Evaluation of Current DEM Accuracy for Condamine Catchment

Kevin McDougall [1 +], Xiaoye Liu [1], Badri Basnet [1] and Armando Apan [1]

[1] Australian Centre for Sustainable Catchment, and
Faculty of Engineering and Surveying,
University of Southern Queensland,
West Street, Toowoomba, QLD 4350, Australia

Abstract. A digital elevation model (DEM) is one of the most important datasets for catchment management and planning. It provides elevation information that is useful for many environmental applications including hydrologic modelling and flood management planning. Currently, the most comprehensive catchment wide DEM in the Condamine Catchment is a dataset derived from 1:100,000 topographic mapping. It is identified as the Department of Natural Resources and Water (NRW) DEM and it has an estimated average accuracy of approximately 10m vertically based on a 25m horizontal grid. The Shuttle Radar Topographic Mission (SRTM) derived DEM is also available for this catchment. It has a horizontal resolution of 87m and a vertical accuracy of about 16m. The accuracy of these DEMs may not be suitable for all application areas. Therefore, accuracy assessment of current DEM was deemed necessary. In this study existing ground survey marks were used as 'true' elevation data for DEM accuracy assessment. For assessment purposes, the catchment area was classified into flat, moderate and steeper slope categories and each category was evaluated separately. Elevation data corresponding to the existing survey marks were extracted from each of the above DEMs. Differences were calculated between the survey marks and the elevations extracted from the DEMs. These differences were grouped into several error ranges for each slope category and each DEM type. The result indicated that the NRW 25m DEM has better than 10m accuracy at 90% confidence level. The SRTM 87m DEM over the same area has proven to be slightly better with a 95% confidence of better than 10m. However, the accuracy assessments of these DEMs vary over the different slope categories and land use utilization.

Keywords: digital elevation model, shuttle radar topographic mission, accuracy assessment, catchment

1. Introduction

A digital elevation model (DEM) is an array of numbers that contains the elevation of the ground surface at a series of sample points (Carson & Reuterbuch 1997). The US Geological Survey defines a DEM as a digital cartographic representation of the elevation of the terrain at regularly spaced intervals in x and y directions using z-values referenced to a common vertical datum (Maune et al. 2007). Basically, a DEM is a digital representation that approximates the Earth's topographic surface (Podobhnikar 2007; Ramirez 2006). Two commonly available elevation models are grid based digital elevation model (DEM) and triangulated irregular network (TIN). A TIN is often interpreted as irregular spaced DEM since elevation points are spaced at an irregular interval whereas they are spaced at a regular interval in a gridded DEM (AUSLIG 2001).

Digital elevation models are increasingly used for visual and mathematical analysis of topography, landscape and landforms and modeling land surface processes (Kamp et al. 2003). They serve as a data source for the extraction of a number of topographic parameters including elevation, slope, aspect, inter-visibility and curvature (Erskine et al. 2007; Liu et al. 2007). Most geographic information systems and image processing systems have in-built utilities that use DEMs to produce attributes such as slope, aspect and elevation for further analysis (Carson & Reuterbuch 1997). These attributes are

[+] Corresponding author. Tel.: +61-7-46312545; fax: +61-7-46312526.
E-mail address: mcdougak@usq.edu.au

useful in catchment related applications such as water and flood management planning, ecology and landscape management, modelling of hydrologic functions, climate impact assessment, agriculture and forestry production planning and resource management (Maune et al. 2007). DEM is also useful in finding features such as drainage basins, drainage networks, peaks and pits and other landforms on the terrain.

The usefulness of a DEM for these applications may however depend on the quality of the DEM itself since extracted terrain attributes are sensitive to its accuracy. Spatial resolution of a DEM is found to have effect on many derived attributes. The elevation error at a single point in a DEM is found to be dependent on the cell resolution of the DEM and the roughness of the surface that is being modeled (Hutchinson 1996). Slope is the most important aspect of roughness. Hence, the elevation error is greater in mountainous area (AUSLIG 2001). Erskine et al. (2007) found decreasing sensitivity of extracted terrain attributes (e.g. land surface curvature) to the DEM accuracy as grid cell size increased. Takagi (1998) observed the effect of spatial resolution on slope inclination sensitivity.

The accuracy of a DEM depends on many factors including the level of detail, density and distribution of data source, interpolation algorithm and DEM resolution (Liu et al. 2007; USGS 2000). Accuracy also depends on the method of elevation representation. A DEM introduces greater error as compared to TIN because the surface of the Earth (i.e. relief) is more accurately represented with irregular network of triangles than regular grids (Ramirez 2006). In general, the more accurate and the denser the sampled terrain data, the more accurate is the produced DEM (Liu et al. 2007).

The Condamine catchment in south-east Queensland (Australia) is the area of interest in this study. The most comprehensive DEM currently available for this catchment is constructed by the Queensland Department of Natural Resources and Water (NRW) from 1:100,000 topographic mapping data. The original data source used for the construction of this NRW-DEM consisted of contours, spot heights and drainage lines digitized from existing mapping. The average accuracy of the data source is considered to be ± 25 meters in the horizontal position and ± 10 meters in height (Kelly 2007). The Shuttle Radar Topographic Mission (SRTM) derived DEM is also available for the catchment. The SRTM project was a joint endeavor of NASA, the National Geospatial-Intelligence Agency, and the German and Italian Space Agencies, and was flown in February 2000 (Farr et al. 2007). The SRTM-DEM was produced using C-band synthetic aperture radars and it has a horizontal resolution of 87meters (Kelly 2007) and an estimated vertical accuracy of 14-16 meters (Weydahl et al. 2007). The accuracy of these DEMs are not be suitable for all applications that are associated with catchment management. In fact, application requirements play an important role in determining the accuracy of an expected DEM. Generally, coarse analyses require lower accuracy DEM. For instance, regional analysis or deriving contours lines may require a lower accuracy DEM as compared to calculating slopes and aspects and/or modeling hydrographical networks (Podobhnikar 2007). In most cases, a very high quality DEM should cover all application demands. However, production of a high quality DEM may cost much more in terms of time, money, software/hardware requirement and expertise (Podobhnikar 2007). Therefore, the accuracy assessment of currently available DEMs is necessary to be able to make best use of existing resources.

DEM accuracy is quantified by comparing linear interpolation elevations in the DEM with corresponding map location elevations and computing the root mean square error (RMSE) or statistical standard deviation (USGS 2000). Since, RMSE involves comparing elevations in the DEM with that of the corresponding elevation on the map, it is not a direct estimate of the accuracy of a DEM in terms of representing a ground surface (Carson & Reuterbuch 1997). Instead, it is a measure of matching accuracy of a DEM with the topographic map. Therefore, it is possible to use more accurate elevation data such as ‘survey marks’ instead of topographic map location elevations to calculate RMSE if such data is available. This study is therefore using ‘survey marks’ as reference elevation data in assessing DEM accuracy.

2. Methods

2.1. Study area

The study area in this paper covers the Condamine Catchment which is located west of the Great Dividing Range in southern Queensland, Australia and covers an area of 24,434 km^2. Over half of the catchment is represented by slopes of less than 1 percent. These areas primarily form the floodplains and encompass the Condamine River and its various tributaries. The land use over the catchment varies with approximately 895,000 ha (31.3%) of the catchment area utilized for both irrigated and dry land agricultural production. Intensive and urban land use comprises of approximately 146,000 ha (5.8%) of the catchment. However, by far the largest land use is production from relatively natural environments which comprise approximately 1,518,000 ha or 59.7% of the catchment.

2.2. Data sources

In this study, two existing DEMs (i.e. NRW-DEM and SRTM-DEM) were assessed using existing ‘survey marks’ as ‘true’ elevation data. The 25m floating-point grids of NRW-DEM were produced using ANUDEM modeling software. The source data for this DEM consisted of contour and spot height information from the 1:100,000 mapping over the catchment with breakline data in the form of the drainage network. The average accuracy of the source data is estimated to be ± 25m in the horizontal position and ±10m in elevation (Kelly 2007). The SRTM-DEM produced from a joint endeavor of NASA, the National Geospatial Intelligence Agency and German and Italian Space Agencies was used as second set of data in this study. The absolute horizontal and vertical accuracy for SRTM-DEM is quoted as 87m and 16m respectively at a 90% confidence level (USGS 2007).

2.3. Processing of data

For the assessment purpose, the catchment area was classified into flat, moderate and steeper slope categories and each category was evaluated separately. As shown in Figure 1 the lower and flatter parts of the catchment are found in the north-western areas of the catchment, whilst the steeper areas are found in the eastern and southern areas which form part of the Great Dividing Range.

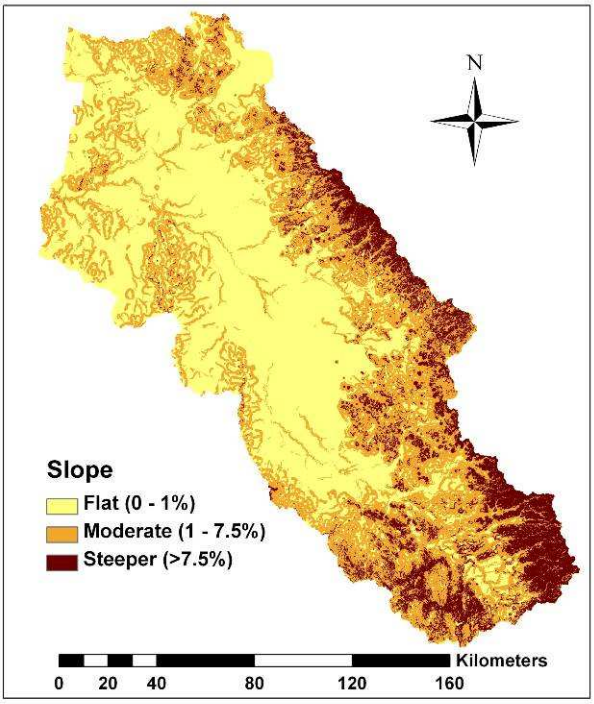

Figure 1: Slope classification

The area coverage of three slope categories is listed in the Table 1 below. It shows that over half of catchment is very flat (51.6%), approximately 36.7% area is in moderate slope and only 11.7% area is in steeper slope (>7.5%).

Table 1: Slope classes over the catchment and their corresponding coverage

Slope	Area coverage
Flat (0-1%)	51.60%
Moderate (1%-7.5%)	36.70%
Steeper (>7.5%)	11.70%

Over 4000 survey marks, containing both positional and height information from NRW Survey Control Data Base were identified over the catchment. These high quality survey marks were used as the ground truth for accuracy assessment of the DEMs. Elevation data, corresponding to the existing survey marks, were extracted from each of the above DEMs. Differences were calculated between survey marks and the elevation extracted from the DEMs. These differences were grouped into several error ranges for each slope category and each DEM type.

3. Results and comparison

Initial comparisons of the two DEMs identified similar variations across the catchment with respect to the minimum, maximum and mean height values. As shown in Table 2, the catchment elevation varies from approximately 280m elevation in the north-west to almost 1370m in the south-east, a variation of almost 1100m.

Table 2: Key elevation statistics of the NRW DEMs over the catchment

	NRW DEM Statistics
Min Elevation	279.23m
Max Elevation	1367.03m
Mean Elevation	428.94m

The elevation differences between the two DEMs and ground survey marks in three slope categories is listed in the Table 3. The results indicate that approximately 42% of NRW 25m DEM has an accuracy of better than 3m in the flat and moderate sloping terrain, whilst only 27% of control points agree to better than 3m in the steeper slope terrain. Surprisingly, the comparisons with the SRTM 87m DEM indicated that 74% of the marks had less than 3m difference over the flat areas, approximately 55% agreement in the moderate slopes and approximately 29% in steeper terrain. These comparisons found that the STRM-DEM has a relatively high DEM accuracy in the flat terrain and may be useful for many environmental applications but would not satisfy the requirements for flood mapping.

Table 3: Comparison between ground points and NRW and SRTM DEMs

Elevation Difference (m)	NRW 25m Resolution DEM			Shuttle Radar 87m Resolution DEM		
	Flat area	Moderate area	Steeper area	Flat area	Moderate area	Steeper area
>50	0.39%	0.38%	1.01%	0.31%	0.25%	2.27%
>25	1.09%	1.09%	4.29%	0.54%	1.13%	6.82%
>15	3.57%	2.89%	11.36%	1.24%	2.30%	13.39%
>10	8.69%	7.99%	28.53%	1.71%	5.15%	24.75%
>5	33.57%	33.01%	57.82%	10.25%	24.88%	52.78%
>3	58.07%	57.70%	73.22%	25.70%	45.07%	71.21%
<3	41.93%	42.30%	26.78%	74.30%	54.93%	28.79%

These differences can be seen more clearly in the Figure 2 below.

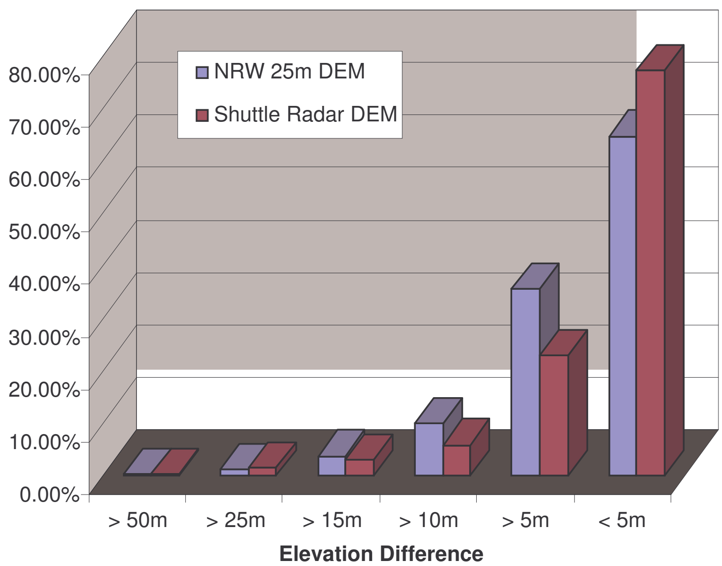

Figure 2: Graphical representation of variations with each DEM

The reasons for some of the spatial variations between ground survey points and each of the DEMs can be explained by Figure 3. As can be seen in the maps of the catchment, the majority of the larger variations tend to be in the upper part of the catchment where the terrain variations are quite large and the accuracy of the DEMs decreases due to the spatial accuracy of both DEMs. The coverage over the majority of the lower parts of the catchment and the flood plain provides the best comparison with the ground marks.

Figure 4 illustrates the difference DEM between the NRW DEM and the SRTM DEM. As expected this difference DEM highlighted the areas where there was the closest agreement (<5m) and the areas where the two DEMs vary significantly. These generally follow a similar patter to figure 3 where the best agreement can be found in the floodplain areas and greater difference in the higher and steeper elevation areas of the catchment.

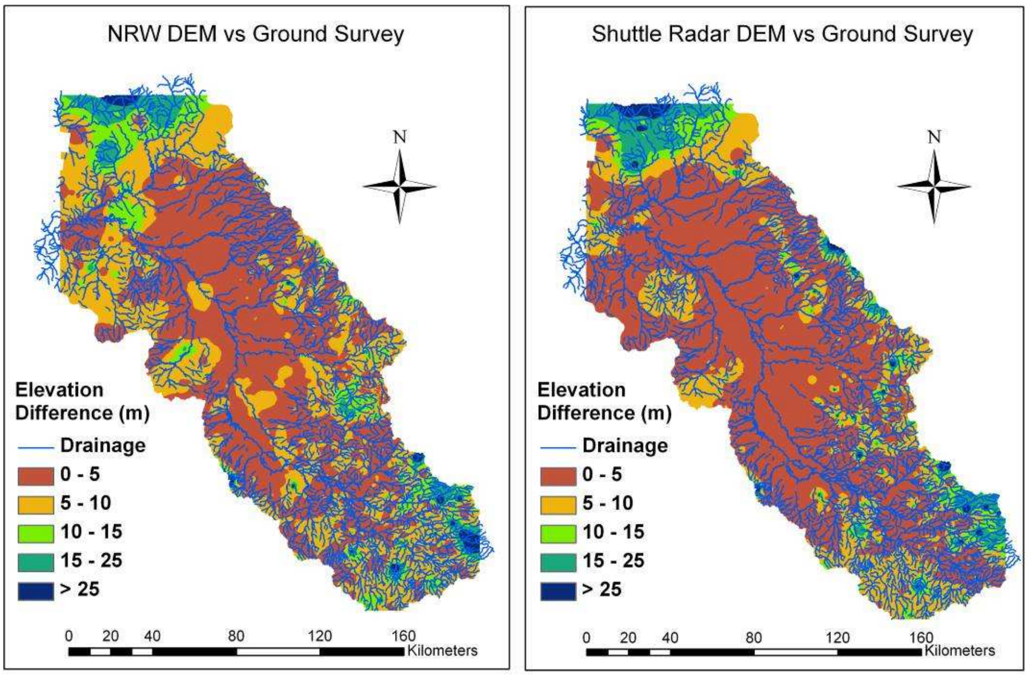

Figure 3: Comparison of NRW-DEM and Shuttle Radar DEM with ground survey marks

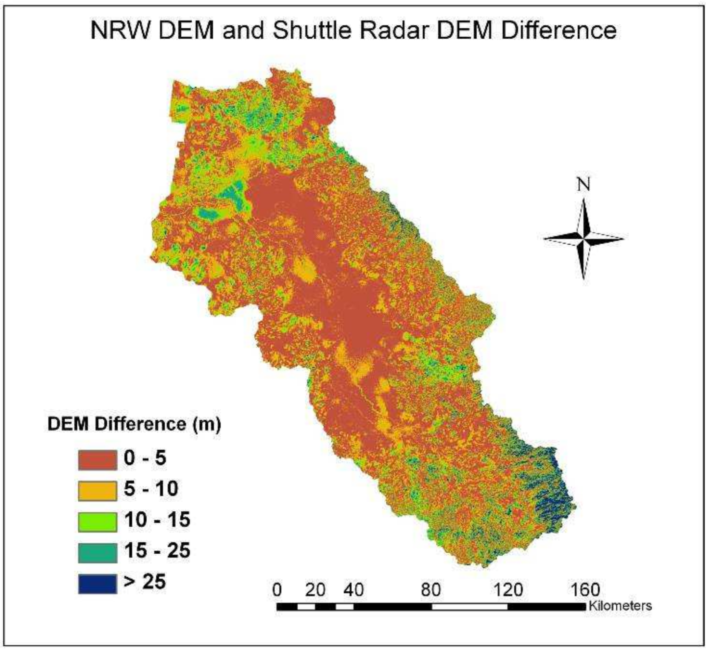

Figure 4: DEM difference model (NRW - SRTM)

The comparison of the DEMs was undertaken initially using the raw DEM cell sizes of 25m and 87m for the NRW and the SRTM-DEM respectively. A secondary comparison was also completed after re-sampling the NRW-DEM to the same grid cell resolution as the SRTM i.e. 87m.

However, no significant improvement in the comparison of the DEM data was found and as expected the NRW data further deteriorated in quality after the resample as shown in Table 4.

Table 4: Comparison of DEMs after re-sampling

Elevation Difference (m)	NRW 25m DEM	NRW 87m DEM	Shuttle Radar 87m DEM
> 50m	0.17%	0.30%	0.27%
> 25m	1.13%	1.55%	1.30%
> 15m	3.64%	4.63%	2.85%
> 10m	9.94%	11.49%	5.78%
> 5m	35.42%	38.62%	22.81%
< 5m	64.58%	61.38%	77.19%

4. Discussion

Digital elevation models (DEM) are now being increasingly recognised as a critical fundamental data set for the planning, design and ongoing management of infrastructure and resources. However, the dispersed and variable quality of the digital currently held by mapping agencies has limited the wider application of DEM to areas such as catchment management. 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. Although Australia has made significant advances in the collection and coordination of spatial data, there are still many areas of the country where very limited data exists or the quality and currency of the data is poor.

The results of this assessment revealed a number of interesting outcomes which are relevant to the development and use of DEMs for catchment management. Typically, the requirements for the accuracy and applications of digital elevations models will vary across a catchment. In many inland catchments the lower and flatter areas of catchments are often part of a floodplain that is utilized for productive agriculture, particularly cropping and animal production. With over 51% of the Condamine catchment having slopes of less than 1%, neither the NRW nor the SRTM-DEM is considered to be of sufficient accuracy for floodplain analysis. Studies across inland floodplains have found that accuracies of better than 0.5m are required for floodplain analysis (National Research Council 2007).

Upon examination of the results it is apparent that the SRTM-DEM has compared more favourably to the ground control than the NRW-DEM which was derived from 1:100,000 topographic mapping. In particular, the SRTM data has performed the best in the floodplain areas which are characterized by cropping and open grazing land with limited natural vegetation coverage. In this situation the shuttle radar had a good opportunity to acquire a near "bare earth" model. Over 74% of the control points having less than 3m elevation differences to the SRTM-DEM compared to 42% for the NRW-DEM, indicating that the SRTM has performed significantly better than its stated accuracy. Although the SRTM stated vertical accuracy is +/-16m, the global accuracy varies across continents. Australia has one of the higher continental accuracies with a 90% absolute vertical accuracy of +/-6.0m and +/-4.7m in relative elevation accuracy (Rodríguez et al. 2006).

In the flat to moderate slope category (1-7.5% slopes) the differences between the two DEM comparisons is less pronounced, although still considered significant. In the Condamine catchment, these slope areas are generally characterized by a range of mixed land use including, cropping, grazing and natural vegetation landscapes. The performance of the SRTM was still significantly better than the NRW data with 55% of control marks differing by less than 3m compared to 42% of the NRW-DEM.

The steeper slopes of the catchment i.e. those areas classified at greater than 7.5%, represent less than 12% of the overall catchment. These areas are generally located around the upper part of the catchment with the steeper slopes limiting the productive land use options. These areas are characterized by limited cropping with the dominant land use consisting of grazing and natural environments. The SRTM and the NRW DEMs have performed similarly with approximately 29% and 27% respectively achieving differences of less than 3m. This tends to confirm that the heavier vegetation cover and increased slope will reduce the effectiveness of the SRTM-DEM. Scattering and reflections of the radar from vegetation is known to artificially increase the elevation data by approximately 40% of the canopy height. In theory, the photogrammetrically determined NRW DEM should perform more consistently in the steeper and more heavily vegetated areas as photogrammetric operators have control over the selection of ground points.

Finally, from an accuracy perspective it should also be noted that the control data and DEM comparisons will also deteriorate as the slope increases. In flat terrain, a 1% slope will correspond to 0.25m over the distance of a 25m NRW grid cell and 0.87m over an 87m SRTM cell. At 10% slope the 25m grid cell accounts for 2.5m whilst the SRTM cell accounts for 8.7m. Therefore, the accuracy comparisons with ground control points become increasingly problematic when slopes increase beyond 10%.

5. Conclusions

This paper has compared two DEMs over a large catchment area to assess their accuracy as a function of slope. The SRTM-DEM generally proved to be more accurate than the existing NRW photogrammetrically derived DEM, particularly in the flatter (lower) areas of the catchment. However, the differences tend to converge in the stepper and more heavily timbered areas of the catchment. In these areas the smaller grid cell size and a human determined photogrammetric mapping approach should yield better results.

The relatively course accuracy of both DEMs means that these datasets may not be suitable for operational management of the large floodplain areas. However, they do provide a valuable resource for the purpose of catchment planning and can assist the identification of the extents of the floodplain that may require more accurate data capture strategies such as LIDAR.

6. Acknowledgements

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7. References

[1] AUSLIG 2001, *A digital elevation model of Australia with a grid spacing of nine seconds in longitude and latitude*, Canberra, <http://www.ga.gov.au/image_cache/GA4783.pdf>.

[2] Carson, WW & Reuterbuch, SE 1997, 'A rigorus test of the accuracy of USGS digital elevation models in forested areas of Oregon and Washington', paper presented to ACSM 57th and ASPRS 63rd Annual Convention, Washington.

[3] Erskine, RH, Green, TR, Ramirez, JA & MacDonald, LH 2007, 'Digital Elevation Accuracy and Grid Cell Size: Effects on Estimated Terrain Attributes', *Soil Science Society of America Journal*, vol. 71, no. 4, pp. 1371-80.

[4] Farr, T, P. Rosen, E.Caro, crippen, R, Duren, R, Henley, S, Kobrick, M, Paller, M, Rodriguez, E, Roth, L, Seal, D, Shaffer, S, Shimada, J, Umland, J, Werner, M, Oskin, M, Burbank, D & Alsdorf, D 2007, 'The Shuttle Radar Topography Mission', *Reviews of Geophycis*, vol. 45, no. RG2004.

[5] Hutchinson, MF 1996, 'A locally adaptive approach to the interpolation of digital elevation models.' paper presented to Third International Conference Integrating GIS and Environmental

[6] Modeling, Santa Barbara, 21-21 January 1996.

[7] Kamp, U, Bolch, Ta & Olsenholler, J 2003, 'DEM generation from ASTER satellite data for geomorphmetric analysis of Cerross Sillajhuay, Chile/Bolivia.' paper presented to ASPRS 2003 Annual Conference, Alaska.

[8] Kelly, P 2007, *National Elevation Data Framework Business Plan (Draft).*

[9] Liu, X, Zhang, Z, Peterson, J & Chandra, S 2007, 'The effect of LiDAR data density on DeM accuracy', paper presented to International Congress on Modelling and Simulation, Christchurch, 10-13 December 2007.

[10] Maune, DF, Kopp, SM, Crawford, CA & Zervas, CE 2007, *Introduction*, 2nd edn, Digital Elevation Model Technologies and Applications: The DEM Users Manual, American Society for Photogrammetry and Remote Sensing, Maryland.

[11] National Research Council 2007, *Elevation Data for Floodplain Mapping Technologies*, National Academy of Sciences.

[12] Podobhnikar, T 2007, *Suitable digital elevation model*, <http://www.gisdevelopment.net/technology/tm/tm003pf.htm>.

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

[14] Rodríguez, E, Morris, C & Belz, J 2006, 'A Global Assessment of the SRTM Performance', *Photogrammetric Engineering and Remote Sensing*, vol. 72, no. 3, pp. 249–60.

[15] USGS 2000, *US GeoData Digital Elevation Models*, US Geological Survey, <http://erg.usgs.gov/isb/pubs/factsheets/fs04000.pdf>.

[16] USGS 2007, *Shuttle Radar Topography Mission*, viewed December 2007 2007, <http://srtm.usgs.gov/index.php>.

[17] Weydahl, DJ, Sagstues, J, Dick, OB & Ronning, H 2007, 'SRTM DEM accuracy assessment over vegetated areas in Norway', *International Journal of Remote Sensing*, vol. 28, no. 16, pp. 3513-27.