A Catchment Based Assessment Of The 3-Arc Second SRTM Digital Elevation Data Set

[a]Martinez, C., [a]G.R. Hancock, [a,b]K.G. Evans, and [b]D.R. Moliere

[a]School of Environmental and Life Sciences, The University of Newcastle, Australia

Email cristina.martinez@studentmail.newcastle.edu.au

[b]Hydrological and Ecological Processes Program, Environmental Research Institute of the Supervising Scientist, Darwin, Northern Territory, Australia.

Keywords: *DEM; geomorphology; hydrology; hydrological modeling.*

EXTENDED ABSTRACT

Digital elevation models (DEMs) are three-dimensional representations of the earth's surface, providing a valuable source of data within geomorphological and hydrological studies. In recent years new methods for creating DEMs have become available, with many new data sets available for public use. The recently released Shuttle Radar Topography Mission (SRTM) 3-arc second DEM is an example of such a data set, providing an almost complete global coverage of the earth's land surface at a resolution of approximately 90m horizontal grid size. Concerns over the quality of these new data sets has seen an abundance of studies examining the effect of different DEM grid scales on their ability to accurately and reliably represent catchment form and function (Zhang and Montgomery, 1994).

In this paper we examine the SRTM data for two Australian catchments of different climates, geology and resultant geomorphology. The SRTM data is compared with high resolution DEMs using basic hydrological and geomorphological statistics and descriptors including the area-slope relationship, hypsometric curve, width function, Strahler (1964) and stream networking statistics. The SRTM data was also assessed for catchment hydrology and runoff properties using the Hydrogeomorphic Steady State (HGSS) model of Willgoose and Perera (2001).

Results demonstrate that the SRTM data provides a poor catchment representation (Figure 1). Hillslopes appear as a linked set of facets, displaying little of the complex curvature observed in high resolution data. While catchment area-slope and area-elevation (hypsometry) properties are largely correct, catchment area, relief and shape (as measured by the width function) are poorly captured by the SRTM data. The large grid size of the SRTM data also results in incorrect drainage network patterns and runoff properties. Consequently, for quantitative assessment of catchment hydrology and geomorphology care must be used, as in all cases SRTM derived catchment area is incorrect and smaller DEM grid sizes are required for accurate catchment wide assessment.

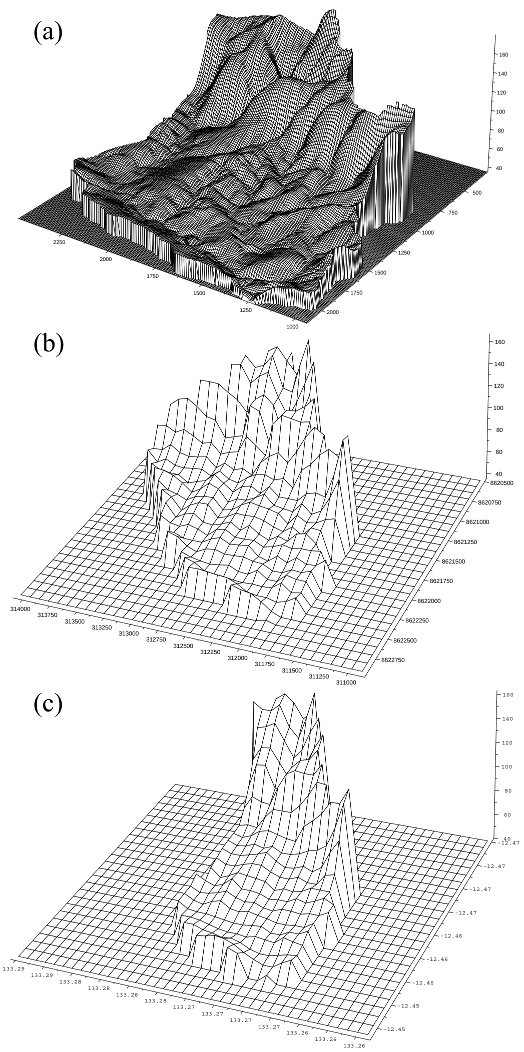

Figure 1: Tin Camp Creek catchment using (a) high resolution 10m DEM (b) 90m DEM and (c) the 90m SRTM DEM.

1. INTRODUCTION

DEMs provide a wealth of information regarding catchment geomorphology and hydrology. Recently, many new methods of creating DEMs have been developed, closely matching the growth in DEM availability and applicability. However, these data sets are often used without much prior knowledge of the quality of the data, thus compromising the accuracy of DEM-derived products.

This study examines the recently released Shuttle Radar Topography Mission (SRTM) 3-arc second digital elevation data for its ability to correctly capture catchment geomorphology and hydrology. The SRTM data is compared with high resolution DEMs for two catchments. It is important that this data set be evaluated, for if it proves to be reliable, it will provide a new and powerful tool with which to examine the earth's surface, in our case the interest being hydrological and geomorphological processes.

2. STUDY SITES

The SRTM data is compared to high resolution DEMs for two catchments in Australia, covering different climates, catchment areas, geology and geomorphology. The locations and characteristics of these catchments are described below.

2.1 Tin Camp Creek

Tin Camp Creek (200ha) is a natural site largely undisturbed by Europeans in Arnhem Land, Northern Territory, Australia (Hancock *et al*., 2002). The site is in the seasonally wet/dry tropical environment of northern Australia, with an annual rainfall of 1389 mm. Tin Camp Creek is part of the Ararat Land System, consisting of closely dissected terrain on mica schists, and developed in the late Cainozoic by the retreat of the Arnhem Land escarpment, resulting in a landscape dissected by active gully erosion. The native vegetation is open dry-sclerophyll forests and is dominated by *Eucalyptus* and *Acacia* species (Story *et al*., 1976).

2.2 Kennedy Creek

Kennedy Creek (900ha) is in the Krui River catchment in the Upper Hunter Valley, New South Wales, Australia. The geology of the area is tertiary basalt (Story *et al*., 1963), a product of Cainozoic volcanism which took place throughout much of eastern Australia (Branagan and Packham, 2000).

Much of the original vegetation in the region has been cleared, the extent of which has largely been influenced by topography. In the north (Liverpool Range), where terrain is rugged, accessibility is restricted, and the area has thus remained largely vegetated. To the south (Merriwa Plateau), clearing has been more extensive due to the rolling to hilly terrain, ensuring greater accessibility. Grazing and cropping activities dominate cleared areas, due to the high fertility of basaltic soils.

3. DIGITAL ELEVATION MODEL DATA

The SRTM data is compared to high resolution DEMs for Tin Camp Creek and Kennedy Creek. These data sets are described below.

3.1 Shuttle Radar Topography Mission (SRTM) 3-Arc Second (90m) DEM

The Shuttle Radar Topography Mission (SRTM) was a collaborative effort by the National Aeronautics and Space Administration (NASA), National Imagery and Mapping Agency (NIMA), German space agency, and Italian space agency (Rabus *et al*., 2003). The mission was launched February 11 2000, aboard the Space Shuttle *Endeavour*. Using radar interferometry, 3-arc second (SRTM-3) and 1-arc second (SRTM-1) DEMs were produced for almost the entire globe. The Australian SRTM-3 data was publicly released in July of 2004. The SRTM-1 data is yet to be released.

Data was collected using two interferometers, C-band (American) and X-band (German) systems, at 1-arc second (30m) (Rabus *et al*., 2003). The 3-arc second DEM was created by 3 x 3 averaging of the 1-arc second data (i.e. 9 data points combined to form a single 3-arc second data point).

Each data tile covers an area spanning one degree in latitude and longitude. Elevation values are given in metres and WGS84 is used as horizontal and vertical datum (Rabus *et al*., 2003). In this study the Tarboton *et al*. (1989) method was used to remove all pits in the data.

3.2 Land and Property Information New South Wales 25m DEM

The 25m DEM from the Land and Property Information New South Wales (LPI) was used for comparison with the Kennedy Creek SRTM data. The DEM is in raster format, with a grid spacing of 25m, and is based on the Australian Map Grid (AMG) coordinate system. Elevation values are provided in metres and referenced to the AUS66 geoid. As for the SRTM data, the Tarboton *et al.* (1989) method was used to remove all pits.

3.3 Tin Camp Creek DEM

Tin Camp Creek landscape data (XYZ coordinates) were determined by digital photogrammetry by AIRESEARCH Pty Ltd, Darwin, and supplied as irregularly spaced data points within an irregularly shaped boundary. Delaunay triangulation was used to interpolate the landscape elevation data on to a 10m grid. This method ensures that triangles close to equilateral are generated and overlay the grid on top of this triangulation (Sloan, 1987). This 10m spacing was equivalent to the average spacing of the original AIRESEARCH data over the catchments examined. Further DEMs were produced at 90m matching that of the SRTM data (Figure 1). As for the previous data sets, the Tarboton *et al.* (1989) method was used to remove all pits.

4. RESULTS OF GEOMORPHOLOGICAL ASSESSMENT

Qualitative or visual assessment of catchment morphology has been shown to provide an important first step in assessing and comparing catchments (Hancock *et al.*, 2002). In this paper, the catchments are assessed using both qualitative (visual) and quantitative measures. Quantitative measures used are the area-slope relationship, hypsometric curve, and the width function. These geomorphic descriptors, along with Strahler (1964) and stream networking statistics, are believed to be integrative measures which graphically describe the surface morphology of a catchment, therefore integrating catchment geology, climate and vegetation over geological time.

The area-slope relationship is the relationship between the area draining through a point versus the slope at the point. It quantifies the local topographic gradient as a function of drainage area. A relationship of the form

$$A^{\alpha}S = \text{constant} \tag{1}$$

where A is the contributing area to the point of interest, α is the slope of the fluvial region of the area-slope relationship, and S is the slope of the point of interest. The area-slope relationship is considered to be a fundamental geomorphic relationship with the value of α ranging between 0.4 and 0.7 for natural catchments (Hack, 1957; Flint, 1974).

Two distinct regions of the relationship are typically observed. Region one represents small catchment areas dominated by diffusive processes that round or smooth the landscape. As catchment area becomes larger, a break in gradient of the curve occurs, where slope decreases as catchment area increases. This region is dominated by fluvial erosive processes.

The hypsometric curve is a non-dimensional area-elevation curve which allows a ready comparison of catchments with different area and steepness. It has been used as an indicator of the geomorphic maturity of catchments and landforms, as Strahler (1952, 1964) divided landforms into youth, mature and monadnock characteristic shapes, reflecting increasing catchment age. Willgoose and Hancock (1998) demonstrated that these characteristic shapes were also consistent with different catchment erosion processes, catchment geometry and network form.

Descriptors of channel networking properties used here are the width function, Strahler statistics and network convergence. The width function (Surkan, 1968) is a plot of the number of channels at a given distance from the basin outlet, measured along the network. A slightly more general interpretation is adopted here, because it is difficult to determine what is channel and what is hillslope on a DEM. The width function used here is therefore the number of drainage paths (whether they be channel or hillslope) at a given distance from the outlet.

The Strahler stream ordering system is considered a fundamental property of drainage networks because it relates to the relative discharge of a channel segment (Summerfield, 1991). Other Strahler statistics used include bifurcation ratio, length ratio, slope ratio, and area ratio.

Catchment drainage network convergence is the average number of channels draining into a point in a catchment. Convergence statistics provide, in addition to the width function, a further method of analysing catchment drainage and network properties (Ibbitt *et al.*, 1999).

4.1 Tin Camp Creek

The Tin Camp Creek catchment displays well-rounded hillslope of regular curvature and hillslope length over the entire domain and is well-dissected by a regularly spaced drainage network (Figure 1). Visual examination of the catchments with different grid spacings demonstrates a loss of surface morphological detail at a grid scale of 90m. Using the 90m grid, the catchment appears as a set of linked linear facets, with hillslope curvature being poorly represented. Much of the hillslope and channel detail has been lost.

Catchment area also differs among the DEMs. Neither the 90m or SRTM DEMs capture the same catchment area as the 10m data, with some catchments missing from the main catchment area (Figure 1 and Table 1). Nevertheless, catchment relief, while lower for the 90m and SRTM data sets than the 10m DEM, is similar.

An examination of the area-slope data for the different grid spacing demonstrates that as grid size increases, detail in the area-slope relationship is lost (Figure 2). At a grid spacing of 90m, the curvature in the diffusive region is lost and the area-slope relationship is log-log linear for its entire domain. The slope (α value) of the log-log linear section of the curve also varies, with a large difference between the 10m and 90m DEMs (Table 1).

Comparison of the hypsometric curve for the catchment over the different grid scales demonstrates that both the 90m and SRTM data sets are slightly higher (larger integral) (Table 1) than the 10m high resolution data, but all have the same shape (Figure 2). This suggests that the distribution of area and elevation in a catchment is scale invariant and that the hypsometric curve is largely insensitive to grid scale, as it provides little information on the loss of hillslope and channel definition as grid size increases (Hancock, 2005).

Table 1: Catchment statistics for Tin Camp Creek and Kennedy Creek.

	Tin Camp Creek			Kennedy Creek	
	10m	**90m**	**90m SRTM**	**25m**	**90m SRTM**
Area (ha)	197	250	189	900	859
Relief (m)	144	129	117	634	636
Hypsometric Integral	0.25	0.28	0.27	0.42	0.41
α	0.34	0.57	0.40	0.43	0.50
Strahler Order	6	4	4	6	5
Bifurcation Ratio	5.46	7.11	5.44	4.43	4.36
Slope Ratio	1.14	2.35	1.88	1.14	1.34
Length Ratio	1.24	2.41	1.92	1.38	1.35
Area Ratio	4.91	8.43	6.40	4.51	4.33
Network Convergence	1.36	2.07	1.92	1.24	1.42

The width function displays considerable spatial variability as a result of both catchment shape and catchment size (Figure 2). The 90m data follows the high resolution data for the rising limb, but provides a poor match for the falling limb, whereas the SRTM data is the opposite. This reflects the different catchment shapes and resultant drainage network of the DEMs. The width function appears to be a sensitive indicator of differences in grid spacing (Hancock, 2005).

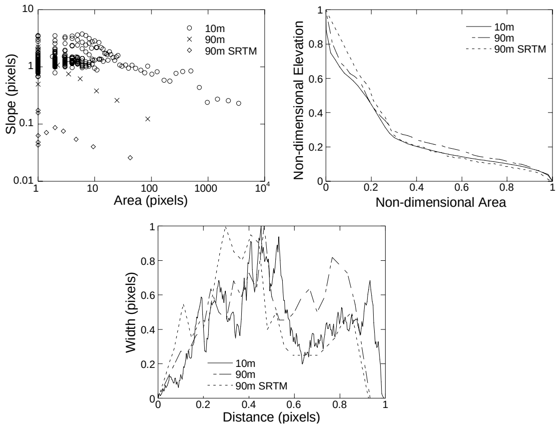

Figure 2: Tin Camp Creek area-slope relationship (for clarity results were divided by an increasing factor of 10) (top left); hypsometric curve (top right); and normalised width function (bottom).

The Strahler network statistics reveal that as catchment grid spacing increases, the maximum stream order of the catchments decreases while the bifurcation, slope, length and area ratios increase (Table 1). This demonstrates that choice of DEM grid spacing has a direct impact on Strahler network properties and is reflecting a more branched network as grid size increases.

Convergence statistics (Table 1) demonstrate that the 90m and SRTM data have a higher network convergence than the high resolution 10m DEM. This suggests that the 10m DEM has a less branched network than the 90m and SRTM DEMs. This demonstrates that as catchment grid spacing increases so does the network convergence value, suggesting that grid size has an effect on drainage network characterization.

4.2 Kennedy Creek

Visual examination of the catchment suggests that catchment shape, relief and hillslope morphology are different for the 25m and 90m SRTM data (Figure 3). The coarser grid size of the SRTM data appears to lose hillslope and drainiage network definition, similar to that seen for Tin Camp Creek. Catchment area is also slightly different (Table 1).

Examination of the area-slope results suggest there are differences between the 25m and SRTM DEMs (Figure 4). Similar to Tin Camp Creek, as grid size increases, detail in the area-slope relationship is lost, as much of the curvature in the diffusive region of the SRTM data is lost. The α values also differ between the 25m and SRTM data sets, recording values of 0.43 and 0.50 respectively (Table 1).

(a)

(b)

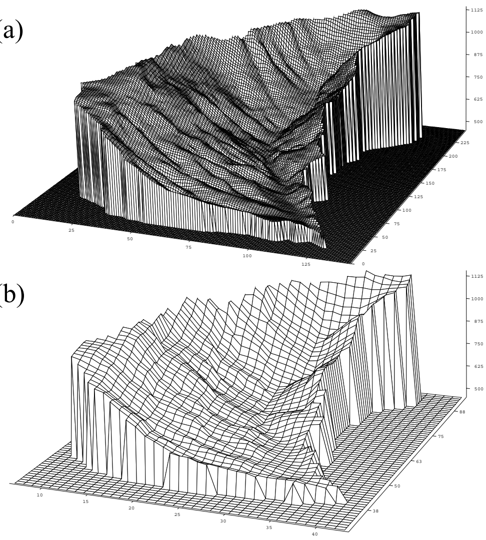

Figure 3: Kennedy Creek catchment using (a) 25m DEM and (b) the 90m SRTM DEM.

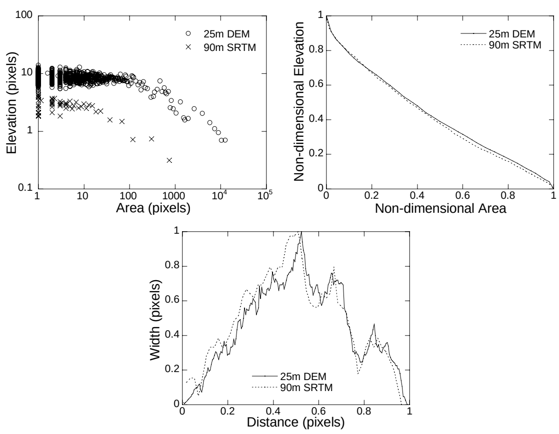

Figure 4: Kennedy Creek area-slope relationship (for clarity SRTM data was divided by 10) (top left); hypsometric curve (top right); and normalised width function (bottom).

The results of the hypsometric analysis suggest there is no difference between the 25m and SRTM DEMs (Figure 4 and Table 1). The hypsometric curves overlay each other, displaying a mature shape curve, with similar integrals demonstrating that both data sets have very similar area-elevation properties (Figure 4 and Table 1).

An examination of the width function indicates minor differences exist between the DEMs (Figure 4). The overall shape of the width function is comparable for the two DEMs, with the 90m SRTM data largely following the rising and falling limbs of the 25m DEM.

Strahler network statistics suggest minor differences exist between the two DEMs (Table 1). The Strahler stream order is 6 for the 25m DEM and 5 for the SRTM data, reflecting the loss of hillslope and channel network detail seen for the coarser SRTM data (Figure 3). All other statistics, except for the slope ratio, are slightly higher for the 25m DEM, while network convergence is higher for the SRTM data, suggesting a more branched network than the 25m DEM.

5. ASSESSMENT OF CATCHMENT HYDROLOGY FOR THE 10M, 90M AND 90M SRTM DEMS

Wetness indices have been extensively used to assess the runoff properties of catchments (Moore *et al.*, 1991). In order to assess the impact of different DEM grid scale on runoff properties of the catchments the Hydrogeomorphic Steady State (HGSS) model of Willgoose and Perera (2001) was used for Tin Camp Creek. This model incorporates catchment organization and geomorphological relations of the area-slope relationship and the cumulative area distribution.

In this study, the wetness index λ_i is used to describe the relative area of the catchment saturated when water saturates the total depth of the soil profile. The saturation of the soil profile and resultant saturation excess runoff is a typical runoff process in the monsoonal tropical climate of the Northern Territory. The wetness index (λ_i) is calculated by

$$\lambda_i = \frac{A_i^{1+\alpha}}{C} \qquad (2)$$

where A_i is catchment area draining through a point, α and C are the exponent and constant in the area-slope relationship (Equation 1) for the entire catchment. In this case α and C are taken from the 10m, 90m and SRTM data sets for Tin Camp Creek (Table 1).

The wetness index was overlaid on the drainage network for each catchment (Figure 5). The results demonstrate that the 10m data produce saturated areas along the major drainage lines (areas that would be expected to be saturated each season) but for the 90m and SRTM data sets a much greater area of the catchment is saturated. Consequently, use of this coarse grid size data is likely to result in an overestimate of runoff in these catchments.

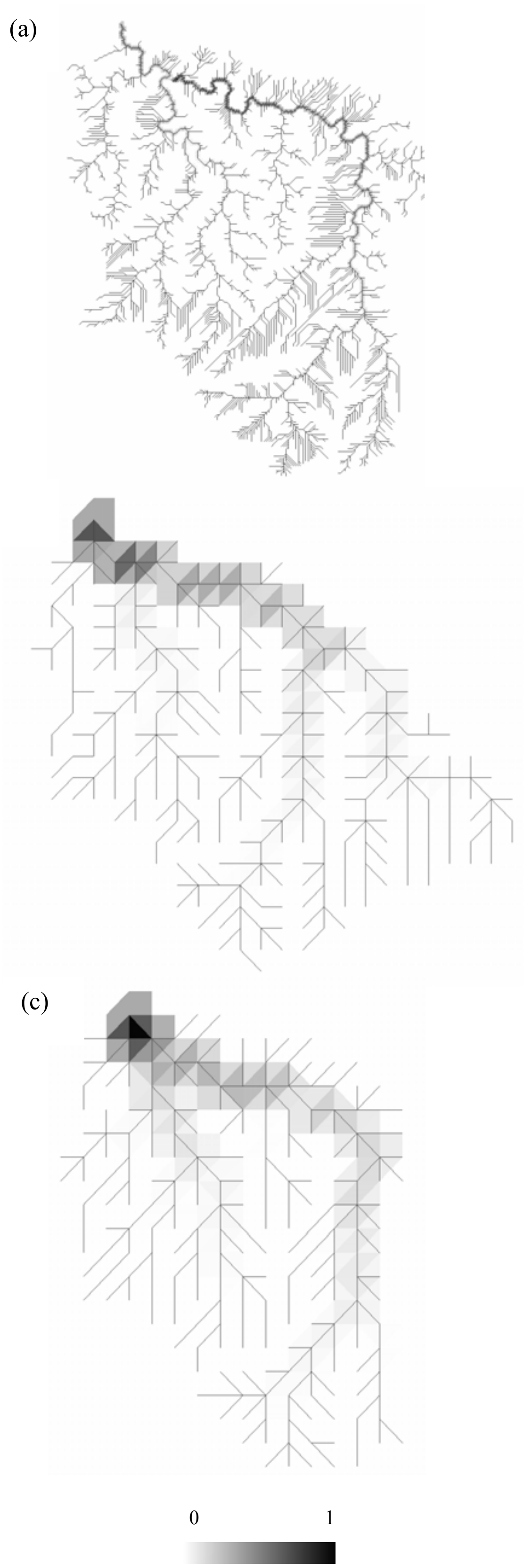

Figure 5: Drainage network and wetness index for Tin Camp Creek for the (a) 10m (b) 90m and (c) 90m SRTM DEMs. Saturated areas appear along drainage lines for 10m data.

6. DISCUSSION AND CONCLUSIONS

New spatial data sets (such as the SRTM) require detailed assessment before they can be used reliably. The results of this study demonstrate that for the smaller Tin Camp Creek catchment, the SRTM data provides a poor catchment representation. Hillslopes appear as a linked set of facets and display little of the complex curvature observed in high resolution data. While catchment area-slope and area-elevation (hypsometry) properties are largely matched in all cases, catchment area, relief and shape (as measured by the width function) is poorly captured by the SRTM data. Catchment networking statistics are also variable. These findings, together with the larger area likely to be saturated in the large grid size DEMs, raises questions about the viability of the SRTM data for hydrological modelling. Therefore, caution must be used when applying this data set.

A major concern of this study is the inability of this coarse resolution data to correctly capture catchment area. Large differences occur between the high resolution and SRTM data. The SRTM data is not sufficiently fine to capture critical stream junctions, which leads to loss of stream lines and resultant area. These two factors combine to produce catchments which have very different geomorphological and hydrological characteristics than that of what is expected to occur in the field.

Results demonstrate that the fluvial region of the area-slope relationship of the SRTM compares well with the high resolution data (Table 1). This finding, together with the scale invariance of the hypsometric curve, shows that the SRTM data is correctly capturing catchment area-elevation properties. Consequently, for catchment area-elevation analysis, the SRTM data appears reliable for the cases examined. The reliability of the area-slope data also suggests that the SRTM data set may be useful in broad scale derivation and assessment of hydrological and erosion model parameters (Willgoose, 1994; Hancock *et al.*, 2002).

Nevertheless, for larger catchments such as Kennedy Creek, the SRTM data is largely able to capture catchment properties (despite incorrect catchment area). The results demonstrate that for broad scale qualitative assessment of large catchments, the SRTM data is of benefit. Higher resolution DEM data is required for a reliable catchment wide assessment. Nevertheless, for quantitative assessment of catchment hydrology and geomorphology care must be used.

7. ACKNOWLEDGMENTS

The traditional owners of the land in the Northern Territory, Parks Australia North, The Northern Land Council and Supervising Scientist Group staff, especially John Lowry are thanked for their cooperation and assistance. The support of Landholders in the Merriwa region is also gratefully acknowledged. The advice and support of Olivier Rey-Lescure (DEM preparation), Garry Willgoose together with review comments by David O'Brien is very much appreciated.

8. REFERENCES

Branagan, D.F. and G.H. Packham (2000), *Field Geology of New South Wales* (3rd edition), New South Wales Department of Mineral Resources, 418 pp., Sydney.

Flint, J.J. (1974), Stream gradient as a function of order, magnitude and discharge, *Water Resources Research*, 10(5), 969-973.

Hack, J.T. (1957), Studies of longitudinal stream profiles in Virginia and Maryland, *United States Geological Survey Professional Paper*, 292(B), 45-97.

Hancock, G.R. (2005), The use of digital elevation models in the identification and characterization of catchments over different grid scales, *Hydrological Processes*, in press

Hancock, G.R., G.R. Willgoose, and K.G. Evans (2002), Testing of the SIBERIA landscape evolution model using the Tin Camp Creek, Northern Territory, Australia, field catchment, *Earth Surface Processes and Landforms*, 27(2), 125-143.

Ibbitt, R.P., G.R. Willgoose, and M.J. Duncan (1999), Channel network simulation models compared with data from the Ashley River, New Zealand, *Water Resources Research*, 35(12), 3875-3890.

Moore, I.D., R.B. Grayson, and A.R. Ladson (1991), Digital terrain modelling: A review of hydrological, geomorphological and biological applications, *Hydrological Processes*, 5, 3-30.

Rabus, B., M. Eineder, A. Roth, and R. Bamler (2003), The shuttle radar topography mission – a new class of digital elevation models acquired by spacebourne radar, *ISPRS Journal of Photogrammetry and Remote Sensing*, 57, 241-262.

Sloan, S.W.A. (1987), Fast Algorithm for constructing Delaunay triangulations in the plane, *Advanced Engineering Software for Workstations*, 9 (1), 34 -55.

Story, R., R.W. Galloway, J.R. McAlpine, J.M. Aldrick, and M.A.J. Williams (1976), *Lands of the Alligator Rivers area, Northern Territory*, Land Research Series N^{o}. 38, CSIRO, 171 pp., Melbourne.

Story, R., R.W. Galloway, R.H.M. van de Graaff, and A.D. Tweedie (1963), *General Report on the Lands of the Hunter Valley*, Land Research Series No. 8, CSIRO, Australia, 152 pp., Melbourne.

Strahler, A.N. (1952), Hypsometric (area-altitude) analysis of erosional topography, *Geological Society of America Bulletin*, 63, 1117-1142.

Strahler, A.N. (1964), Quantitative geomorphology of drainage basins and channel networks, in Chow, V. T. (ed) *Handbook of applied Hydrology*, McGraw-Hill, pp 4.40-4.74, New York.

Summerfield, M.A. (1991), *Global Geomorphology An introduction to the study of landforms*, Addison Wesley Longman Limited, 537 pp., England

Surkan, A.J. (1968), Synthetic hydrographs: Effects of network geometry, *Water Resources Research*, 5(1), 112-128.

Tarboton, D.G., R.L. Bras, I. Rodriguez-Iturbe (1989), *The analysis of river basins and channel networks using digital terrain data*, *TR 326*, Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, Boston.

Willgoose, G.R. (1994), A physical explanation for an observed area-slope-elevation relationship for catchments with declining relief, *Water Resources Research*, 30(2), 151-159.

Willgoose, G.R. and G. Hancock (1998), Revisiting the hypsometric curve as an indicator of form and process in transport limited catchment, *Earth Surface Processes and Landforms*, 23, 611-623.

Willgoose, G.R. and H. Perera (2001), A simple model of saturation excess runoff generation based on geomorphology, steady state soil moisture, *Water Resources Research*, 37(1), 147-155.

Zhang, W. and D.R. Montgomery (1994), Digital elevation model grid size, landscape representation, and hydrologic simulations, *Water Resources Research*, 30(4), 1019-1028.