevation Data Framework (NEDF). A Steering Committee and Project Management Team has been established to guide the development of the framework. During 2007/08 a number of milestones were achieved which will guide the long-term development of the NEDF. These have included:

1. User Needs Analysis based on a series of State workshops which provided direct contact with stakeholders representing all levels of government, industry and the research community around Australia.
2. Business Plan, setting out the intent and potential form of a NEDF, identifying key stakeholders and a preliminary review of existing usage of elevation data sets and products in Australia.
3. Science Case to support the implementation of the project and its review by the Australian Academy of Science and the Australian Academy of Technological Sciences and Engineering through a National Workshop
4. The development of national guidelines for the acquisition and processing of elevation data based on existing standards and current best practice.
5. Implementation Plan using the User Needs Analysis and feedback from stakeholders on issues such as governance arrangements, funding and standards.

Further information on the National Elevation Data Framework can be found on the ANZLIC site at http://www.anzlic.org.au/nedf.html.

1.3 Elevation Data - An Overview

The concept of a national elevation data set is relatively straightforward, namely the provision of bare-earth elevations, referenced to a vertical datum that is common to both the bare-earth elevations and bathymetric data. Realisation of a national elevation data set, however, is a more complex proposition for a number of reasons, which include the data acquisition technologies involved, issues with the definition of a uniform vertical datum, the horizontal density and vertical resolutions involved, data quality and data formats.

The term Digital Elevation Model (DEM) is used to describe bare earth elevations within a grid at a specified spacing. A term that is often used synonymously with DEM is DTM or Digital Terrain Model. DTM often implies that the elevation data is not gridded. Instead a DTM may incorporate breaklines that describe discontinuities in the terrain (e.g. creeks or ridge lines) and mass points for characterising topographic features.

Virtually all data acquisition technologies for the generation of elevation data are based on remotely sensing the terrain and sea floor from above. As a consequence the surface modelled in the first instance is the ‘reflective’ surface that comprises buildings and vegetation as well as the bare earth. The digital surface model (DSM) is a very useful elevation data set in its own right. In the context of the provision of a national elevation data set using newly acquired data, a national DSM must in effect also be generated, with the former then being created through a post-processing of the latter. The accurate and comprehensive removal of ‘above ground’ features or ‘artefacts’ remains one of the significant challenges in DTM/DEM generation, especially in urban and heavily vegetated areas.

DTM/DEM generation is already an everyday process within the spatial information industry. There are a number of sensor types currently being employed to produce DSMs, and subsequently ground models, with varying levels of horizontal resolution and vertical accuracy, and with differing levels of process automation and cost. The various technologies are discussed in Section 2 - Review of Elevation Acquisition Technologies.

1.4 Review of Existing Guidelines and Recent Requests for Tender

The NEDF stakeholder workshops identified a need to develop and apply national standards for elevation data. To initiate this process a review of existing published material relating to the acquisition, processing and quality assurance of elevation and bathymetry data and related products, including recent requests for tender has been carried out, and forms the basis for these guidelines.

A number of documents from each Australian State and Territory, New Zealand, Canada, the United States and the International Hydrographic Organisation (IHO) have been reviewed and summarised in an attempt to develop best practices guidelines described in this document. In, all approximately 40 documents were reviewed, with 23 of these being recent tenders for the acquisition of data by local, state and Australian Government agencies. Other documents, including the NEDF Science Case prepared by the Cooperative Research Centre for Spatial Information (CRCSI), and the United States National Digital Elevation Program (NDEP) Guidelines for Digital Elevation Data have also been extensively used in the preparation of this report.

Given that the stakeholder sessions identified a particular need for high resolution, high spatial accuracy DEM data, this review, although acknowledging other DEM acquisition technologies, has focused on the two technologies currently being utilised the most in Australia for the capture of high resolution elevation and bathymetry DEMs; aerial photography and airborne laser scanning (ALS). It is expected that other technologies like IFSAR will be the subject of a separate review, and will be incorporated into the guidelines in the near future.

2. Elevation Acquisition Technologies

A review of available Elevation Acquisition Technologies was included in the NEDF Science Case prepared by CRCSI and has been included here for background and reference. This paper, along with other background information can be found at http://www.anzlic.org.au/nedf.html.

Any new elevation data acquisition programs that are to be undertaken within the foreseeable future for the purpose of building a national elevation data set are going to involve one of a finite number of sensor technologies. The purpose of the following discussion is to overview the current techniques for elevation data generation, primarily to illustrate their capabilities. The technologies covered are photogrammetry; airborne light detection and ranging (LIDAR), also termed airborne laser scanning; interferometric synthetic aperture radar (IFSAR) and bathymetric sonar. In the case of photogrammetry and IFSAR, the sensor platforms can be either airborne or spaceborne. Also, airborne laser scanning can be used for shallow water bathymetry as well as topographic surface modelling. All technologies generate, in the first instance, DSMs though both LIDAR and multi-band IFSAR have the potential of penetrating vegetation to provide bare-earth elevations.

2.1 Photogrammetry

As a tool for topographic mapping, photogrammetry has a long history spanning more than 60 years and has consistently delivered reliable results. The technology can use stereo frame or line scan data from aerial or satellite sensors. Historically it was a manual process to observe elevation data but with the advent of digital softcopy photogrammetric processes, automated DSM generation through image matching technology became feasible. Today the generation of a DSM from digital aerial or satellite imagery is almost a fully automatic batch process. Nevertheless, the cost of the DSM-to-DEM conversion can be very significant, and can exceed the total cost of producing the DSM.

Broad area DTM/DEM generation via photogrammetry is presently not the preferred approach, particularly over densely vegetated areas. It does however potentially provide advantages where high accuracy DTM/DEMs of better than 10cm vertical resolution are required over sparse vegetation, for applications such as 3D city modelling, or where the DTM/DEM is highly reliant on breaklines.

High resolution satellite imaging systems have gained popularity for DSM generation at vertical resolutions within the range of about 1m to 10m. For example, the recently launched World View 1 satellite has a 50cm GSD, which, although not verified, may support DSM extraction to around 1-1.5m vertical accuracy; and the dedicated DEM generation program of SPOT Image, namely the SPOT 5 HRS system, yields DEMs with a nominally 8m or so height accuracy and 20-30m horizontal resolution. All satellite imaging systems used for 3D terrain modelling use line scanner technology, with the 2.5m resolution ALOS PRISM satellite having a 3-line scanner geometry similar to that in the ADS40 aerial camera.

While aerial photogrammetry remains a flexible and accurate means of topographic mapping, it tends not to be a preferred technology for stand-alone DEM generation over large project areas where terrain models with vertical accuracies in the 10cm to 1m range are required.

ALS technology is presently a more popular alternative. Nevertheless ortho-rectified aerial photography provides a distinct advantage when processing ALS data and it is often acquired for that purpose. The image can be used to verify the shape of the DEM surface is logical for the terrain it covers. (i.e. large flat areas, rivers, built up areas, steep terrain and water surfaces.)

2.2 ALS or LIDAR

Airborne laser scanning or LIDAR has evolved over the last decade into the clear ‘technology of choice’ for the generation of high-resolution elevation models, as characterised by vertical accuracies of 10-50cm and horizontal post spacings of 1-3m. The advantages of LIDAR centre upon its relatively high-accuracy of 10-15cm in height and 30cm to 60cm in the horizontal, and upon the very high mass point density of at least 1 point/m^2. This high point density greatly assists artefact removal in the DSM-to-DEM conversion. Moreover, LIDAR has high productivity of around 300 km^2 of coverage per hour, and it can be operated ‘locally’, day or night. In practise, data acquisition is generally confined to daylight hours since most LIDAR units nowadays come with dedicated digital cameras (usually medium format), the resulting imagery being used both to assist in the artefact removal process and for orthoimage production.

One of the most significant attributes of LIDAR is multi-pulse sensing, where the first returned pulse indicates the highest point encountered and the last the lowest point. There may also be mid pulses. As a consequence, LIDAR has the ability to ‘see through’ all but thick vegetation and it can be safely assumed that a good number of the last returns will be from bare earth. This greatly simplifies the DSM-to-DEM conversion process in vegetated areas. The advantages of LIDAR over high-resolution photogrammetry in urban and city environments are less pronounced since the reflections of surfaces such as the sides of buildings can complicate shape definition and obscure breaklines. A further shortcoming of LIDAR units designed for terrain modelling is that the typically 1m or so laser wavelengths employed do not support water penetration. There are, however, airborne laser systems specifically designed for shallow water bathymetry or airborne laser bathymetry (ALB), the Australian developed LADS system being a prime example. ALB will be discussed in a later section.

As with the photogrammetric DSM-to-DEM conversion, considerable manual post processing of the filtered and thinned out LIDAR DEM is required to ‘clean’ the bare-earth representation. The cost of the manual post-processing stage has been reduced over recent years as software systems have become more sophisticated. Although the manual intervention may account for 90% of the post-processing budget, it is now down to something in the order of 20%-30% of the overall project budget.

In many respects LIDAR data is similar to image acquisition from aerial photography: flights are carried out in strips, with a nominal side overlap of around 30%, depending upon terrain. ‘Accuracy’ is again a function of flying height, but in the case of LIDAR the height accuracy (i.e. ranging accuracy) remains reasonably constant whereas the ground sampling density varies. In general, LIDAR is less expensive than standard photogrammetry, with the cost advantages becoming more pronounced as project areas become larger.

When compared to airborne IFSAR as a technology for DEM generation, LIDAR displays advantages that go beyond its inherently higher accuracy. For a start, LIDAR is a near nadir sensing system, with its field of view extending only about 20^0 each side of the vertical. This allows penetration into urban canyons and enhanced prospects for penetration through vegetation. As will be discussed in the next section, IFSAR is side-looking, which can leave shadowing and data voids in the oblique ranging data, thus complicating somewhat DEM acquisition over urban areas. Over small areas LIDAR displays cost advantages over airborne IFSAR, but when it comes to very large area coverage IFSAR is more cost competitive. A complicating factor in any IFSAR versus LIDAR cost comparison in Australia at the present time is that neither of the world's two prominent commercial providers of airborne IFSAR surveys base a sensor unit locally. Thus, the highly specialised aircraft carrying the IFSAR platform would need to be brought in from overseas, likely from North America.

2.3 IFSAR

Interferometric Synthetic Aperture Radar (IFSAR) systems determine the relative heights of imaged ground points as a function of the phase difference of the coherently combined signals received at two antennas. At the present time there are basically two commercial providers of airborne IFSAR DEMs, both being US-based. One is Intermap Technologies, who operate a number of X-band sensors, and the other is Fugro EDI whose GeoSAR system employs X- and P-band sensors. In broad terms, both commercial providers offer similar radar imaging and DEM generation services. Both these systems can produce DSMs to around 1m vertical accuracy and with a post spacing of 5m. Also the use of stereo radar imagery as a complement to the process allows a semi-automated DSM-to-DEM conversion.

Airborne IFSAR can record data at a very rapid rate, with swath widths exceeding 10km, and importantly, data collection is not impeded by clouds. As a tool for providing DEM data within the NEDF, airborne IFSAR holds a lot of promise, but it is likely only to be cost effective at the present time for large area DEMs with vertical accuracy of around 1m and horizontal resolutions between 5m and 30m. The absence of any locally based Airborne IFSAR operator further escalates the cost of using this technology. Based on these limitations and the limited number of IFSAR service providers globally, it will not be further considered in this review, however it is recognised that IFSAR offers potential and the use of this technology will need to considered in the future as the number of service providers increases.

2.4 Airborne Laser Bathymetry

Airborne laser bathymetry (ALB) is an attractive, cost-effective and accurate alternative to shipborne sonar recording in conditions of relatively clear water where the depth is less than 50m. From the point of view of maritime charting ALB is a complement rather than competitor to sonar, since it may have insufficient resolution to pick up all sea-floor hazards. From a DTM/DEM generation perspective, however, ALB offers an attractive stand-alone technology for near-shore elevation determination (subject to water clarity) and shoreline mapping. There are a number of operating ALB systems, one of the first and most well-known being the Australian developed Laser Airborne Depth Sounder (LADS), operated by the Australian Hydrographic Service (Royal Australian Navy) and Tenix LADS Corporation. The data acquisition rate of LADS is some 20 times that of vessel-based sonar surveys, and the depth/height accuracy can be as high as 30cm in favourable conditions. The cost of ALB is higher than LIDAR but from every perspective, the cost is much more attractive than sonar alternatives. It is noteworthy in the context of the NEDF that some ALB systems are capable of gathering topographic data but not necessarily simultaneously with near-shore bathymetric data.

2.5 Sonar

Sonar is a well-known acoustics based technique which is most commonly seen in marine echo sounders. In the context of the NDEF initiative, virtually all deeper water bathymetric data which might be integrated into a national DEM will have been gathered by sonar survey systems, and most commonly nowadays multi beam sonar. Sonar systems, and indeed the acoustic technology variations employed for bathymetric surveying will not be further considered in this review. Sonar is still used extensively in the littoral zone up to 2m in depth (there are some areas where ALB is just not suitable for - e.g. surf zones, high turbidity).

3. General Descriptions

3.1 Definitions

Appendix A provides a list of key words and their associated definitions based on the material reviewed. In some instances there are conflicts in definitions of key words or terms. For example the Digital Elevation Model (DEM) in some material was used to define random point data while in others the term referred to gridded ground surface data. The term Digital Terrain Model (DTM) in many cases was interchanged with Digital Elevation Model (DEM). An attempt has been made to provide the internationally accepted or most commonly used definition.

3.2 Data Types

Elevation data can take many forms and include both ground and non-ground surface information. However, when looking from an 'acquisition' through to 'user' perspective, data can broadly be divided into three types:

1) System Data,
2) Primary Data and
3) Derived Data

3.2.1 System Data

System specific data sets are usually produced at the time of acquisition or during the preliminary processing stage prior to production of elevation data.

For ALS/ALB surveys this includes system specific laser return measurements, inertial navigation data, GPS data, ground control, tidal observations, tidal models, etc. For Photogrammetry this may include negatives, image files, inertial navigation data, GPS data, ground control, aerotriangulation data, etc.

These data sets are not normally delivered as part of a contract for the supply of elevation data and they usually remain with the supplier. However, in some circumstances it may be appropriate to include some of these preliminary, system specific, data sets as part of the deliverable to the purchaser.

3.2.2 Primary Data

In the case of an ALS survey this would include reduced elevation data that has been corrected using INU/GPS data and calibrated against test points on the ground. This is usually supplied in LAS or ASCII format. Files may include all returns, first or last returns, ground only returns, non-ground returns, thinned ground returns etc. Data is typically supplied in tiles (e.g. 2km x 2km).

For photogrammetry this would include elevation data consisting of random or regular spot heights and sometimes breaklines. They may also include other data, for example polygons around areas of dense vegetation where the elevation data is likely to be less reliable or non existent.

Primary data sets are generally mandatory and must form part of the deliverable to the Purchaser.

3.2.3 Derivative Data

Derivative data sets are interpolated from the Primary data sets. These can include triangular irregular networks (TINs), contours and regular grid (or DEM) files interpolated from the primary (mass ground point or DTM) data. Other examples include vegetation density, hill shading, slope and aspect grids, overland flow paths, catchment or watershed boundaries, etc.

These data sets are optional and may be requested by the Purchaser.

3.3 Data Models

3.3.1 NDEP Guidelines for Digital Elevation Data

The following elevation types are detailed in the National Digital Elevation Program (NDEP) - Guidelines for Digital Elevation Data Version 1.0. This document can be found at http://www.ndep.gov/NDEP_Elevation_Guidelines_Ver1_10May2004.pdf.

3.3.1.1 Mass Points

Mass points are irregularly spaced points, each with x/y location coordinates and z-values. When generated manually, mass points are ideally chosen so that subtle terrain characteristics (i.e., gradual variations in slope or aspect) are adequately represented in the data. However, when generated automatically; for example, by LIDAR or IFSAR scanners, mass point spacing and pattern depend upon the characteristics of the technologies used to acquire the data. A mass point file containing ground only points is known as a Digital Terrain Model (DTM).

3.3.1.2 Breaklines

A breakline is used to represent a relatively abrupt linear change in the smoothness or continuity of surface slope or aspect. Breaklines may appear within a DTM.

The two most common forms of breaklines are as follows:

A soft breakline ensures that known z-values along a linear feature are maintained (For example, elevations along a pipeline, road centreline or drainage ditch, or gentle ridge), and ensures that linear features and polygon edges are maintained in a TIN (triangulated irregular network) surface model, by enforcing the breaklines as TIN edges. They are generally synonymous with 3-D breaklines because they are depicted with series of x/y/z coordinates. Somewhat rounded ridges or the trough of a drain may be collected using soft breaklines.

A hard breakline defines interruptions in surface smoothness, For example, to define streams, shorelines, dams, ridges, building footprints, and other locations with abrupt surface changes. Although hard breaklines are often depicted as 3-D breaklines, they can also be depicted as 2-D breaklines because features such as shorelines and building footprints are normally depicted with series of x/y coordinates only, often digitised from digital orthophotos that include no elevation data.

3.3.1.3 Triangular Irregular Network (TIN)

A fundamental data structure frequently used to model mass points from photogrammetry and LIDAR collection is the TIN. A TIN is a set of adjacent, non-overlapping triangles computed from irregularly spaced points with x/y coordinates and z-values. The TIN data structure is based on irregularly spaced point, line, and polygon data interpreted as mass points and breaklines and stores the topological relationship between triangles and their adjacent neighbours. The TIN structure is often superior to other data models derived from mass points because it preserves the exact location of each ground point sample.

3.3.1.4 Grids

Grids are the most common structures used for modelling terrain and bathymetric surfaces. There are several advantages to grids over other types of elevation models. A regular spacing of elevations requires that only one point be referenced to the ground. From this point, and using coordinate referencing information supplied with the grid, the location of all other points can be determined. This eliminates the need to explicitly define the horizontal coordinates of each elevation and minimizes the file size. Grids are also efficient structures for data processing. A grid containing ground only data is known as Digital Elevation Model (DEM)

3.3.1.5 Contours

Contours are lines of equal elevation on a surface. A contour is also defined as an imaginary line on the ground, all points of which are at the same elevation above or below a specified reference surface (vertical datum).

3.3.1.6 Cross Sections

Cross sections are a string of x/y/z coordinates along a designated line from point A (zero station) to point B (terminal station). Cross section points may be surveyed conventionally on the ground, to include subsurface terrain, or "cut" from 3-D surfaces such as mass points, TINs, and DEMs for above or below water surfaces.

3.3.1.7 Other Product Types

It may be advantageous to acquire other types of products simultaneously during elevation data capture. For example, recent ortho-imagery is useful during the edit and quality assurance phase of LIDAR processing. These images assist the operator with identifying the causes of surface anomalies and eliminating effects of surface cover during bare-earth processing. If recent images are not available, it may be necessary to capture the data during LIDAR collection. Simultaneous digital imagery capture by ALB systems is now routine for operations during daylight.

3.4 Data Formats

3.4.1 NDEP Guidelines for Digital Elevation Data

The following commentary on data formats comes from the National Digital Elevation Program (NDEP) - Guidelines for Digital Data Version 1.0.

3.4.1.1 Digital Contour Lines and Breaklines

Digital contours and breaklines are vector datasets that are typically produced in any of the following file formats: .DGN, .DO (DLG Optional), .DWG, .DXF, .E00, .MIF/.MID, .SHP, SDTS, or VPF. Other vector file formats may be specified if required.

3.4.1.2 Mass Points and TINs

Mass points are typically produced as ASCII x/y/z files, ASCII files with additional attribute data, LAS, or BIN format. They may be converted and stored in a TIN format, but TIN files are much larger than the mass point files from which they are derived because the TIN structure has to accommodate the topological data structure that exists between each TIN triangle and its adjoining neighbouring triangles. For this reason, users often store the x/y/z point data files in ASCII format, and then reconstruct TINs when needed. The Australian Hydrographic Office generally provides mass point bathymetric data in the Hydrographic Transfer Format (HTF). The HTF format includes headers and footers which provide detailed metadata.

3.4.1.3 Common Lidar Data Exchange Format - .LAS

The Common Lidar Data Exchange Format - .LAS is seeing greater use for the delivery, exchange, analysis and manipulation of lidar data between data providers, data analysts and data users has been identified as an area where substantial improvements could be made by the adoption of an industry-wide binary data format. The .LAS format is now being offered by a large number of commercial providers.

The LAS file format is a public file format for the interchange of LIDAR data between vendors and customers. This binary file format is an alternative to proprietary systems or a generic ASCII file interchange system used by many companies. A problem with proprietary systems is that data cannot be easily taken from one system or process flow to another. In addition, processing performance is degraded because the reading and interpretation of ASCII elevation data can be very slow and the file size can be extremely large, even for small amounts of data. This can be a significant barrier for first-time users of lidar data. Another problem is that all raw data and information specific to the LIDAR data collection is lost. This can inhibit troubleshooting and debugging of problem data sets and limit third-party analysis of data integrity. The .LAS file format is intended to address many of these issues. It is a binary file format that maintains information specific to the LIDAR nature of the data while not being overly complex.

3.4.1.4 Grid Elevations

Grid elevations are typically produced in any of the following file formats: ASCII x/y/z, .BIL, .BIP, .DEM (USGS standard), DTED (NGA standard), ESRI Float Grid, ESRI Integer Grid, GeoTIFF, or .RLE. Other grid elevation formats may be specified if required.

3.5 Horizontal and Vertical Data Standards

3.5.1 NDEP Guidelines for Digital Elevation Data

The following commentary on data formats comes from the National Digital Elevation Program (NDEP) - Guidelines for Digital Data Version 1.0.

3.5.1.1 Vertical Accuracy Requirements

Vertical accuracy is the principal criterion in specifying the quality of digital elevation data, and vertical accuracy requirements depend upon the intended user applications (see Chapter 11, "Digital Elevation Model Technologies and Applications: The DEM Users Manual," ASPRS, 2001). There are five principal applications where high vertical accuracy is normally required of digital elevation datasets: (1) for marine navigation and safety, (2) for storm water and floodplain management in flat terrain, (3) for management of wetlands and other ecologically sensitive flat areas, (4) for infrastructure management of dense urban areas where planimetric maps are typically required at scales of 1:1200 and larger scales, and (5) for special engineering applications where elevation data of the highest accuracy are required. Whereas there is a tendency to specify the highest accuracy achievable for many other applications, users must recognise that lesser standards may suffice, especially when faced with the increased costs for higher accuracy elevation data.

The NDEP recommends that users attempt to assess vertical accuracy requirements in terms of potential harm that could be done to the public health and safety in the event that the digital elevation data fail to satisfy the specified vertical accuracy. Many US states have regulations that require digital elevation data to be produced by licensed individuals to protect the public from any harm that an incompetent data producer may cause. Licensing is generally linked to experience in proving that products are delivered in accordance with the National Map Accuracy Standards, or equivalent.

It is important to specify the vertical accuracy expected for all final products being delivered. For example, when contours or gridded DEMs are specified as deliverables from photogrammetric or LIDAR-generated mass points, a TIN may first be produced from which a DEM or contours are derived. If done properly, error introduced during the TIN to contour/DEM process should be minimal; however, some degree of error will be introduced. Accuracy should not be specified and tested for the TIN with the expectation that derivatives will meet the same accuracy. Derivatives may exhibit greater error, especially when generalization or surface smoothing has been applied to the final product. Specifying accuracy of the final product(s) requires the data producer to ensure that error is kept within necessary limits during all production steps.

If specific accuracy is to be met within other ground cover categories, “supplemental” accuracies should be stated for individual or multiple categories. It may be preferable to specify a different vertical accuracy in forested areas, for example, than in tall grass. Supplemental accuracy requirements should be explained in attached documentation.

3.5.1.2 Horizontal Accuracy Requirements

Horizontal accuracy is another important characteristic of elevation data; however, it is largely controlled by the vertical accuracy requirement. If a very high vertical accuracy is required then it will be essential for the data producer to maintain a very high horizontal accuracy. This is because horizontal errors in elevation data normally (but not always) contribute significantly to the error detected in vertical accuracy tests.

Horizontal error is more difficult than vertical error to assess in the final elevation product. This is because the land surface often lacks distinct (well defined) topographic features necessary for such tests or because the resolution of the elevation data is too coarse for precisely locating distinct surface features. For these reasons, the NDEP does not require horizontal accuracy testing of elevation products. Instead, the NDEP requires data producers to report the expected horizontal accuracy of elevation products as determined from system studies or other methods.

3.5.2 Australian Horizontal and Vertical Datum and Geoid Models

The Geocentric Datum of Australia 1994 (GDA94) is Australia's standard horizontal datum and should be used for all land surveys. GDA94 is defined by the International Terrestrial Reference Frame (ITRF) at epoch 1st January 1994. Hydrographic surveys commonly refer to the World Geodetic System 1984 (WGS84), a world system that is also based on the ITRF. WGS84 is generally more applicable to hydrographic data that is typically of lower horizontal accuracy and used by shipping that needs a world reference system rather than a national one.

It is recommended that all surveys be coordinated in terms of the International Terrestrial Reference Frame (ITRF) at a specified epoch. For example ITRF92 held fixed at 1st January 1994.

The Australian Height Datum (AHD) is the official vertical datum of Australia and should be used for all land surveys. In the case of bathymetric surveys Ellipsoidal heights must be reduced to AHD heights using the AUSGeoid98 model. Where survey materials refer to other datum's such as Lowest Astronomical Tide (LAT) a connection must be established to allow conversion to AHD.

AUSGeoid98 is the latest in a series of national geoid models for Australia produced by Geoscience Australia. It uses the latest available data and techniques. It consists of a 2' by 2' grid (approximately 3.6km) of geoid-ellipsoid separations (N Values) in terms of the GRS80 ellipsoid, which is also used for GDA94. These values are suitable for use with GPS and will significantly improve the achievable accuracy of AHD height transfer by GPS.

Further information can be found through the Intergovernmental Committee on Survey and Mapping site http://www.icsm.gov.au/gda/gdatm/index.html.

3.5.2.1 The Need for Common Reference Frames

The ITRF (or datum linked to the ITRF at a specific epoch, like GDA94 or WGS84) provides the obvious horizontal reference frame; it is the vertical reference frame that will no doubt generate the most discussion. The issues around vertical datum are more complex and are touched on in the Science Case prepared the CRCSI and included below.

The orthometric height reference for Australia, the Australian Height Datum (AHD) was established nearly 40 years ago. In order to tie the geodetic levelling data, which is by nature referenced to a geopotential surface, to mean sea level, the MSL values at 30 tide station locations around the country were held fixed. AHD thus corresponded well to MSL in 30 locations but the non-linear variations between the geoid (equipotential surface) and local MSL beyond the region of these 30 tide gauges has yet to be comprehensively modelled. This might well be of minor consequence for non-coastal regions, but the MSL-AusGeoid separation can amount to almost 1m in Northern Australia and is in many places in excess of 70cm. Compounding the difficulty in tying the bathymetric data to MSL and subsequently to AHD and AusGeoid98 is the fact that lowest astronomical tide (LAT) for a particular chart, or portions thereof, might well have been determined with respect to local tide gauge information, independent of the MSL implicit in elevations with respect to AHD. Some such tide gauges, which currently number 100 or more around the Australian coastline, may well have levelling ties to AHD, but many do not. The issue of tying bathymetry datum into a DEM reference datum on a national basis is particularly vexing, at least at the resolution level of 10-30cm, which would correspond to the highest vertical accuracy level within the National DEM.

The Land Information New Zealand Research Project (P029 – Data Integration Using Ellipsoidal Heights) looked at combining land and bathymetric data into a common data set based on an ellipsoidal datum. The International Hydrographic Organisation (IHO) also makes the suggestion in their IHO Standards for Hydrographic Surveys (SP44) that tidal observations be related to a geodetic reference frame based on the International Terrestrial Reference System (ITRS) (e.g. WGS84) to allow for bathymetric data to be better exploited in the future.

Both ALS and photogrammetric acquisition technologies use inertial navigation systems linked to GNSS to control position. As a result, by default, all land data is collected by reference to an ellipsoidal datum and adjusted, generally using AUSGeoid98, to orthometric (AHD) heights via connections to local survey control. ALB on the other hand, measures depth from the surface and therefore the vertical datum is derived from tidal observations. Given that many tide gauges are not connected to AHD creates issues if ellipsoidal heights/depths are required. Nevertheless, the ellipsoid is a logical datum to use as long as users can reliably transform from the ellipsoidal datum to either AHD, LAT or other project specific vertical datum.

Two programs are currently underway that will have significant impact in this area. Firstly, there is a program to connect over 130 continuous tide gauges (a combination of Australia Tsunami network and State run gauges) to ITRF and AHD. Secondly, a new geoid model is being developed that will allow improved translation between AHD and the ellipsoid. Once completed, these programs will go some way to resolving the problems with translating data between ITRF ellipsoid, AHD and LAT. Nevertheless, this is an area that will require further discussion and careful consideration in the future.

3.6 Testing and Reporting of Accuracy

3.6.1 NDEP Guidelines for Digital Elevation Data

The following commentary on data formats comes from the National Digital Elevation Program (NDEP) - Guidelines for Digital Data Version 1.0.

3.6.1.1 Fundamental Accuracy

The fundamental vertical accuracy of a dataset must be determined with check points located only in open terrain, where there is a very high probability that the sensor will have detected the ground surface. The fundamental accuracy is the value by which vertical accuracy can be equitably assessed and compared among datasets. Fundamental accuracy is calculated at the 95-percent confidence level as a function of vertical RMSE.

3.6.1.2 Supplemental and Consolidated Vertical Accuracies

In addition to the fundamental accuracy, supplemental or consolidated accuracy values may be calculated for other ground cover categories or for combinations of ground cover categories. Because elevation errors often vary with the height and density of ground cover, a normal distribution of error cannot be assumed and, therefore, RMSE cannot be used to calculate the 95-percent accuracy value. Consequently a nonparametric testing method (95th Percentile) is employed for supplemental and consolidated accuracy tests.

95th Percentile

For supplemental and consolidated accuracy tests, the 95th percentile method shall be employed to determine accuracy. The 95th percentile method may be used regardless of whether or not the errors follow a normal distribution and whether or not errors qualify as outliers. Computed by a simple spreadsheet command, a "percentile" is the interpolated absolute value in a dataset of errors dividing the distribution of the individual errors in the dataset into one hundred groups of equal frequency. The 95th percentile indicates that 95 percent of the errors in the dataset will have absolute values of equal or lesser value and 5 percent of the errors will be of larger value. With this method, Accuracy is directly equated to the 95th percentile, where 95 percent of the errors have absolute values that are equal to or smaller than the specified amount.

Prior to calculating the data accuracy, these steps should be taken:

- Separate checkpoint datasets produced according to important variations in expected error
- Edited collected checkpoints to minimize errors
- Interpolate elevation surface for each checkpoint location
- Identify and eliminate systematic errors and blunders

Once these steps are completed, the fundamental vertical accuracy must be calculated. If additional land cover categories are to be tested, supplemental and/or consolidated accuracies may also be computed.

Fundamental Vertical Accuracy Test

Using check points in open terrain only:

1) Compute the vertical $RMSE_z = sqrt[\Sigma(z_{data\ i} - z_{check\ i})^2 /n]$
2) Compute $Accuracy_z = 1.9600 \times RMSE_z$ = vertical accuracy at 95 percent confidence level.
3) Report $Accuracy_z$ as **"Tested ______(meters) fundamental vertical accuracy at 95 percent confidence level in open terrain using $RMSE_z$ x 1.9600."**

The following accuracy statements are optional. When used they must be accompanied by a fundamental vertical accuracy statement. The only possible exception to this rule is the rare situation where accessible pockets of open terrain (road clearings, stream beds, meadows, or isolated areas of exposed earth) do not exist in sufficient quantity for collecting the minimum test points. Only in this instance may supplemental or consolidated accuracies be reported without an accompanying fundamental accuracy. However, this situation must be explained in the metadata. Most likely, when producing an elevation surface where little or no accessible open-terrain exists, the data producer will employ a collection system that has been previously tested to meet certain accuracies and a "compiled to meet" statement would be used in lieu of a "tested to" statement.

Supplemental Vertical Accuracy Tests

When testing ground cover categories or combinations of categories excluding open terrain:

1) Compute 95th percentile error (described above) for each category (or combination of categories).
2) Report **"Tested ______(meters) supplemental vertical accuracy at 95th percentile in (specify land cover category or categories)"**
3) In the metadata, document the errors larger than the 95th percentile. For a small number of errors above the 95th percentile, report x/y coordinates and z-error for each QC check point error larger than the 95th percentile. For a large number of errors above the 95th percentile, report only the quantity and range of values.

Consolidated Vertical Accuracy Tests

When 40 or more check points are consolidated for two or more of the major land cover categories, representing both the open terrain and other land cover categories (for example, forested), a consolidated vertical accuracy assessment may be reported as follows:

1) Compute 95th percentile error (described above) for open terrain and other categories combined.
2) Report **"Tested ______(meters) consolidated vertical accuracy at 95th percentile in: open terrain, (specify all other categories tested)"**
3) In the metadata, document the errors larger than the 95th percentile. For a small number of errors above the 95th percentile, report x/y coordinates and z-error for each QC check point error larger than the 95th percentile. For a large number of errors above the 95th percentile, report only the quantity and range of values.

If the fundamental accuracy test fails to meet the prescribed accuracy, there is a serious problem with the control, collection system, or processing system or the achievable accuracy of the production system has been overstated. If a systematic problem can be identified, it should be corrected, if possible, and the data should be retested.

3.6.1.3 Reporting Vertical Accuracy of Untested Data – NDEP Requirements

Use the 'compiled to meet' statement below when the above guidelines for testing by an independent source of higher accuracy cannot be followed and an alternative means is used to evaluate accuracy. Report accuracy at the 95 percent confidence level for data produced according to procedures that have been demonstrated to produce data with particular vertical accuracy values as:

> *Compiled to meet ___ (meters) fundamental vertical accuracy at 95 percent confidence level in open terrain*

The following accuracy statements are optional. When used they must be accompanied by a fundamental vertical accuracy statement.

> For ground cover categories other than open terrain, report:
>
> *Compiled to meet ___ (meters) supplemental vertical accuracy at 95th percentile in (specify land cover category or categories)*
>
> For all land cover categories combined, report:
>
> *Compiled to meet ___ (meters) consolidated vertical accuracy at 95th percentile in: open terrain, (list all other relevant categories)*

3.6.1.4 Testing and Reporting Horizontal Accuracy – NDEP requirements

The NDEP does not require independent testing of horizontal accuracy for elevation products. When the lack of distinct surface features makes horizontal accuracy testing of mass points, TINs, or DEMs difficult or impossible, the data producer should specify horizontal accuracy using the following statement:

> *Compiled to meet ___ (meters) horizontal accuracy at 95 percent confidence level*

The expected accuracy value used for this statement must be equivalent to the horizontal accuracy at the 95 percent confidence level = $Accuracy_r = RMSE_r \times 1.7308$. This accuracy statement would be appropriate for the following situation. LIDAR vendors normally advertise that their systems deliver data with an $RMSE_r$ of approximately 1 meter. Such accuracy is difficult to verify, except for calibration test ranges where coordinates of the four corners of rooftops of several buildings are accurately surveyed (in addition to ground control points surrounding these buildings) and compared with LIDAR calibration flights flown over the calibration area from multiple directions. The horizontal accuracy with which these building breaklines can be determined provides a good estimate of the achievable horizontal accuracy of LIDAR datasets obtained under similar conditions.

For very high-resolution elevation data where well-defined surface features such as narrow stream junctions, small mounds, or depressions can be identified, it may be possible and desirable to actually test and report the resulting horizontal accuracy. It may also be possible to independently test the horizontal accuracy of LIDAR and IFSAR elevation surfaces if the corresponding intensity data is earth-referenced by the same process used for the elevation data, and if the intensity values enable a sufficient number of clearly defined planimetric features to be located. For example, white numbers and lines on airport runways and painted stripes on roads are often visible on LIDAR intensity images. When this occurs, it is possible to survey those features on the ground and compare their horizontal coordinates with those derived from the LIDAR intensity images. In this way, LIDAR intensity images become comparable to photogrammetric images for which $RMSE_r$ can be computed in accordance with standard NSSDA testing procedures. Results of horizontal accuracy tests should be reported using the following statement:

Tested ___ (meters) horizontal accuracy at 95 percent confidence level.

3.6.1.5 Accuracy Assessment Summary

Providers of digital elevation data use a variety of methods to control the accuracy of their products. Photogrammetrists use survey control points and aerotriangulation to control and evaluate the accuracy of their data. LIDAR and IFSAR providers may collect hundreds of static or kinematic control points for internal quality control and to adjust their datasets to these control points. To the degree that such control points are used in a fashion similar to control for aerotriangulation, for which the LIDAR or IFSAR datasets are adjusted to better fit such control points, then the data providers may use the "compiled to meet" accuracy statements listed above. With mature technologies such as photogrammetry, users generally accept "compiled to meet" accuracy statements without independent accuracy testing. However, with developing technologies such as LIDAR or IFSAR, users often require independent accuracy tests for which accuracy reporting is more complex, especially when errors include "outliers" or do not follow a normal distribution as required for the use of RMSE in accuracy assessments. Because of these complexities, the NDEP mandates the "truth in advertising" approach, described above, that reports vertical accuracies in open terrain separately from other land cover categories, and that documents the size of the errors larger than the 95th percentile in the metadata.

3.6.1.6 Relative Vertical Accuracy

The accuracy measurement discussed above refers to absolute vertical accuracy, which accounts for all effects of systematic and random errors. For some applications of digital elevation data, the point-to-point (or relative) vertical accuracy is more important than the absolute vertical accuracy. Relative vertical accuracy is controlled by the random errors in a dataset. The relative vertical accuracy of a dataset is especially important for derivative products that make use of the local differences among adjacent elevation values, such as slope and aspect calculations. Because relative vertical accuracy may be difficult to measure unless a very dense set of reference points is available, this NDEP guideline does not prescribe an approach for its measurement. If a specific level of relative vertical accuracy is a stringent requirement for a given project, then the plan for collection of reference points for validation should account for that. Namely, reference points should be collected at the top and bottom of uniform slopes. In this case, one method of measuring the relative vertical accuracy is to compare the difference between the elevations at the top and bottom of the slope as represented in the elevation model vs. the true surface (from the reference points). In many cases, the relative vertical accuracy will be much better than the absolute vertical accuracy, thus the importance of thoroughly measuring and reporting the absolute accuracy, as described above, so the data users can have an idea of what relative accuracy to expect.

3.7 Quality Assurance Methods and Reporting

Generally the onus is on the contractor to verify that the accuracy standards and other requirements have been met. To provide confidence to the Purchaser it is common to require the Contractor to prepare a Quality Assurance Plan.

Other quality assurance deliverables include flight plans, reports on ground control and check points, connections to state control and reports on accuracy tests. Given that Photogrammetry is a well understood technology accuracy testing is generally not required. Nevertheless there is still a requirement for accuracy reporting through the provision supporting documentation on GPS reductions, ground control and aerotriangulation results which can be used to show that accuracy expectations have been met.

Recommendations for quality assurance methods and documentation are provided in the guidelines section (Section 5.).

3.8 Coordinate Systems and Units

Project-based users are generally more comfortable dealing with grid coordinate systems (east, north and zone) rather than geographical coordinates (latitude and longitude). Often elevation acquisition projects also include the acquisition and production of orthophoto data to help classify the elevation data and sort out ground and non ground returns. The scale of the x and y axis with geographic coordinates are different away from the equator and the difference increases with latitude. Orthophoto data is difficult to re-project from geographic to grid on the fly, so to avoid these distortions Map Grid of Australia 1994 (MGA94) coordinates in metres as defined by GDA94 are generally preferred. Also, due to the number of decimal places required to record position in decimal degrees it may not possible to accurately record data in geographical coordinates within the LAS format.

3.9 Metadata Standards

Metadata is structured information that describes information or services. The information in the metadata enables people to find, manage, control, understand and preserve their data assets. A metadata standard improves the discoverability, utility and management of resources by adopting standard and structured descriptions, enabling organisations to improve the visibility and accessibility of their resources.

A metadata standard is a key component of an organisation's information management. By investing time and effort to provide quality and consistently structured metadata, organisations can significantly increase the return on investment of their assets.

Creating and maintaining quality metadata is a significant organisational commitment; however, it should not be seen as a major burden on resources or business processes. Organisations that conform to the ANZLIC Metadata Profile should find that the creation and maintenance of metadata becomes an integral and seamless component of their business processes.

The ANZLIC Metadata Profile will facilitate efficient access to descriptions of information resources, and in particular geographic (or spatial) data. Adoption of, and compliance with, the ANZLIC Metadata Profile will ensure a consistent approach to spatial information resources throughout Australia and New Zealand. This will help people and applications to locate resources without detailed knowledge of the data or resources being sought or an understanding of complex jurisdictional or organisational structures.

The use of standardised descriptions will enable online search engines to process queries more efficiently. This helps to ensure that people and applications conducting searches are presented with relevant and meaningful results. Custodians of geospatial data assets will benefit as their information resources become discoverable by a much wider range of potential users, at negligible cost, than could ordinarily be found through traditional marketing and distribution channels.

The ANZLIC Metadata Profile defines the appropriate content of metadata for resources and how this metadata will be implemented throughout Australia and New Zealand. The Profile has been derived from the base standard: AS/NZS ISO 19115:2005, *Geographic information - Metadata* (including changes made in ISO 19115:2003/Cor.1:2006, *Geographic information - Metadata –Technical - Corrigendum 1*).

Specific details relating to the ANZLIC Metadata Profile can be found on the ANZLIC site at: http://www.anzlic.org.au/metadata/

A summary of the recommended elements, specific to elevation data provided in Section 5.

3.10 Surface Treatment Factors

3.10.1 NDEP Guidelines for Digital Elevation Data

The following commentary comes from the National Digital Elevation Program (NDEP) - Guidelines for Digital Data Version 1.0.

The surface types presented previously in section three, although useful for general discussion, define only broad categorizations of elevation surface characteristics. Merely specifying a “bare-earth” or “top surface” elevation model does not sufficiently define how all terrain features are to be represented in the final surface. For example, specifying a bare-earth surface usually implies that elevations on buildings and vegetation should be removed but it does not necessarily imply that overpasses and bridges should be removed from the surface.

The intended application of an elevation model typically dictates the particular terrain features to be represented and how those features are to be depicted. Conventions for depicting various features have changed over time. Because of the increasing variety of applications for elevation models, the trend is moving away from strict standardization of how features should be depicted and is moving toward customisation for the primary data application.

The customer should always provide explicit instructions for representation of the features discussed below or any other terrain feature that might require special treatment. Data producers should document special feature treatments in the metadata.

3.10.1.1 *Hydrography*

Hydro-enforcement is also explained in the introductory chapter of ASPRS, 2001. Hydro enforcement, performed to depict the flow of water in digital elevation models, is required when remote sensing systems capture man-made structures as well as natural irregularities in the terrain, including shorelines that appear to undulate up and down. There are different forms of hydro-enforcement that may include any or all of the following: levelling of ponds, lakes and reservoirs that ought to be flat instead of undulating; rivers, streams and narrow drains that ought to depict the downward flow of water instead of undulating up and down; manmade structures that actually impede the flow of water (in the case of buildings) as opposed to other structures that only appear to impede the flow of water (in the case of bridges and overpasses); and sinkholes and depressions that actually exist as opposed to artificial puddles that fail to depict natural outlet drains or culverts. Each of these topics is further explained in the following sections.

- Water body areas are naturally occurring areas of constant elevation, provided that currents and other physical forces do not significantly alter the water surface. Oceans, bays, or estuaries at mean sea level were traditionally assigned an elevation value of zero, although more recent datums (such as NAVD 88) properly account for the physical situation that mean sea level actually equates to different elevations along different coastlines because of variations in ocean topography, currents, and winds. Ponds, lakes and reservoirs are assigned their known or estimated elevations, and their shorelines may be treated as breaklines with constant elevation. The horizontal position and shape of water body shorelines is normally determined from digital orthophotos or other georeferenced image source.
- Rivers and streams are also naturally occurring but normally have variable elevations to depict the downward flow of water. These features are generally wide enough that both shorelines can be represented in the elevation model. The horizontal position and shape of the double shorelines is normally determined from digital orthophotos or other georeferenced image source. These shorelines are also treated as breaklines in one of several ways.
  - When contour lines exist, polygons can be established, bounded by the dual shorelines and upstream and downstream crossing contours, with a uniform elevation assigned to the entire polygon to match that of the lower crossing contour. This is a simple approach but causes the drainage polygons to be "stair-stepped" according to the contour interval.
  - When contour lines exist, the crossing contours can be used to establish the elevations at discrete points along the breaklines that delineate the double shorelines. Elevations are then linearly interpolated for each shoreline vertex between the discrete points. These shoreline breaklines are now 3-D breaklines in which the elevation gradually decreases from the upstream contour elevation to the downstream contour elevation. This is a form of hydro-enforcement. The elevations of midstream points are then interpolated from the surrounding shoreline elevations.

  - When contour lines do not exist, the horizontal position and shape of the double shorelines may still be determined from digital orthophotos or other georeferenced image source. Then, alternative methods may be used to estimate the water elevations at various locations along the stream for creating sloping 3-D shorelines. With LIDAR, for example, there are normally some pulses that reflect off of water ripples. When there are a dozen or more returns in water areas that depict consistent elevations, these values may be used to estimate the water elevation at those locations. Alternatively, the lowest elevations along stream banks at selected intervals or locations can be used for the same purpose, and then interpolated to depict continuously sloping shorelines as 3-D breaklines.

- Narrow Drains. When continuous downstream drainage is desirable, narrow drainage channels may be enforced by a single 3D breakline. Breakline enforcement in this situation ensures that no false dams or puddles are represented in the model. Such erroneous features commonly occur in elevation surfaces captured or represented by randomly or uniformly spaced discrete points. A drainage breakline, captured as described under Rivers and Streams, may be used to represent the actual drain channel in a TIN or may be used to assign a lowest local-area elevation to the nearest point in an elevation grid.

3.10.1.2 Man-made Structures

- Buildings. For most applications, a bare earth DEM means that elevation points on buildings (and trees) are removed, basements are neglected, and the terrain where the building exists is smoothed and interpolated from ground elevations surrounding the buildings. However, for hydraulic modeling of floodplains, elevations of buildings may be retained to show that buildings occupy spaces where floodwaters flow and they also impede the natural flow of flood waters.

- Bridges. Because most aerial and satellite sensors detect the first reflective surface, bridge surfaces and supporting structures are represented in the original source data. When the surface is intended primarily for road network modeling, such representation may be desirable. If so, the desired bridge structure (for example, road surface without superstructure) should be specifically requested for the elevation model. If, however, water modeling is the primary purpose for the data, it may be preferable to request that elevations falling on bridge surfaces be edited out and replaced with a logical stream-flow surface.

- Overpasses present the same issues as bridges. Desired treatment of overpasses should be specifically documented.

- Culverts. Drainage through small culverts is typically not depicted in elevation models. Whereas bridges and large concrete box culverts are obvious on most images, metal pipe culverts are often concealed, making it difficult for hydro-enforced DEMs to reflect all drainage features associated with roads and railroads. For some large-scale drainage applications it may be desirable to model the drainage surface of the culvert, but usually the cost of collecting necessary information on culverts significantly outweighs the benefits of this type of hydrographic enforcement. Large concrete culverts may be more easily identified from project photography allowing the underlying drain surface to be affordably modeled.

3.10.1.3 Special Earthen Features

Special earthen features are natural features of the earth that require special consideration. These include:

- Sinkholes should be verified whenever possible and should be depicted as depressions in the elevation model.
- Natural bridges. Typically, the top surface of a natural bridge is represented in the model. When water flow modeling is the primary application for an elevation surface, it may be preferable to treat natural bridges similar to man-made bridges and depict the stream surface below the bridge.

3.10.1.4 Artefacts

An important quality factor for a DEM is its "cleanness" from artefacts. Artefacts are detectable surface remnants of buildings, trees, towers, telephone poles or other elevated features in a bare-earth elevation model. They may also be detectable artificial anomalies that are introduced to a surface model via system-specific collection or processing techniques.

The majority of artefacts are normally removed by automated post-processing. However, the final cleaning of the last 10 percent of the artefacts may take 90 percent of the post-processing budget. Because of costs, users sometimes accept a moderate amount of artefacts, whereas others find artefacts totally unacceptable. Cleanness can be specified as a percentage of the total area. However, quantifying and testing to an acceptable threshold of artefacts is a difficult, subjective, and time-consuming process. Because artefacts are so difficult to quantify, it is best if the user discusses with the data provider the types of artefacts, which artefacts are acceptable (if any), and which artefacts are unacceptable and must be eliminated.

3.10.1.5 Special Surfaces

- No-Data Areas. Specific information needs to be provided by the data producer that differentiates whether the lack of data is intentional or unintentional. Some indication must be provided outside of the data model (for example in the project metadata or as a polygon) that describes where these areas are in the elevation deliverable. Examples of intentional No-Data Areas would be areas outside the project area, large bodies of water on DEM tiles that are deliberately not collected to lower production costs or areas of sensitive information such as military bases. Unintentional No-Data Areas are those where high winds, pilot or navigation errors cause gaps between adjoining strips. For both intentional and unintentional No-Data Areas a unique value, such as –32768, may be used to flag the areas.
- Suspect areas. Areas of elevations for which there is a relatively low degree of confidence. They are areas where the producer questions whether the elevations compiled or sensed represent the bare earth. Some indication must be provided outside of the data model (for example in the project metadata or as a polygon) that describes where these areas are in the elevation deliverable.

4. Recommended Classification of Surveys

The Science Case developed for the review of the National Elevation Data Framework (http://www.anzlic.org.au/nedf.html) highlighted that any major new data acquisition programs that are to be undertaken within the foreseeable future are likely to involve one of a finite number of sensor technologies. Three ranges of vertical resolution are readily realisable with today's technology, these being: 10-30cm; 50cm-2m, and 5-15m. These elevation acquisition technologies, namely photogrammetry, Lidar and IFSAR have been summarised in section 2.

Given that survey costs are generally directly proportional to resolution we suggest that elevation surveys may be classified into four broad categories to assist planning in relation to different accuracy requirements

These are defined below and in table 1 which summaries the suggested requirements for each and typical applications for which each may suitable.

4.1 Special Order

Suitable for special high accuracy elevation surveys required for engineering or infrastructure design purposes. Special Order surveys would typically be better than 10cm in vertical accuracy.

This is difficult, though not impossible, to achieve with ALS due to limitations in capacity to measure the location and tilts of the sensor at time of acquisition. These accuracies can however be achieved using photogrammetric techniques with large scale aerial photography because sensor position and tilts can be determined post flight through an aerotriangulation process.

4.2 Category 1

This Category is achievable from both ALS (excluding ALB) and photogrammetric techniques. Accuracies of around 10-15cm are close to the best that can be expected from ALS. Used when the highest practical accuracy for large areas is required. Suitable for multiple uses including:

- modelling of inundation from floods or storm surges in areas of high value assets,
- production of 0.5m contours and
- high resolution grid (1m DEM) files

4.3 Category 2

This Category is achievable from both ALS (including ALB) and photogrammetric techniques. It provides a compromise between cost and accuracy. Suitable for multiple uses including:

- in the case of ALB, modelling under clear water where the depth is less than 50m and clear of the surf zone,
- modelling of inundation from floods or storm surges in areas with minimal infrastructure,
- production of 1m contours and
- medium resolution grids (2m DEM) files

Note the position accuracy of airborne laser bathymetry is affected by a number of factors including:

- the positioning accuracy of the aircraft
- the pointing accuracy of the scanning system
- the footprint size of the laser beam which is is 2.5 to 3 metres in diameter at the water surface; this is necessary to achieve the required power to penetrate the water column and still maintain laser eye safety.
- the footprint size gradually increases with depth due to the scattering of light in the water column.
- the affect of sea state on refraction at the water surface.

As a result the positional accuracy of the airborne LIDAR bathymetric surveys is generally considered to be better than +/- 5 metres (95% confidence), equivalent to IHO Class 1. This is +/- 2m at 1 sigma. As a result a more relaxed horizontal accuracy has been applied for ALB surveys.

4.4 Category 3

- Although photogrammetric techniques are suitable for accuracies much lower than +/- 50cm, this represents the least accuracy we would expect from an ALS survey. This Category provides for maximum coverage at minimal cost for ALS surveys. Suitable for multiple uses including:
- in the case of ALB, modelling under clear water where the depth is less than 50m and clear of the surf zone,
- modelling of large areas for preliminary route assessment,
- production of 2m contours and
- medium resolution grids (5m DEM) files

As discussed above in Section 4.3, due to nature of ALB surveys a more relaxed horizontal accuracy requirement of +/-5m has been applied for ALB surveys

4.5 Classification Summary

Category	Special	1	2	3
Typical Use	Surveys required for engineering and infrastructure design	Modelling of inundation from floods or storm surges in areas of high value assets	Modelling of inundation from floods or storm surges in areas with minimal infrastructure.	Modelling of large areas for preliminary route assessment.
Vertical Accuracy (RMSE, 1 sigma or 68%)	<0.1m	+/-0.15m	+/-0.3m	+/-0.5m
Horizontal Accuracy (RMSE, 1 sigma or 68%)	<0.3m (typically 2 or 3 times the vertical accuracy)	+/-0.45m	+/-0.9m (+/-2m ALB)	+/-1.5m (+/-5m ALB)
Recommended contour interval	<0.3m	0.5m	1m	2m
Minimum grid cell size (DEM)	<1m	1m	2m (5m ALB)	5m (10m ALB)
Maximum tile size	1km x 1km	2km x 2km	2km x 2km	4km x 4km

Table 1 – Uses, Specifications and Accuracy of the Categories of DEMs

Accuracy is specified in terms of Root Mean Square Error (RMSE) and refers to points/measurements on clear ground or seabed in the case of ALB.

5. Guidelines for the Acquisition of Digital Elevation Data

The following guidelines for the acquisition of elevation data suitable for inclusion in a National Elevation Data Set have been prepared for ALS, ALB and photogrammetric methods only. It is expected that other technologies like IFSAR will be the subject of a separate review, and will be incorporated into the guidelines in the near future. Addition specifications relating to derived products such as vegetation canopy height models and buildings are also likely to be addressed in future revisions.

The guidelines have been developed by the Intergovernmental Committee on Surveying and Mapping Elevation Working Group under the auspices of the National Elevation Data Framework (NEDF) initiative currently under development.. This Working Group involves experts from State and Federal mapping agencies, industry and academia.

The guidelines represent a first cut in the preparation of 'best practice' guidelines for Australia and have been prepared as an outcome of a review of existing available material from around Australia and selected countries supplied by various agencies to Geoscience Australia and via an internet search for relevant material. Moreover, rapid advances in Lidar and other high resolution terrain mapping technologies may see the guidelines presented here quickly dated and consequently, there will be a requirement for regular review and update.

These guidelines have been endorsed by the Intergovernmental Committee on Surveying and Mapping and are considered a living document. If you have any questions or comments on the guidelines please email icsm@ga.gov.au.

5.1 Airborne Laser Scan (ALS) Survey

5.1.1 General Guidelines

	General Guidelines	Description
5.1.1.1	Category of Survey	Special Order ☐ Category 1 ☐ Category 2 ☐ Category 3 ☐
5.1.1.2	Coverage	Provide a full description to define the extent of the survey
5.1.1.3	Horizontal Datum	All surveys must be coordinated in terms of the International Terrestrial Reference Frame (ITRF) at a specified epoch. For example: GDA94 is International Terrestrial Reference Frame 1992 (ITRF92) held fixed at 1st January 1994.
5.1.1.4	Vertical Datum	All elevation data must be supplied as heights above/below Australian Height Datum (AHD). Ellipsoid heights must be reduced to AHD heights using AUSGeoid98 model. Other height datums may also be specified in addition to the above: Ellipsoid height (above/below GDA94) ☐ Ellipsoid height (above/below ITRF @ epoch___)…………………….. ☐ Other (please specify)……………………………………………………. ☐
5.1.1.5	Map Projection	All elevation data must be supplied in terms of the Map Grid of Australia (MGA) coordinate system. Other coordinate systems may also be specified in addition to the above: Geographical Coordinates…………………………………………………………... ☐ Other (please specify)……………………………………………………. ☐
5.1.1.6	Survey Control	Horizontal and vertical position must be controlled by reference to existing approved permanent survey marks with established ITRF coordinates and accurate levels on a datum specified above. Survey to establish new control should use techniques to achieve a minimum standard of: Horizontal: Class B Vertical: Class B or LD, As described in the ICSM publication SP1. Elevation data must be tested and corrected for systematic errors to ensure accuracy specifications are met. Documentation should describe how this has been achieved.
5.1.1.7	Data Tiling	All Primary data sets should be supplied in predefined tiles. *(tiles based on the MGA coordinate system or geographicals).*
5.1.1.8	Ortho-Rectified Imagery	Is Ortho-rectified aerial imagery required?………………………....yes/no Resolution (please specify)………………………………………………… Spatial Accuracy (please specify)…………………………………………..
5.1.1.9	Special Considerations	Purchaser to provide details of any special considerations applicable to the project. For example: All coastal data should be acquired at low tide (+/-2hrs) on any day. ☐ Capture of breaklines from ortho-rectified imagery?...………………..yes/no Floodplain / wetland data to be captured outside of times of significant surface inundation due to natural events and /or regulated environmental flows Provide details (eg water bodies, drainage features, roads, etc) ………………………………………………………………………………… Other special considerations (please specify) ☐ ………………………………………………………………………………………… ………………………………………………………………………………

5.1.2 Quality Assurance Documentation

It is expected the documentation will provide detailed information on systems to be used in the survey, including all equipment details and relevant calibration certification (manufacturer and prior to survey), operational information to be captured during the survey (eg. mission date, time, flight altitude, sensor sampling configurations), maps of survey coverage and boundary overlaps, flight plans and any other pertinent survey information. It should also include the methodology for determining accuracy and an independent accuracy test.

	QA Deliverables	Description
5.1.2.1	Quality Assurance Plan	The Contractor shall prepare and submit to the Purchaser a Quality Assurance Plan that conforms to an identified management system and generally complies with ISO 9001. The plan must address the organisation and management of the project, work procedures, environmental considerations, safety and risk control and test procedures. The Quality Assurance Plan must detail the procedures to be used in verifying that the deliverables meet the required specification. Approval by the Purchaser to commence the aerial survey is contingent on acceptance in writing by the Purchaser or a Quality Assurance Plan.
5.1.2.2	Pre-Survey Quality Assurance Deliverables	Proposed ALS flight plan Details of proposed calibration and test sites.
5.1.2.3	Post-Survey Quality Assurance Deliverables	Final ALS flight plan Details of calibration and test sites. Contractors report comprising a technical discussion addressing how each of the contract specifications has been met, a statement of consistency with any identified standards, results of accuracy tests, metadata statements and extra-ordinary issues that may have affected the nature or delivery of the project.

5.1.3 Quality Checking Documentation

For all ALS surveys the contractor is required to carry out an independent accuracy test to verify that fundamental accuracy specifications have been met and to provide information on the supplementary accuracy and therefore reliability of the elevation data in various land cover categories. The total number of land cover categories and check points within each will be covered in the specific project brief but the following land cover categories and check point numbers should be used as guide.

Category	Description	Total Number of Test Points
1	Clear ground	40
2	Grass or low lying bushes	40
3	Scrubland, woodland and open forest	40
4	Dense vegetation	40

The above land cover types are indicative only and should be modified to take into account the proposed application of the data, size of the area, nature of the terrain and the expected land cover types.

	QA Deliverables	Description
5.1.3.1	Quality Check Report	Full report detailing the coordinates of test points and their interpolated height values from the elevation data. Full statistical analysis detailing RMSE (likely uncertainty) of the data within each specified land cover type.

5.1.4 Elevation Data Deliverables

The primary elevation data from ALS surveys are mass points, some of which form a DSM while others form a DTM. It is usual to require the delivery of all return data in either a LAS or ASCII format. It is also standard practice to filter the point data to separate out 'ground' and 'non-ground' points into separate data sets. The 'non-ground' data set can in turn be further classified, usually with the assistance of ortho-rectified imagery, into 'vegetation' and 'structures/buildings' (sometimes further classified by height above ground). Also, to minimise file size, it is common practice to specify the delivery of a 'thinned' ground point data set. This is achieved by the removal of superfluous points that do not significantly add value to the surface model. Even though the 'classified' point data sets are in effect 'derived' from the 'all points' data set they are still essentially primary data sets in their own right because, other than the point classification, the data has come straight from the primary source and has not been changed in any way.

	Elevation Data Deliverables	Description
3.1.4.1	Primary Data	LAS v1.1 (v2.0 once released) All returns Mandatory ASCII (x,y,z,i) All Returns Mandatory The following primary data sets will be subjected to some filtering or thinning to separate points from the 'all returns' data set. ASCII (x,y,z,i) First Returns Mandatory ASCII (x,y,z,i) Last Returns Mandatory ASCII (x,y,z,i) Ground Returns Mandatory ASCII (x,y,z,i) Non-ground Returns Mandatory ASCII (x,y,z,i) Thinned Ground Returns Mandatory ASCII (x,y,z,i) Vegetation Returns…………………………………........... ☐ ASCII (x,y,z,i) Vegetation classification (high, med, low)…................... ☐ ASCII (x,y,z,i) Buildings/Structures Returns………………………............ ☐ ASCII (x,y,z,i) Buildings/Structures classification (high, med, low)…… ☐
3.1.4.2	Derivative Data	Are Contours Required?………………………………………………...yes/no Contour Interval 0.5m……………………………………………………………………….. ☐ 1m………………………………………………………………………….. ☐ 2m………………………………………………………………………….. ☐ Other (please specify)…………………………………………………… ☐ Format for Contour Data ESRI 3D Shape (with the elevation as a Z value)...…………….……… ☐ ESRI Shape (with Elevation attribute)…………………………….… ☐ MapInfo (with Elevation attribute)……………………………………...... ☐ Other (please specify)…………………………………………………… ☐

		Are Grid files (DEM) Required……….……………………………………yes/no DEM Resolution 1m………………………………………………………………………….. ☐ 2m………………………………………………………………………….. ☐ 3m………………………………………………………………………….. ☐ 4m………………………………………………………………………….. ☐ 5m………………………………………………………………………….. ☐ Other (please specify)………………………………..………………….. ☐ Grid Format ESRIGrid (floating point)....………………………………………………… ☐ Vertical Mapper (MapInfo)………………………………………………….. ☐ GeoTIFF (32bit, floating point)...……………………………….…………… ☐ ASCIIGrid…………………………………………………………..………. ☐ Other (please specify)…...……………………………………...………… ☐ Other Derivative Data from ALS Purchaser to specify details of any other derivative data sets required. …………………………………………………………………………………… …………………………………………………………………………………… …………………………………………………………………………………… …………………………………………………………………………………… …………………………………………………………………………………… …………………………………………………………………………………… …………………………………………………………………………………… ……………………………………………………………………………………

5.1.5 Metadata

For each supplied elevation data product a complete metadata statement to the current ANZLIC standard (http://www.anzlic.org.au/infrastructure_metadata.html) is required. Metadata should be supplied in either text (.txt) or Word (.doc) format. The following metadata elements should be included.

Metadata Element	Digital Ortho Photography	ALS
Acquisition Start Date	X	X
Acquisition End Date	X	X
Device Name	X	X
Flying Height (AGL)	X	X
INS/IMU Used	X	X
Number of Runs	X	X
Number of Frames	X	
Frame Dimensions (columns and lines)	X	
Swath Width		X
Flight Direction	X	X
Photo Scale	X	
Forward Overlap	X	
Side Overlap	X	X
Output Pixel Size	X	
Horizontal Datum	X	X
Vertical Datum	X	X
Map Projection	X	X
Description of Aerotriangulation Process Used and Residuals Results	X	X
Description of Rectification Process Used	X	
Spatial Accuracy – Horizontal	X	X
Spatial Accuracy – Vertical	X	X
Surface Type		X
Average Point Spacing	X	X
Laser Return Types		X
Data Thinning		X
Laser Footprint Size		X
Limitations of the Data	X	X
System calibration certification (Manufacturer / Qualified Company)		X

5.2 Airborne Laser Bathymetry (ALB) Survey

5.2.1 Related Standards

The following standards may also be applicable to these guidelines:

- Australian Hydrographic and Oceanographic Instructions (AHOI) Ed 7, AHP 14. – Royal Australian Navy Hydrographic Office.
- Australian Hydrographic and Oceanographic Orders (AHOO) – Royal Australian Navy Hydrographic Office.
- Standards for Hydrographic Surveys. Special Publication No. 44. February 2008 Ed 5. – International Hydrographic Organisation.
- Special Publication SP1 – Standards and Practices for Control Surveys
- Special Publication SP9 – Australian Tides Manual

5.2.2 General Guidelines

	General Guidelines	Description
5.2.2.1	Category of Survey	Special Order n/a Category 1 n/a Category 2 ☐ Category 3 ☐
5.2.2.2	Coverage	Provide a full description to define the extent of the survey. Also define if the area is to be sounded at 100% or 200% coverage (to minimise gaps due to turbidity, surf or kelp). 100% ☐ 200% ☐
5.2.2.3	Horizontal Datum	All surveys must be coordinated in terms of the International Terrestrial Reference Frame (ITRF) at a specified epoch. For example: GDA94 is International Terrestrial Reference Frame 1992 (ITRF92) held fixed at 1st January 1994.
5.2.2.4	Vertical Datum	All elevation data must be supplied as heights above/below Australian Height Datum (AHD). Ellipsoid heights must be reduced to AHD heights using AUSGeoid98 model. Other height datums may also be specified in addition to the above: Ellipsoid height (above/below GDA94)…………………………………… ☐ Ellipsoid height (above/below ITRF @ epoch___)……………………... ☐ LAT (with established connection to AHD)………………..……………… ☐ Other (please specify)…………………………………………………….. ☐
5.2.2.5	Map Projection	All elevation data must be supplied in terms of the Map Grid of Australia (MGA) coordinate system. Other coordinate systems may also be specified in addition to the above: Geographical Coordinates………………………………………………………………….. ☐ Other (please specify)……………………………………………………… ☐
5.2.2.6	Survey Control	Horizontal and vertical position must be controlled by reference to existing approved permanent survey marks with established ITRF coordinates and accurate levels on a datum specified above. Survey to establish new control should use techniques to achieve a minimum standard of: Horizontal: Class B Vertical: Class B or LD, As described in the ICSM publication SP1. Elevation data must be tested and corrected for systematic errors to ensure accuracy specifications are met. Documentation should describe how this

		has been achieved.
5.2.2.7	Data Tiling	All Primary data sets should be supplied in predefined tiles (Geoscience Australia to provide index). *(tiles based on the MGA coordinate system or geographicals?).*
5.2.2.8	Special Considerations	Purchaser to provide details of any special consideration applicable to the project. For example: All coastal data should be acquired at low tide (+/-2hrs) on any day. ☐ All coastal data should be acquired at high tide (+/-2hrs) on any day. ☐ Areas should be surveyed at neap tides only, or may be surveyed at springs and neaps. ☐ Other special consideration (please specify) ☐ …………………………………………………………………………………… ……………………………………………………………………………………

5.2.3 Quality Assurance Documentation

It is expected the documentation will provide detailed information on systems to be used in the survey and calibration (manufacturer and prior to survey), operational information to be captured during the survey (eg. mission date, time, flight altitude, sensor sampling configurations), maps of survey coverage and boundary overlaps, flight plans and any other pertinent survey information. It should also include the methodology for determining accuracy.

	QA Deliverables	Description
5.2.3.1	Quality Assurance Plan	The Contractor shall prepare and submit to the Purchaser a Quality Assurance Plan that conforms to an identified management system and generally complies with ISO 9001. The plan must address the organisation and management of the project, work procedures, environmental considerations, safety and risk control and test procedures. It is expected that the Plan will include a Turbidity Management Plan. The Quality Assurance Plan must detail the procedures to be used in verifying that the deliverables meet the required specification. Approval by the Purchaser to commence the aerial survey is contingent on acceptance in writing by the Purchaser or a Quality Assurance Plan.
5.2.3.2	Pre-Survey Quality Assurance Deliverables	Proposed ALB flight plan Details of proposed tide gauge sites.
5.2.3.3	Post-Survey Quality Assurance Deliverables	Final ALB flight plan Contractors report comprising a technical discussion addressing how each of the contract specifications has been met, a statement of consistency with any identified standards, metadata statements and extra-ordinary issues that may have affected the nature or delivery of the project.

5.2.4 Elevation Data Deliverables

The primary Elevation data from ALB surveys is point data in the form a DTM.

	Elevation Data Deliverables	Description
5.2.4.1	Primary Data	ASCII (x,y,z,i) All Returns Mandatory
5.2.4.2	Derivative Data	Are Contours Required…………………………………………….....yes/no Contour Interval 1m……………………………………………………………………………. ☐ 2m……………………………………………………………………………. ☐ Other (please specify)……………………………………………………..…… ☐ Format for Contour Data ESRI 3D Shape (with the elevation as a Z value)...………………..……… ☐ ESRI Shape (with Elevation attribute) ………………………………. ☐ MapInfo (with Elevation attribute)……………………………………….…... ☐ Other (please specify)……………………………………………….…….…… ☐ Are Grid files (DEM data) Required……………………………………yes/no DEM Resolution 5m……………………………………………………………………………. ☐ 10m……..………………………………………………………………………. ☐ Other (please specify)……………………………………..………………….. ☐ Grid Format ESRIGrid (floating point).....…………………………………………………… ☐ Vertical Mapper (MapInfo)……………………………………………………. ☐ GeoTIFF (32bit, floating point)..……………………………….…………… ☐ ASCIIGrid………………………………………………………………..………. ☐ Other (please specify)…………………………………………...………. ☐ Other Derivative Data from ALB for example seabed reflectivity or seabed classification data or maps. Purchaser to specify details of any other derivative data sets required. ………………………………………………………………………………… ………………………………………………………………………………… ………………………………………………………………………………… ………………………………………………………………………………… ………………………………………………………………………………… ………………………………………………………………………………… ………………………………………………………………………………… …………………………………………………………………………………

5.2.5 Metadata

For each supplied elevation data product a complete metadata statement to the current ANZLIC standard (http://www.anzlic.org.au/infrastructure_metadata.html) is required. Metadata should be supplied in either text (.txt) or Word (.doc) format. The following metadata elements should be included.

Metadata Element	ALB
Acquisition Start Date	X
Acquisition End Date	X
Device Name	X
Flying Height (AGL)	X
INS/IMU Used	X
Number of Runs	X
Swath Width	X
Flight Direction	X
Side Overlap	X
Horizontal Datum	X
Vertical Datum	X
Map Projection	X
Description of Process Used to Control Position and Residuals Results	X
Description and Details of Tidal Observations Used to Link Depth Observations to Vertical Datum	X
Spatial Accuracy – Horizontal	X
Spatial Accuracy – Vertical	X
Surface Type	X
Average Point Spacing	X
Laser Return Types	X
Laser Footprint Size	X
Limitations of the Data	X

5.3 Photogrammetry Survey

5.3.1 General Guidelines

	General Guidelines	Description
5.3.1.1	Category of Survey	Special Order ☐ Category 1 ☐ Category 2 ☐ Category 3 ☐
5.3.1.2	Coverage	Provide a full description to define the extent of the survey
5.3.1.3	Horizontal Datum	All surveys must be coordinated in terms of the International Terrestrial Reference Frame (ITRF) at a specified epoch. For example: GDA94 is International Terrestrial Reference Frame 1992 (ITRF92) held fixed at 1st January 1994.
5.3.1.4	Vertical Datum	All elevation data must be supplied as heights above/below Australian Height Datum (AHD). Ellipsoid heights must be reduced to AHD heights using AUSGeoid98 model. Other height datums may also be specified in addition to the above: Ellipsoid height (above/below GDA94) ☐ Ellipsoid height (above/below ITRF @ epoch___)…………………….. ☐ Other (please specify)……………………………………………………. ☐
5.3.1.5	Map Projection	All elevation data must be supplied in terms of the Map Grid of Australia (MGA) coordinate system. Other coordinate systems may also be specified in addition to the above: Geographical Coordinates………………………………………………………….. ☐ Other (please specify)……………………………………………………. ☐
5.3.1.6	Survey Control	Horizontal and vertical position must be controlled by reference to existing approved permanent survey marks with established ITRF coordinates and accurate levels on a datum specified above. Survey to establish new control should use techniques to achieve a minimum standard of: Horizontal: Class B Vertical: Class B or LD, As described in the ICSM publication SP1. Elevation data must be tested and corrected for systematic errors to ensure accuracy specifications are met. Documentation should describe how this has been achieved.
5.3.1.7	Data Tiling	All Primary data sets should be supplied in predefined tiles (Geoscience Australia to provide index). *(tiles based on the MGA coordinate system or geographicals?).*
5.3.1.8	Ortho-Rectified Imagery	Is Ortho-rectified aerial imagery required?………………………...yes/no Resolution (please specify)………………………………………………. Spatial Accuracy (please specify)…………………………………………..
5.3.1.9	Special Considerations	Purchaser to provide details of any special consideration applicable to the project. For example: All coastal data should be acquired at low tide (+/-2hrs) on any day. ☐ Capture of breaklines from ortho-rectified imagery?...………………..yes/no Provide details (eg water bodies, drainage features, roads, etc) ………………………………………………………………………………. Other special considerations (please specify) ☐ ………………………………………………………………………………. ……………………………………………………………………………….

5.3.2 Quality Assurance Documentation

It is expected the documentation will provide detailed information on systems to be used in the survey and calibration (manufacturer and prior to survey), operational information to be captured during the survey (eg. mission date, time, flight altitude, forward and side overlap), maps of survey coverage and boundary overlaps, flight plans and any other pertinent survey information. It should also include the methodology for determining accuracy.

	QA Deliverables	Description
5.3.2.1	Quality assurance Plan	The Contractor shall prepare and submit to the Purchaser a Quality Assurance Plan that conforms to an identified management system and generally complies with ISO 9001. The plan must address the organisation and management of the project, work procedures, environmental considerations, safety and risk control and test procedures. The Quality Assurance Plan must detail the procedures to be used in verifying that the deliverables meet the required specification. Approval by the Purchaser to commence the aerial survey is contingent on acceptance in writing by the Purchaser or a Quality Assurance Plan.
5.3.2.2	Pre-Survey Quality Assurance Deliverables	Proposed aerial photography flight plan Diagram showing the proposed location and spread of ground control points.
5.3.2.3	Post-Survey Quality Assurance Deliverables	Final aerial photography flight plan Diagram showing the proposed location and spread of ground control points. Aerotriangulation adjustment results Contractors report comprising a technical discussion addressing how each of the contract specifications has been met, a statement of consistency with any identified standards, results of accuracy tests, metadata statements and extra-ordinary issues that may have affected the nature or delivery of the project.

5.3.3 Elevation Data Deliverables

Typically in the softcopy photogrammetric data capture process uses a 'strategy', specific to the terrain and land cover type, to extract a ground only elevation model. That is, an attempt is not made to extract a DSM. Instead the auto-terrain extraction process attempts to filter out buildings and trees on the fly to produce a DEM. The resulting DEM is then manually edited to correct cells/points that have been allocated incorrect values. In this instance the primary data set is a DEM.

In some instances DEM edits may include the additional points or breaklines which are placed manually by a photogrammetrist to better define the surface. In these instances the primary data set is, by default, a DTM.

	Elevation Data Deliverables	Description
5.3.3.1	Primary Data	The primary data set from Photogrammetry is either a DEM or a DTM. This should be delivered as per following: **DEM** Resolution 1m……………………………………………………………………………… ☐ 2m……………………………………………………………………………… ☐ 5m……………………………………………………………………………… ☐ 10m…………………………………………………...……………………….... ☐ 15m………...………………………………………..………………………… ☐ Other (please specify).………………………………………………….……….. ☐

		Format ESRIGrid (floating point)………… ☐ Vertical Mapper (MapInfo)………… ☐ GeoTIFF (32bit, floating point)………… ☐ ASCIIGrid………… ☐ Other (please specify)………… ☐ **DTM** Nominal point spacing 1m………… ☐ 2m………… ☐ 5m………… ☐ 10m………… ☐ 15m………… ☐ Other (please specify)………… ☐ Format ESRI 3-d Shape ………… ☐ DXF………… ☐ Other (please specify)………… ☐
5.3.3.2	Derivative Data	Are Contours Required?…………yes/no Contour Interval 0.5m………… ☐ 1m………… ☐ 2m………… ☐ Other (please specify)………… ☐ Format for Contour Data ESRI 3D Shape (with the elevation as a Z value)………… ☐ ESRI Shape (with Elevation attribute) ………… ☐ MapInfo (with Elevation attribute)………… ☐ Other (please specify)………… ☐ Are Grid files (DEM) Required?…………yes/no DEM Resolution 1m………… ☐ 2m………… ☐ 3m………… ☐ 4m………… ☐ 5m………… ☐ Other (please specify)………… ☐ Grid Format ESRIGrid………… ☐ Vertical Mapper (MapInfo)………… ☐ GeoTIFF (32bit, floating point)………… ☐ ASCIIGrid………… ☐ Other (please specify)………… ☐ Other Derivative Data from ALS Purchaser to specify details of any other derivative data sets required. ………………………… ………………………… ………………………… ………………………… …………………………

5.3.4 Metadata

For each supplied elevation data product a complete metadata statement to the current ANZLIC standard (http://www.anzlic.org.au/infrastructure_metadata.html) is required. Metadata should be supplied in either text (.txt) or Word (.doc) format. The following metadata elements should be included.

Metadata Element	Analog Photography	Digital Photography
Acquisition Start Date	X	X
Acquisition End Date	X	X
Device Name	X	X
Lens	X	
Focal Length	X	
Flying Height (AGL)	X	X
INS/IMU Used	X	X
Number of Runs	X	X
Number of Frames	X	X
Frame Dimensions (columns and lines)	X	X
Flight Direction	X	X
Film Type	X	
Photo Scale	X	X
Forward Overlap	X	X
Side Overlap	X	X
Film Scanner Used	X	
Scan Resolution	X	
Output Pixel Size	X	X
Horizontal Datum	X	X
Vertical Datum	X	X
Map Projection	X	X
Description of Aerotriangulation Process Used and Residuals Results	X	X
Description of Rectification Process Used	X	X
Spatial Accuracy – Horizontal	X	X
Spatial Accuracy – Vertical	X	X
Average Point Spacing	X	X
Limitations of the Data	X	X

5.4 Data Acceptance and Testing

5.4.1 Background

Verification of remotely sensed data for conformance with contract specifications is an important component of client acceptance testing. For photogrammetry and ALS data and derived products and digital imagery, quality assurance and quality checks should be undertaken pre- and post-survey respectively. While the contractor is expected to fully document pre-survey quality assurance and post survey quality assurance, it is considered good practice to undertake an independent assessment of contract deliverables as part of the acceptance testing. The acceptance testing described here focuses on a suite of quality checks designed to assess whether contract deliverables are to specification.

5.4.2 Acceptance Testing Plan

The plan objectives are to:

- Determine the adequacy of the contractor's pre-survey quality assurance documentation. It is expected the documentation will provide detailed information on systems to be used in the survey and calibration (manufacturer and prior to survey), operational information to be captured during the survey (eg. mission date, time, flight altitude, sensor sampling configurations), maps of survey coverage and boundary overlaps, flight plans and imagery for nominated ground types and any other pertinent survey information. It should also include the methodology for determining accuracy or uncertainty is the elevation data.
- Determine the adequacy of the contractor's post-survey quality assurance documentation and quality checks in demonstrating conformance with contract requirements.
- Describe the independent checks to be conducted as part of the client acceptance testing.
- Provide a report summarising the results of the acceptance testing

Element	Data Type	Quality Assessment
Contractor Quality Assurance procedures	Contractor's Quality Assurance Plan and documentation	Qualitative assessment to ensure contractor has addressed adequately the identified items to be covered in the plan
Coverage density	Primary data	Data to be loaded into a GIS and point spacing assessed for compliance with point spacing specifications
Completeness	Primary data	Review of flight plan. Random checks will be carried out to confirm no terrain has been missed
Absolute horizontal and vertical accuracy	Primary data – ground only	Review of Accuracy Test Report and/or Quality Assurance Plan
Capture time	LAS	Check that data been acquired during period of low tide/low water level.
Filtering	Non ground data	Qualitative assessment for reliability in terms of coincidence with non-ground features such as trees, buildings using aerial imagery
Resolution of Grid files	DEMs	File format and grid spacing to be checked within a GIS for compliance in terms of grid resolution and coverage.

Appendix A Definitions

Term	Definition
Accuracy	The closeness of an estimated (for example, measured or computed) value to a standard or accepted [true] value of a particular quantity. Note: Because the true value is not known, but only estimated, the accuracy of the measured quantity is also unknown. Therefore, accuracy of coordinate information can only be estimated.
Absolute Accuracy	A measure that relates the stated elevation to the true elevation with respect to an established vertical datum. The computed value for the absolute vertical accuracy (tested, or compiled to) should be included in the metadata file.
Artefacts	Buildings, trees, towers, telephone poles or other elevated features that should be removed when depicting a DEM of the bare-earth terrain. Artefacts are not just limited to real features that need to be removed. They also include unintentional by-products of the production process, such as stripes in manually profiled DEMs. Any feature, whether man-made or system-made, that unintentionally exists in a digital elevation model.
AHD	The Australian Height Datum. Established in 1971 as a national datum for elevations based on observed mean sea level around the Australian coast line. Determined on the Australian mainland by an adjustment of a national levelling network constrained to mean sea level from continuous tidal observations over a period of 3 years at 30 tide gauges. AHD (Tasmania) was re-established in 1983 by adjusting the Tasmanian levelling network to mean sea level determined from one year of tidal observations at 2 tide gauges.
ALS	Airborne Laser Scanning (ALS). A terrain definition process which utilises an airborne laser source to accurately measure the earth surface from computation of laser range and return signal intensity, measurements recorded in-flight along with position and altitude data derived from airborne GPS and inertial subsystems. Falls into the category of airborne instrumentation known as LiDAR (Light Detection and Ranging). May also include Airborne Laser Bathymetry (ALB)
ASCII File	American Standard Code for Information Interchange (ASCII) file. A file whose data is in ASCII characters and does not include formatting such as bold, italic, centred text, etc.
Breakline	Linear features that describe a change in the smoothness or continuity of the surface.
Calibration	Procedures used to identify systematic errors in hardware, software, and procedures so that these errors can be corrected in preparing the data derived there from.
CEM	Canopy Elevation Model is a grid that represents the mean canopy height above the ground surface. The CEM is generally derived from the first return LiDAR data. The CEM therefore represents the highest derived vegetation surface.
Checkpoint	One of the points in the sample used to estimate the positional accuracy of the dataset against an independent source of higher accuracy.
Colour digital aerial photography (RGB)	Digital photographic images captured by a digital sensor off an airborne platform such as a plane. Colour aerial photography includes red, green and blue wavelengths. To be acquired for the primary purpose of providing qualitative information of on-ground features, which will be used the development of the digital terrain model. However this could be used for other applications such as mapping broadly defined vegetation types.

Confidence level	The probability that errors are within a range of given values.
Contours	A line connecting points of equal height, used to display a 3D surface on a 2D map or image
DEM	Digital Elevation Model: The representation of continuous elevation values over a topographic surface by a regular array of sampled z-values, referenced to a common datum. To be expressed as a grid or raster data set. The DEM is ground only representation and excludes vegetation such as trees and shrubs and human constructed features such as sheds and houses.
Digital photography	Electronic image usually in a binary format that can be readily stored and edited on a computer. Aerial digital photography is digital photography taken from the vantage of an aircraft such as a helicopter or aeroplane.
DSM	Digital Surface Model – surface including ground, vegetation, building and structures defined by either random points or regular grid of spot heights and may include breaklines. Can be in point (ASCII), vector or raster format.
DTM	Digital Terrain Model: A topographic model of the earth's surface in digital format represented by mass points and may include breaklines. The DTM is a filtered version of a DSM that represents only bare earth surfaces. The DTM representation of ground includes works such as levees, banks and roads.
Elevation	Height above a specific vertical reference.
ESRI	Environmental Systems Research Institute (ESRI).
Ground control points	Permanent survey control marks forming the local site datum, providing sites for GPS base-station control of aircraft trajectory and establishment of check points.
Ground Sample Distance (GSD)	Ground resolution of airborne or satellite imagery, e.g. 30cm GSD
GSD	Ground Sample Distance. Ground resolution of airborne or satellite imagery.
ICSM	Inter-Governmental Committee on Surveying and Mapping
Hydrological enforcement	The removal of elevations from the tops of selected drainage structures (bridges and culverts) in a DEM, TIN or topographic dataset to depict the terrain under those structures. Also referred to as drainage enforced.
IFSAR	Interferometric Synthetic Aperture Radar – AN airborne or spaceborne interferometer radar system, flown aboard rotary or fixed wing aircraft or space-based platforms, that is used to acquire 3-D coordinates of terrain and terrain features that are both man-made and naturally occurring. IFSAR systems form synthetic aperture images of terrain surfaces from two spatially separated antennae over an imaged swath that may be located to the left, right, or both sides of the imaging platform.
IHO	The International Hydrographic Organisation. The International Hydrographic Bureau is the publisher of the IHO Standards for Hydrographic Surveys (Special Publication 44, April 1998)
Image block file	Strip of digital imagery captured from a plane (or similar airborne platform) along a section of a flight run.
Image correlation	A computerised technique to match the similarities of pixels in one digital image with comparable pixels in its digital stereo image to automate or semi-automate photogrammetric compilation. Image correlation provides a faster method for generating DEMs photogrammetrically.
Independent source of higher accuracy	Data acquired independently of procedures to generate the dataset that is used to test the positional accuracy of a dataset. The independent source of higher accuracy shall be of the highest accuracy feasible and practicable to evaluate the accuracy of the dataset.

Interpolation	The estimation of z-values at a point with x/y coordinates, based on the known z-values of surrounding points.
LADS	Laser Airborne Depth Sounding, also referred to as Airborne LIDAR Bathymetry.
LAS	LAS version 1.1 is a standard LiDAR file format, defined by the American Society of Photogrammetry and Remote Sensing (ASPRS). LASV1.1 defines, amongst other things, mandatory data fields and point categories. This includes mandatory metadata documentation See full description at http://www/lasformat.org/
LiDAR	Light Detection and Ranging (LiDAR). A technology that determines distance to a surface using laser pulses. Distance is computed by measuring the time delay between transmission and detection of the reflected signal. Also referred to Airborne Laser Scanning (ALS).
Local Site Datum	Established network of state survey control marks in close proximity to each project area with published coordinates in a specific coordinate system.
Mass points	Irregularly spaced points, each with an x/y location and a z-value, used to form a TIN. When generated manually, mass points are ideally chosen to depict the most significant variations in the slope or aspect of TIN triangles. However, when generated by automated methods, For example, by LIDAR or IFSAR scanners, mass point spacing and pattern depend on characteristics of the technologies used to acquire the data. Mass points are most often used to make a TIN, but not always. They can be used as XYZ point data for interpolation of a grid without an intermediate TIN stage.
MHW	Mean High Water: A tidal level. The average of all high waters observed over a sufficiently long period.
National Digital Elevation Program. (NDEP)	United States program established to promote the exchange of accurate digital land elevation data among government, private, and non-profit sectors and the academic community and to establish standards and guidance that benefit all users.
Near-Infrared digital aerial photography (NIR)	Digital near-infrared imagery captured by a digital sensor from an airborne platform such as a plane.
Order	The accuracy ranking of one measurement or survey with respect to other measurements or surveys.
Projective foliage cover (PFC)	The proportion of ground covered by foliage. PFC represents a measure of the openness of the vegetation canopy when projected vertically onto the ground. For LiDAR data PFC represents the proportion of returns from the vegetation canopy as a proportion of total returns.
Raw digital aerial photography	Digital aerial photography that has not been colour balanced, ortho-rectified or converted into a mosaic, and which still contains redundant imagery such as overlapping images.
RMSE	The square root of the mean of squared errors for a sample.
SP1	ICSM Special Publication No.1 - Standards and Practices for Control Surveys
SP44	International Hydrographic Organisation Standards for Hydrographic Surveys
TIN	A TIN is a set of adjacent, non-overlapping triangles computed from irregularly spaced points with x/y coordinates and z-values. The TIN data structure is based on irregularly spaced point, line, and polygon data interpreted as mass points and breaklines and stores the topological relationship between triangles and their adjacent neighbours. The TIN structure is often superior to other data models derived from mass points because it preserves the exact location of each ground point sample.