DIGITAL ELEVATION MODEL ACCURACY REQUIREMENTS FOR CATCHMENT MANAGEMENT

K. McDougall, X. Liu, B. Basnet and A. Apan
Faculty of Engineering and Surveying,
Australian Centre for Sustainable Catchments
University of Southern Queensland, Australia.

Abstract

Across Australia, recent drought has severely limited water supplies and natural flows in catchments with impacts being felt across communities, business and government. Understanding the flow and accumulation of water across catchments is critical to achieving an improved balance in managing and sustaining catchment resources. Digital elevation models (DEM) are now recognized as a core spatial dataset required for catchment and water resource management. However the availability of comprehensive DEMs for catchments is limited. This paper discusses the importance of digital elevation models to catchment management activities and the technologies available to capture DEMs over large areas. These technologies are examined in the context of their suitability for various applications including natural resource management, flood assessment and management, asset protection and land planning. Strategies for capturing, managing and utilizing these DEMs for the benefit of catchment communities are discussed. A case study over the Condamine Catchment was conducted to assess the digital elevation requirements as a function of slope, landuse and floodplain extents. The role of various stakeholders across these catchments is explored and the collaborative efforts required in realizing the capture of these large spatial data sets is discussed.

Keywords: *digital elevation model, catchment management, accuracy*

Introduction

The continuing drought across Australia and the resulting severe water shortages across many productive catchments have now focussed attention on the use of topographic mapping and digital elevation as a valuable data source to assist in important decisions on infrastructure planning and development. Elevation models are key inputs to derive a number of important parameters such as slope, aspect, inter-visibility line, hillshade, flow direction etc. In hydrologic analysis these models are useful in determining upslope contributing area and down slope flow path which in turn provides the basis for calculating runoff, predicting flood levels and managing water resources (Maune et al. 2007). Large infrastructure projects also require appropriate level of elevation models and topographic mapping to facilitate planning and operational decisions. Therefore, digital elevation models (DEM) are now being increasingly recognised as a fundamental dataset for the planning, design and ongoing management of infrastructure and resources. In recent times, the issue of an improved quality and coverage of digital topographic and elevation models has been considered by both state and federal mapping agencies.

The dispersed and variable quality of DEMs currently held by mapping agencies has however limited their wider application to areas such as catchment management. Although Australia has made significant advances in the collection and coordination of spatial data, there are still many areas in the country where very limited data exists or the quality and currency of the information is poor. In addition, the level of public investment in spatial data infrastructure has declined significantly over the past 30 years with reductions in the capacity of many state and federal mapping agencies. Consequently, significant effort is now required to re-build these vital areas of information infrastructure.

The need for a national DEM was identified as a priority by the Council of Australian Governments (COAG) in 2006 through the National Climate Change Adaptation Framework. The framework concluded that "understanding some potential climate change impacts, particularly on the coast, requires a national DEM – which does not currently exist." It also stated that "such a DEM would also have important benefits for catchment managers and other natural resource managers" (COAG 2006).

From a national perspective the drivers for improved digital elevation data include:

- Environmental (catchment modelling, land use studies, hydro-geological and soil mapping);
- Natural disaster risk assessment and response (coastal vulnerability, community safety);
- Water management as a result of climate change;
- Defence operations and security;
- Infrastructure planning, safety and operations; and
- Transport planning and navigation.

The DEM requirements for catchment management are diverse and include many of the national DEM drivers including environmental management, water management and development of the built environment. In particular, high quality, hydrologically correct DEMs are required for many water resource and catchment management related applications. The data sources, modelling methods, interpolation algorithms and terrain complex are critical factors for generating an accurate DEM for catchment management. Inland river catchments typically contain large tracts of agricultural land which include intensive cropping and animal production, broad-acre farming (both irrigated and non-irrigated) and grazing. Many of these catchments are often characterised by extremely flat terrain (below 0.5%). Therefore the requirements of a DEM for these catchments may vary quite significantly from those of a coastal river catchment where the catchment slopes and extents can differ dramatically. The current mapping programs across the states and territories vary in their coverage and progress for the collection of digital elevation data. From a national perspective this variability limits the wider use of these data across jurisdictional boundaries by either the public or private sectors.

Understanding Digital Elevation Modelling

Digital elevation models are digital representations of the Earth's terrain surface. A natural terrain surface is a continuous surface and comprises an infinite number of points (El-Sheimy *et al.* 2005). With a point sampling method, the terrain surface can be approximated to the required degree of accuracy by DEM with a finite number of sampled points. Different digital elevation models have been developed to represent the terrain surface. The regular grid DEM, the triangular irregular network (TIN), and the contour line model are the most commonly used digital elevation models (Kienzle 2004; Liu 2008; Ramirez 2006). Contour lines of constant elevation at a specified interval are probably the most familiar representation of terrain surface, and have long been used in conventional hard copy maps. Contour line models only indicate surface values along contour lines. Surface variation between contours can not be explicitly represented. The interpolation calculation is required to derive an elevation for locations between contours (El-Sheimy *et al.* 2005). Compared with grid DEM and TIN, contour line model is not efficient in storage and manipulation.

The TIN model builds a terrain surface from a set of irregularly distributed points by connecting these sample points to form a set of contiguous and non-overlapping triangles with x, y coordinates and elevation values for their vertices, along with topological relationship between the triangles and their adjacent neighbours (El-Sheimy *et al.* 2005; Ramirez 2006). Irregularly distributed sample points can be adapted to the terrain, with dense points in areas of rough terrain and sparse points in areas of flat terrain (El-Sheimy *et al.* 2005). Feature specific elements such as peaks, pits, and break lines can be involved in triangle vertices in the creation of a TIN. Therefore, the geomorphologic correctness of the terrain model can be ensured.

The grid DEM uses a matrix structure that implicitly records topological relations between data points (El-Sheimy *et al.* 2005). Each grid cell has a constant elevation value for the whole cell (Ramirez 2006). This constant elevation value is usually obtained by interpolation between adjacent sample points. Of the three digital elevation models, the grid DEM is the simplest and the most efficient approach in terms of storage and manipulate since this data structure is similar to the array storage structure in computer (El-Sheimy *et al.* 2005; Ramirez 2006; Ziadat 2007). However, the size of regular grids cannot be adapted to the complexity of the relief. Feature specific points such as peaks and pits may be missed (El-Sheimy *et al.* 2005), and linear features such as break lines are not well represented. One way to increase the details of the terrain representation is to increase the sample point density and decrease the grid size. This will lead to the redundancy of sample point and the increase of data size.

Terrain data acquisition is the primary stage in digital elevation modelling. DEMs can be generated from a number of different data sources. Traditionally, these data can be obtained directly from field survey using total station or GPS receiver and photogrammetric techniques (Li *et al.* 2005). Field survey methods allow collection of important (or feature-specific) points which is necessary for reasonably comprehensive coverage of data (Li *et al.* 2005). Photogrammetric technique uses a pair of stereo images to construct a stereo model for 3D point coordinates measurement (Li *et al.* 2005). Both analogue and digital methods are available. The accuracy of point coordinates measured with photogrammetric technique is relatively high. However, photogrammetric processes require specifically designed equipments (e.g. stereo plotters) and highly skilled operators. Digital photogrammetric systems processes stereo images in digital format with computer, so the implementation is faster and offers greater ease of use through intuitive software interfaces (El-Sheimy *et al.* 2005).

Traditional methods such as field surveying and photogrammetry can yield high-accuracy terrain data, but they are time consuming and labour-intensive. Moreover, in some situations, for example, in forested areas, it is impossible to use these methods for collecting elevation data. Airborne Light Detection and Ranging (LiDAR) - also referred to as Airborne Laser Scanning (ALS), provides an alternative for high-density and high-accuracy three-dimensional terrain point data acquisition. LiDAR data have become a major source of digital terrain information (Raber et al. 2007) and it has been used widely. However, terrain modelling is the primary focus of LiDAR data collection (Hodgson & Bresnahan 2004). The use of LiDAR for terrain data collection and DEM generation is the most effective way (Forlani & Nardinocchi 2007) and is becoming a standard practice in the spatial science community (Hodgson & Bresnahan 2004).

Case Study for DEM Requirements Capture in the Condamine Catchment

Study Area

The Condamine River catchment in Southern Queensland sits at the top of the Murray Darling Basin and represents an important natural and economic resource for the region. The Condamine River catchment covers an area of 29,150 sq km (CCMA 2001). The catchment includes part or in full 12 local government authorities (LGAs) including Cambooya, Chinchilla, Clifton, Crows Nest, Dalby, Jondaryan, Millmerran, Pittsworth, Rosalie, Toowoomba, Wambo and Warwick. Since March 2008, many of these LGAs have merged to form the Toowoomba Regional Council and parts of the Dalby and Warwick Regional Councils. Theses LGAs have a combined population of approximately 196,000 people (OESR 2007) and include the four major urban centres of Toowoomba, Dalby, Warwick and Chinchilla.

The catchment supports almost 13,000 businesses (OESR 2007) with the majority of these businesses within the agricultural sector. In 1999, the region had a combined gross agricultural production of approximately $850 million or 13.1% of Queensland gross agricultural production (Eastern Downs Regional Planning Advisory Committee 2003a). The region makes a substantial contribution to the Queensland economy with the Condamine floodplains recognised as one of the most important and valuable cropping areas in Australia. The average rainfall across the catchment is approximately 720mm/year, however it is highly variable as much of the rain occurs during high intensity storm events. Periods of severe drought such as those in the 1990s and 2000s are often followed by major flooding events such as experienced in 1996. The hydrology is also highly variable with few streams having permanent flows and supplies of groundwater which vary in both quantity and quality (CCMA 2001).

With increasing pressures being placed on this catchment, it is critical that the interaction between the natural and the built environments is managed effectively. With our water resources now being a key focus for our future, there is a need to better plan water utilisation and natural flows. Accurate terrain information in the form of a digital elevation model (DEM) provides the necessary information to better manage water resources and predict the impacts of natural events such as flooding.

Assessing the Requirements of Stakeholders

In order to assess the broad requirements for a DEM over the catchment, a workshop was conducted in August 2007 to identify the key needs for a catchment DEM both from an operational and a strategic perspective. The workshop was attended by 18 participants from a range of stakeholder organisations including local government, state government, catchment managers, environmental agencies and agricultural industries. The workshop attendees were broken into groups and were asked to consider the applications across the catchment where a high accuracy digital elevation model was required. The applications identified by the participants for a DEM varied in the DEM accuracy requirements from 0.05m to 20m. The diverse range of applications for DEM is detailed in Table 1.

Table 1: DEM applications and accuracy requirements within the catchment

Application Area	**Coverage and Accuracy**
Planning scheme/development assessment*	± 1m
Hydrological modelling*	<0.5m
Farm layout redesign – cultivation and intensive feedlot*	0.05m-0.5m
Transport corridor planning*	± 1m
Salinity prediction and control*	± 5m
Riparian management*	±1-2m
Soil erosion control and modelling*	± 1m
Risk management*	±1-2m
Bio-security – disease spread, spray drift*	± 1m
Visibility analysis – tourism	5-10m
Insurance risk and assessment*	<0.5m
Water management plans and sub-catchment delineation*	0.5-1m
Environmental impact assessment and management	± 5-10m
Disaster planning and management (flood and fire)*	± 1m
Natural resource management	5-10m
Noise studies/assessment – corridor planning*	± 1-2m
Telecommunications planning, visibility analysis*	1-5m
Cross slope/batter analysis*	<1m
Land and water management plans*	<0.5m
Tourism	20m
Infrastructure planning and risk assessment*	0.5-1m

* Applications that cannot be supported by existing DEM

The majority of applications identified an accuracy requirement of less than 2m, with many floodplain and on-farm applications requiring better than 0.5m. Most of these applications cannot be supported by the existing DEMs which are available for the catchment.

The three areas of top priority identified during the workshop were:

1. Water management: particularly floodplain planning and management, including risk assessment and disaster management;
2. Infrastructure: plan, design, management; and
3. Environmental and natural resource management and modelling.

In addition to the priority applications, a number of important issues or principles for any potential DEM upgrade were also discussed. The participants identified the following issues/principles:

1. Any DEM that is compiled should be widely disseminated to the catchment stakeholders. An open access licensing arrangement will encourage the use of the data to address priority problems. This may necessitate an education program to ensure stakeholders understand the value of this data and can avail themselves of this important information source.
2. The timeframes for the development of the DEM may not coincide with state government priorities or mapping programs. Efforts should be made to progress the capture of an improved DEM in a timely manner so that catchment priorities can be addressed quickly.
3. Suitable standards will need to be developed to ensure that any capture program can provide quality data in a form that will deliver the widest possible benefits. Standards should be developed in consultation with state and national DEM initiatives.
4. Private data providers should be encouraged to contribute to the progressive improvement of the DEM over the catchment.

Spatial Analysis of Requirements

Accurate height information is critical to managing land use, water projects, infrastructure and disaster planning. However, the current DEM over the catchment is of low accuracy and limited use for either operational or strategic planning in the lower and more productive areas of the catchment.

Following the identification of priorities through the workshop, a number of spatial analysis operations were undertaken to clearly identify areas requiring improved DEM accuracy. Land use, slope and existing floodplain boundary maps were examined to determine the extent and location of those priority areas within the catchment.

The land use map of the study area (Figure 1) indicated that intensive land use comprises approximately 146,750 ha (5.8%) of the catchment. A further 795,672 ha (31.3%) of the catchment are utilised for both irrigated and dry land agricultural production. Production from relatively natural environments is covering 1,518,334 ha (59.7%) of the catchment area. The existing land use type is one of the most important factors in determining DEM accuracy requirement. Since, a significant proportion of catchment is utilised for intensive and productive land uses; a greater DEM accuracy requirement for most part of the catchment became obvious from the analysis.

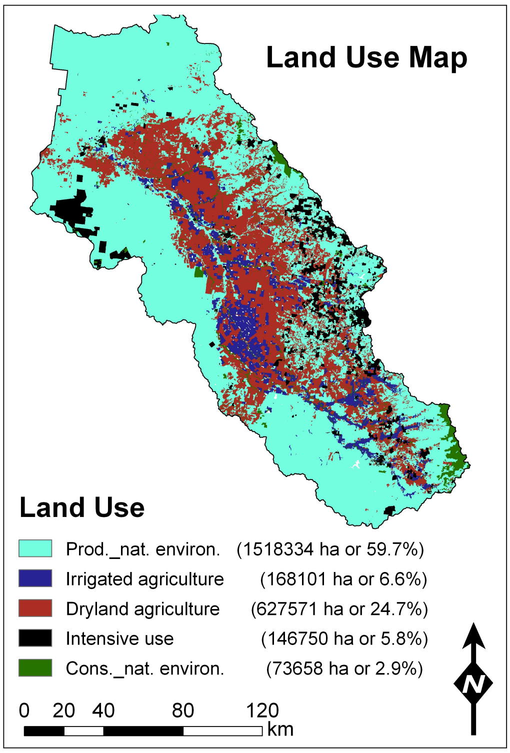

Figure 1: Broad land use distribution across the catchment (Source: 1999 Land Use Mapping NR&W)

Slope is another important factor in determining DEM accuracy requirement. In this case, over half of the catchment is represented by slopes of less than 1% and almost 70% area has less than 2.5% slope (Figure 2). These areas primarily comprise of the floodplains and encompass the Condamine River and its various tributaries. The major landscape elements across the Upper Condamine and Brigalow-Jimbour floodplains including riparian areas, near flat overland flow plains and the undulating overland flows are represented in Figure 3. The map shows that large area of the catchment is covered with floodplains that are sensitive to DEM accuracy.

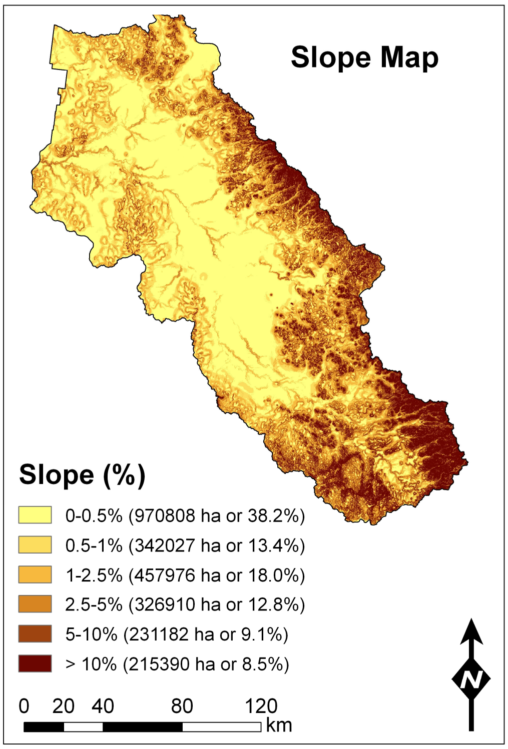

Figure 2: Slope distribution across the catchment derived from 1:100,000 DEM from NR&W

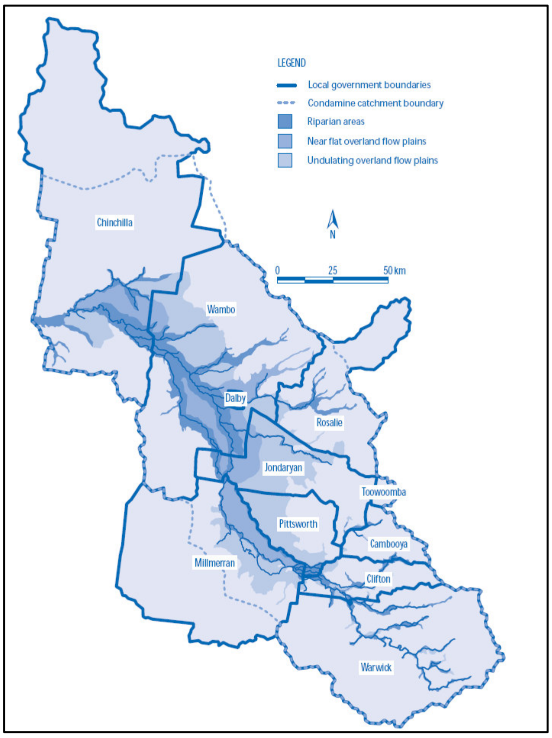

Figure 3: Condamine floodplain landscape elements (Source: EDRPAC 2003)

The breakdown of the areas encompassed by each landscape element within each of pre-2008 local government authorities (LGAs) of the catchment is detailed in Table 2. The total area covered by these landscape elements comprises approximately 667,000 ha (Eastern Downs Regional Planning Advisory Committee 2003a). Other estimates of the extent of Upper Condamine floodplain indicate a figure of approximately 750,000 ha (Upper Condamine Floodplain Project 1998) or approximately 850,000 ha including the Brigalow-Jimbour floodplains (Eastern Downs Regional Planning Advisory Committee 2003b).

Table 2: Condamine floodplain landscape elements by LGA (Source: EDRPAC 2003)

Local government area (LGA)	**Riparian areas**		**Undulating overland flow plains (including runoff plains)**		**Near flat overland flow plains**		**Percentage of total LGA**
	ha	**%**	**ha**	**%**	**ha**	**%**	**%**
Warwick	18625	4.2	5045	1.1			5.4
Wambo	94095	16.4	87582	15.3	56237	9.8	41.6
Rosalie	10805	4.9	9621	4.4	3	<1	9.3
Pittsworth	7070	6.5	49846	45.9	35	<1	52.5
Millmerran	12229	2.7	47442	10.5	32955	7.3	20.6
Jondaryan	11856	6.2	68830	35.9	27429	14.3	56.4
Dalby	733	13.5			4151	86.5	100
Clifton	10436	12.0	11705	13.4			25.4
Chinchilla	42629	4.9	32576	3.7	23204	2.7	11.3
Cambooya	2404	3.8	1217	1.9			5.8
All LGAs	**210882**	**7.0**	**313864**	**10.4**	**144014**	**4.8**	**22.2**

Using the floodplain boundaries as a guide, areas for high accuracy DEM (<0.5m) and medium accuracy DEM (1m) priority areas were defined. The high accuracy areas represent approximately 3,900 sq km and include the lower portions of the catchment surrounding the Condamine River system (Figure 3). This area represents the approximate 1975 flood boundaries as identified in the Department of Natural Resources and Water data set. If the area is widened to include the major portions of the Upper Condamine River and Brigalow-Jimbour flood plains, it would encompass an additional area of approximately 8,500 sq km. It is proposed that this area be covered by a medium accuracy DEM of approximately 1m accuracy. The total area of new DEM coverage would be approximately 12,300 sq km.

Data capture strategy

Formulation of data capture and DEM generation strategies for the development of medium to high accuracy DEM for the catchment is one of the most important considerations. Technical issues associated with a number of different data sources and data capture options were reviewed.

The data capture strategies consider for medium to high accuracy DEM generation included:

- Use of existing photography that is available over the catchment – currently 1:40,000 photography has been captured during the past few years
- Capture of new digital or film photography at an appropriate scale (1:30,000 to 1:40,000) over the desired areas
- Low level photography (1:12,000 scale) over river and road corridors
- Utilisation of satellite imagery to capture the complete catchment
- LIDAR collection over the specified areas

Following the technical review of data capture strategies, a number of private sector mapping firms were contacted to discuss both the technical and logistical issues associated with the collection of an upgraded DEM over the catchment.

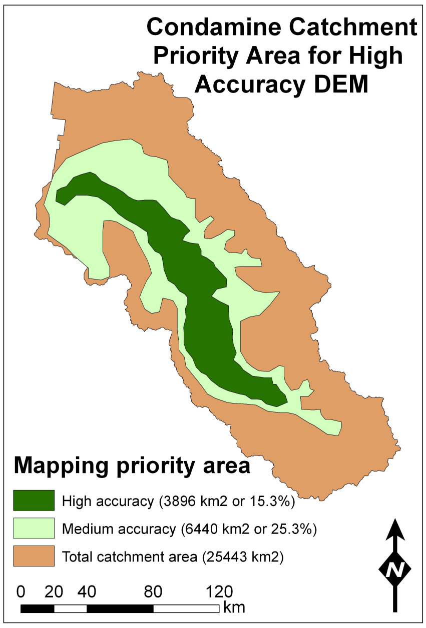

Figure 4: DEM priority areas at 0.25m (high) and 1m (medium) accuracy

As identified in the workshop undertaken with various catchment stakeholders, the majority of applications for digital elevation models varied between 0.5m and 2m in vertical accuracy. The proposed DEM capture areas would satisfy both the requirements of most proposed applications and also is spatially targeted to meet the identified the needs of potential end users.

Discussion

The role of the highly productive floodplains across the Condamine River catchment has long been recognised by the regions landowners, industry and governments. The Condamine floodplains support important dry land and irrigated agriculture, intensive animal production and land and river based ecosystems. Catchment processes are inextricably linked and therefore the management and coordination of the runoff and flow across the floodplain is critical to managing the economic, social and environmental values of the catchment (Eastern Downs Regional Planning Advisory Committee 2003a).

In this analysis, it was confirmed that the land use classification, slope and existing floodplain boundary can be used as the basis for the identification of priority areas for DEM upgrade. Intensive land uses and irrigated agriculture were given high priority in slopes less than 2.0%. These areas generally fell within the broader Upper Condamine Floodplain and the Brigalow-Jimbour Floodplain areas. In a flat floodplain, where a vertical error of 1 m in the DEM may lead to an error of 100s of sq km in flood estimation (Sanyal & Lu 2004), the accuracy of a DEM is extremely important.

Intensively utilised land areas in floodplains with less than 2% slope are also highly susceptible to flooding. Development of a flood management strategy for this area is therefore essential. In flood management applications, development of flood depth maps is quite useful. Flood water intersecting with the slope is the primary indicator of determining flood depth (Sanyal & Lu 2004). However, the accuracy of the estimated flood depth may depend on the spatial resolution and vertical accuracy of the terrain data in a gently sloping topography such as Condamine catchment.

Previous floodplain studies have identified the priorities in relation to runoff and flow coordination within the areas of the Condamine River catchment including:

- Protection of the hydraulic and ecological integrity across the floodplains;
- Improved coordination and management of flows, particularly the retention of natural flow patterns; and
- Reduction of risk to infrastructure, human health and life and environmental values caused by flooding (Eastern Downs Regional Planning Advisory Committee 2003b).

An improved quality DEM over the floodplain areas was identified as critical for effective strategic and operational planning and management. Therefore, the requirement of a medium to high accuracy DEM for these areas of the catchment is considered justifiable.

As identified previously, a range of data capture strategies were considered for upgrading the digital elevation model over the catchment area including photogrammetry, satellite imagery and LIDAR. A matrix of potential strategies, accuracy and strengths and weaknesses is given in Table 2.

Existing stereo photography at a scale of 1:40,000 is available over the majority of the Condamine River catchment. A significant proportion of this photography has been captured by aircraft with on-board GPS positioning which significantly reduces the amount of ground control that is required to process this photography. With this photography it is possible to obtain a +/- 1m accuracy DEM from this source. The capture would also include breaklines to ensure that the resulting DEM retains a high level of hydrological integrity. A secondary product that could be derived includes the development of relatively high resolution orthophoto coverage (0.6m cell size, +/-2m horizontal accuracy). These may be particularly useful over urban or peri-urban areas. Other options for capture include new digital photography at similar scales and lower level photography at 1:12,000 for more detailed modelling around rivers and roads.

Table 3: Matrix of strategies, accuracy, strengths and weaknesses

Data acquisition method/strategy	**DEM Accuracy /Grid**	**Strengths and weaknesses**
Photogrammetry using existing 1:40,000 imagery	±1m 20-50m grid and breaklines	**Strengths:** Existing imagery is available and can be utilised quickly. Breakline and hydrological data will be captured. NRW may provide imagery as project contribution. Orthophotos can be generated at approximately $10 sq km. **Weaknesses:** Does not include Near Infra Red band for imagery. Accuracy will not enable some catchment applications to be undertaken. Imagery may range from 2 to 5 years old which may not accurately reflect current terrain or land use.
Photogrammetry using new digital 1:40,000 imagery	± 1m 20-50m grid and breaklines	**Strengths**: Up to date digital imagery is captured. Breakline and hydrological data will be captured. NIR image band is captured enabling vegetation analysis. **Weaknesses:** Accuracy will not enable some catchment applications to be undertaken. Data capture will require weather window and may slow acquisition.
LIDAR	± 0.25-0.3m 2m sampling rate	**Strengths:** Capture can be done during day or night. High accuracy and fine resolution. Suitable for sub-catchment analysis and almost all identified applications. Can also enable vegetation canopy and structural analysis. **Weakness**: Very large data sets generated. Some limitations may be experienced in acquiring "bare earth" models e.g. heavily foliaged crops may not permit signal penetration.
Photogrammetry using new 1:12,000 scale imagery	± 0.25-0.3m 5-10m sampling	**Strengths:** High accuracy and integrity. Breakline and hydrologic data captured. **Weaknesses**: Costly data acquisition. Acquisition will require suitable weather window and hence may delay project.
Satellite imagery – IKONOS, QuickBird, ALOS, SPOT, ASTER	± 2-25m 10-100m grid	**Strengths**: Multi-spectral data available and competitive pricing. **Weaknesses**: Accuracy variable. Bare earth model not guaranteed;- accuracy varies across scene due to stereo angle, temporal variations can cause image analysis problems

Satellite imagery, from sensors such as IKONOS, SPOT, ASTER and ALOS provide the ability to capture digital surface models (PCI Geomatics 2005). It is important to realise that the images from these satellite sensors are generally processed automatically through an image matching process. The output from this process is a digital surface model which may or may not represent the terrain (Poon *et al.* 2007). In open areas such as cultivation and pasture, the processed model will generally represent the terrain; however in forested areas the model will represent the top of vegetation. For example, SPOT 5 is unlikely to improve on the accuracy of the existing DEM as it is likely that the DEM generated from this data would have a vertical accuracy of between 5 to 10m (Kornus et al. 2004). In addition, the satellite imagery may not accurately identify a bare earth model.

IKONOS and ALOS are perhaps the most promising with accuracy assessments between 2-5m in the determination of a surface model (Poon *et al.* 2007; Takaku *et al.* 2003). These accuracies will not accommodate the majority of identified applications and needs and variability will occur in differing terrain and land covers. Finally, no breakline or hydrological data would be captured from automatically processed satellite imagery and this would further limit its use for floodplain management.

LIDAR capture has the potential to yield DEM accuracies of between 0.15 to 0.5m. The accuracy of LIDAR depends on a range of variables including flying height, terrain, capture density, aircraft speed, power of the laser and aircraft control (Liu 2008). Although no breakline or hydrological data collection is undertaken, the high point density diminishes the need for such additional data. LIDAR has the potential to deliver both a DEM (based on last return) and surface model (first return). Additionally the return signal strength may be further analysed to differentiate objects.

Conclusions

The large inland catchments across Australia are receiving unprecedented attention due to the ongoing issues of climate change, water and sustainable development of our natural resources. This paper discussed the importance of digital elevation models to catchment management activities and the technologies available to capture DEMs over large catchment areas. The study found that it is important to ensure that with any large data capture project that the needs of the various stakeholders should be carefully considered.

It was concluded that no one DEM data capture strategy will meet the needs of all stakeholders when issues of coverage, accuracy and cost are considered. An analysis of the strengths and weaknesses of the various data capture strategies can also prove to be a useful tool in deciding on the final collection strategy. The Condamine catchment consisting of largely flat flood plains with intensive and productive land use and will require medium to high accuracy DEM for most catchment based resource management purposes. The use of land use and slope classification maps as well as existing floodplain boundaries can provide the basis for the identification of priority areas within the catchment.

It is suggested that a collaborative approach has the potential to deliver improved outcomes with respect to the development of a high quality DEM over the catchment. A collaborative approach should optimise the existing investment across the public and private sectors and reduce potential duplication of effort. The resulting DEM should also be made widely available so that it can be more effectively utilised to support decision making on important issues such as water management and disaster assessment and mitigation.

Acknowledgements

We wish to acknowledge the assistance of the Condamine Alliance in funding the DEM investigation over the Condamine Catchment and the input from various stakeholders in the DEM workshop.

References

CCMA 2001, *Condamine Catchment Strategic Plan, June 2001*, Condamine Catchment Management Association, viewed December, 2007 <http://www.condaminecatchment.com.au/strat_executive.htm>.

COAG 2006, *National Climate Change Adaption Framework*, Canberra.

Eastern Downs Regional Planning Advisory Committee 2003a, *Runoff and Flow Coordination Framework for the Condamine Floodplains*, Queensland Department of Local Government and Planning, Brisbane.

Eastern Downs Regional Planning Advisory Committee 2003b, *Guidelines for Incorporating Runoff and Flow Coordination into Local Government Planning Schemes on the Condamine Floodplains*, Queensland Department of Local Government and Planning, Brisbane.

El-Sheimy, N, Valeo, C & Habib, A 2005, *Digital terrain modeling: acquisition, manipulation, and application*, Artech House, Boston and London.

Forlani, G & Nardinocchi, C 2007, 'Adaptive filtering of aerial laser scanning data', *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, vol. 36, no. part 3/W52, pp. 130-5.

Hodgson, ME & Bresnahan, P 2004, 'Accuracy of airborne lidar-derived elevation: empirical assessment and error budget', *Photogrammetric Engineering and Remote Sensing*, vol. 70, no. 3, pp. 331-9.

Kienzle, S 2004, 'The effect of DEM raster resolution on first order, second order and compound terrain derivatives', *Transactions in GIS*, vol. 8, no. 1, pp. 83-111.

Kornus, W, Alamus, R, Ruiz, A & Talaya, J 2004, 'Assessment of DEM accuracy derived from SPOT-5 high resolution stereoscopic imagery', paper presented to ISPRS Congress, Istanbul.

Li, Z, Zhu, Q & Gold, C 2005, *Digital Terrain Modeling: Principles and Methodology*, CRC Press, Boca Raton, London, New York, and Washington, D.C.

Liu, X 2008, 'Airborne LiDAR for DEM generation: some critical issues', *Progress in Physical Geography*, vol. 32, no. 1, pp. 31-49.

Maune, DF, Kopp, SM, Crawford, CA & C.E.Zervas 2007, *Introduction: Digital Elevation Models*, 2nd edn, Digital Elevation Model Technologies and Applications: The DEM Users Manaul, American Society of Photogrammetry and Remote Sensing, Maryland.

OESR 2007, *Local Government Area Profile - The Condamine Region.*

PCI Geomatics 2005, *DEM extraction features in Geomatic OrthoEngine*, viewed April 2008, <http://www.pcigeomatics.com/>.

Poon, J, Fraser, C & Zhang, C 2007, 'Digital Surface Models from high resolution satellite imagery', *Photogrammetric Engineering and Remote Sensing*, vol. 73, no. 11, pp. 1225-31.

Raber, GT, Jensen, JR, Hodgson, ME, Tullis, JA, Davis, BA & Berglend, J 2007, 'Imact of LiDAR nominal post-spacing on DEM accuracy and flood zone delineation', *Photogrammetric Engineering and Remote Sensing*, vol. 73, no. 7, pp. 793-804.

Ramirez, JR 2006, 'A new approach to relief representation', *Surveying and Land Information Science*, vol. 66, no. 1, pp. 19-25.

Sanyal, J & Lu, XX 2004, 'Application of Remote Sensing in Flood Management with Special Reference to Monsoon Asia: A Review', *Natural Hazards*, vol. 33, pp. 283-301.

Takaku, J, Futamura, N, Goto, A, Iijima, T, Tadono, T, Aatsuoka, M, Shimad, M & Shibasaki, R 2003, 'High resolution DEM genaration from ALOS Prism data - Triplet image algorithm evlaution', paper presented to Proc. IEEE IGRASS, Toulose.

Upper Condamine Floodplain Project 1998, *Upper Condamine Floodplain Scoping Study - Publication 2.*

Ziadat, FM 2007, 'Effect of Contour Intervals and Grid Cell Size on the Accuracy of DEMs and Slop Derivatives', *Transactions in GIS*, vol. 11, no. 1, pp. 67-81.

This work is licensed under a Creative Commons Attribution-Share Alike 2.5 Australia License.
To view a copy of the License visit: http://creativecommons.org/licenses/by-sa/2.5/au/