How High Is High Resolution? Implications of a Very-High-Resolution Micro-Relief Erosion Study

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EXTENDED ABSTRACT

This paper describes a very high resolution digital elevation data set covering a 1 m^2 area, measured at varying intervals over a 20 year period to examine soil erosion and deposition. The whole microDEM corresponds to a single cell from a higher end LIDAR DEM. It was sampled 15 times since 1986 and highlights the ability to start quantifying physical processes such as erosion/deposition and the links between scale and resampling intervals.

The paper investigates some of the challenges making DEMs at this resolution, the inferences about processes that can and can't be made through various scales.

The major limitation to this approach is the manual ground-based sampling method which is very time consuming. For this reason data collection was opportunistic and meant that in some instances the data collected was much sparser than the nominal 2.5 cm resolution. While these sparse datasets were insufficient to derive a meaningful DEM they do still provide at least 194 point comparisons in the $1m^2$ between sample dates. Improved (automated) sampling methods could increase the study areas to interesting proportions, or to a representative number of calibration quadrats in a much larger area.

The results show that the erosion rates from high density $1m^2$ sampling compares reasonably with erosion rates measured at 8, wider spaced (20m), star pickets in similar salt-scalded locations. Erosion pin measurements outside the salt scald show different behaviours. The study also shows the necessity to update DEMS more frequently as resolution increases (dependent on the processes of interest).

Selected representative microDEMs provide information on fine-scale spatial patterns of erosion and deposition that cannot be obtained from more widely spaced point data.

The microDEM is useful here because the processes are structured at a very fine scale. We think this is an uncommon situation and is unlikely to be as useful in many other landscape positions and particularly sites with vegetative cover.

The microDEM is like a scale model of the study area catchment, having tributaries draining into the main channel located approximately through the middle.

The advantage of using a microDEM is that it averages many elevation changes over a reasonable area, ie is data rich. Depending on position some points vary markedly and others very little so choosing a single point can introduce more uncertainty.

The main disadvantage of the microDEM is the data collection time. A more cost effective technology, such as remote sensing, could be very useful in capturing a larger number of representative sites (landscape positions) in a catchment, rather than just the one available for this study.

1. INTRODUCTION

This paper follows from significant salinity studies in the early 1980's by CSIRO Division of land Use Research (Bullock and Neil, 1990; Bullock, 1987a,b). These studies included the setting up of an erosion rate experiment at 50 x 20 m resolution and a very small, very fine resolution alternative measurement (microDEM). Long term erosion measurements were planned to investigate the different erosion rates in the fine sandy topsoil and the heavy yellow clay subsoil. With changes in rainfall amount and pattern due to extended drought this has not been achieved. When the project ended the monitoring was sustained in the interest of science, as opportunities permitted. It is now a very useful long term dataset (Richardson, unpub.) for erosion and geomorphological studies.

The datasets from Yarralaw provide an opportunity to compare a large area of spatially sparse measurements with a very small area with spatially dense measurements.

2. OBJECTIVES

Main objective of this work is to explore the processing issues and usefulness of microDEMs with respect to erosion studies. The specific objectives are to:

- compare the erosion rates determined from a large area of spatially sparse measurements and a very small area with spatially dense measurements.

- assess the benefits of a very high resolution DEM to understanding erosion processes.

3. STUDY AREA

The Yarralaw study site is a 4.3 ha salt scald in a 37.8 ha subcatchment situated ~60 km northeast of Canberra (-34^{o} 16' S 149^{o} 53' E) in New South Wales, Australia (Fig. 1). Elevation ranges from 605m to 635m with a well defined N-S valley through the centre of the area. Geology is predominantly porphyritic monzonite intruded through ordivician sediments (Gunn, 1985). Soils, yellow duplex or texture contrast with a strongly bleached A2 horizon, are thixotropic when saturated – a normal occurrence in winter. The fine sandy topsoil is highly erodible when the vegetative cover is removed. Mean annual rainfall is approximately 670mm with an even distribution throughout the year. Natural vegetation was *Eucalyptus rossii, E. melliodora and E. macrorhyncha* that has been cleared to less than 1% cover prior to 1941. A small pine plantation was established near the site in the 1980's together with Eucalyptus regrowth occurring from about that time. Sheep and cattle grazing has been the major land use. Research into salinity and erosion are well advanced on the site through a number of long term studies. Extensive mapping of topography, geology, electromagnetic conductivity, soils, vegetation and groundwater level surveys had taken place as part of traditional methods of assessing and ameliorating erosion and salinity. Evidence of salinity appeared between 1952 and 1962 (4 ha salt scald) with relatively little expansion since.

Figure 1. Location of the Yarralaw study site in southeastern Australia.

The microDEM is situated below the upper boundary of a severe salt scald and next to an actively eroding watercourse. The ground surface bounded by the quadrat has varying sized patches of fine powder, fine sand, pea gravel and bare compact smooth soil. Vegetation cover is absent. Star pickets used for measuring at the coarser spatial resolution are situated about 120m down stream (Fig. 2).

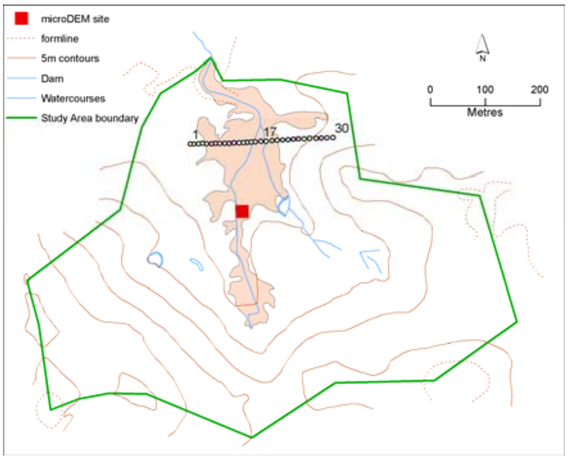

Figure 2. Location of the microDEM and erosion pins (1 to 30) in the study area. The erosion pins provide a cross section through the salt scald while the microDEM is within the scald (pink), close to an upper boundary.

Figure 3. The instrument for measuring the microDEMs in use.

4. METHOD

MicroDEM

The DEM for this work was measured manually using a 1 x 1m steel quadrat that mounts on four corner posts are permanently fixed at the site (Fig. 3). Holes at 2.5 cm spacing on opposite sides of the quadrat allow repeatable alignment of a movable cross bar on the N-S axis while 2.5 cm spaced holes on the cross bar allow a measuring pin to be lowered to the surface across the E-W axis. Data points were imported from a spreadsheet directly into Arcinfo GRID with no interpolation.

Capturing the data in this manner takes 4 – 8 hours depending on the number of operators. When a full (F) survey of 1600 points could not be done either a half (H) of ~800 points or small (S) of 196 points were undertaken. Between 1986 and 2007 ten Full, two Half and three Small surveys were collected. For comparisons of microDEMs only the Full surveys were used. For comparisons with the coarser erosion pin data five Full and one Small datasets that corresponded with erosion pin data were used.

Erosion pin study

The erosion pins consist of standard steel star fencing pickets. Measurements were taken from the top of each picket to ground surface on the western side of the post using a steel tape measure. Measurement issues related to the star pickets were described in field notes. These related to broken (rusted through) star pickets and erosion/deposition anomalies caused by the interference of star pickets themselves. Surface cover was noted also, ie, scald, semi-scald or grass. In 1996 a fence was constructed across the scald aligned with the existing erosion pins that were removed in the process. The 30 star pickets in the new fence became the measuring pins used for this study. A subset of 8 fence pickets that were initially classified as scald (not semi scald or grass) were taken to test if they were more representative of the microDEM site, which was also salt scalded. The 8 pins (7, 9-13, 15,16) are near the middle of the 30 pins.

Rainfall for the entire period is taken from Bungonia, the nearest station about 10km North of the study area.

5. RESULTS

The results are presented in 2 steps: a) The sequence of microDEMs that were fully surveyed and b) the erosion pin analysis, comparing the average elevation change over the microDEM with the averages from both the 30 pin erosion experiment and the 8 pin subset.

Sequence of DEMs surveyed

The effects of the erosion/deposition processes are shown in Figures 4 and 5. They show that there was a very rapid period of erosion in the first interval which has slowed progressively following a pronounced initial lowering. There are some areas, particularly noticeable at the pourpoint, where later surfaces are higher than (i.e. intersecting) earlier ones.

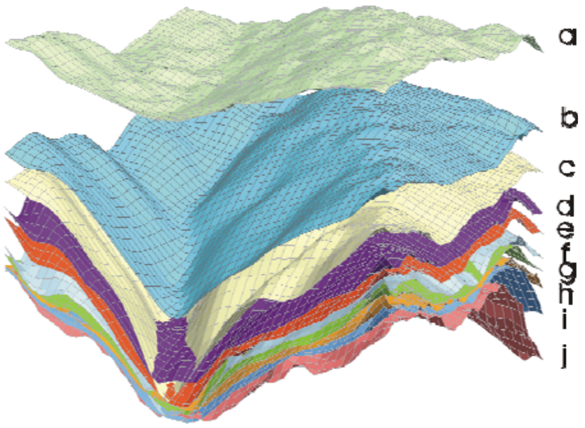

Figure 4. Elevation surfaces for each of the fully sampled micro relief surveys. Surfaces are plotted at actual heights showing the rate of change erosion through time. Areas of intersection highlight strong erosional (yellow) and depositional (purple or red) phases.

Erosion pin analyses

Table 1 shows erosion rates per year for the microDEM and the two sets of erosion pins. Erosion rates in the microDEM before erosion pins were measured were high until 1998 after which there was significant slowing.

Table 2 and Figure 6 show cumulative changes in surface height for the microDEM and the two sets of erosion pins.

From the beginning of the erosion pin data there is a large initial erosive phase followed by relatively small (<4mm/y) erosion rates. The 30 pin average has 3 depositional phases which has a contribution from some of the 8 pin subset. Except for the first interval erosion rates are higher for periods with higher rainfall.

Table 1. Average rate of change in elevation (mm/y) for each interval between surveys. Note that 13/4/2002 is a Small survey where only the measured cells were averaged.

Survey Date	Interval (years)	DEM (mm/yr)	8 Pins (mm/yr)	30 Pins (mm/yr)	Rain (mm/y)
24/03/1986 F	-	-	-	-	-
10/1/1992 F	5.80	-8.90			
9/12/1993 F	1.91	-11.78			
5/1/1996 F	2.07	-5.94			
2/1/1997 F	0.99	-6.93	0.00	0.00	633.69
2/1/1998 F	1.00	-8.73	-10.13	-14.88	483.92
29/12/1998 F	0.99	-3.67	-3.54	0.03	730.79
3/1/2001 F	2.02	-1.92	-3.10	0.60	626.57
13/04/2002 S	1.27	-2.76	-4.03	-0.55	670.00
23/12/2002 F	1.97	2.20			
18/04/2007 F	5.01	-1.70	-1.30	1.12	473.86

Table 2. Cumulative change in elevation (mm) from the start date. Note that 13/4/2002 is a Small survey where only the measured cells were averaged.

Survey Date	Interval (years)	DEM (mm)	8 Pin (mm)	30 Pin (mm)
2/1/1997	0.00	0.00	0.00	0.00
2/1/1998	1.00	-8.73	-10.13	-14.88
29/12/1998	1.99	-12.35	-13.63	-14.83
3/1/2001	4.00	-16.22	-19.88	-13.63
13/04/2002	5.28	-19.74	-25.00	-14.33
18/04/2007	10.29	-28.25	-31.50	-8.73

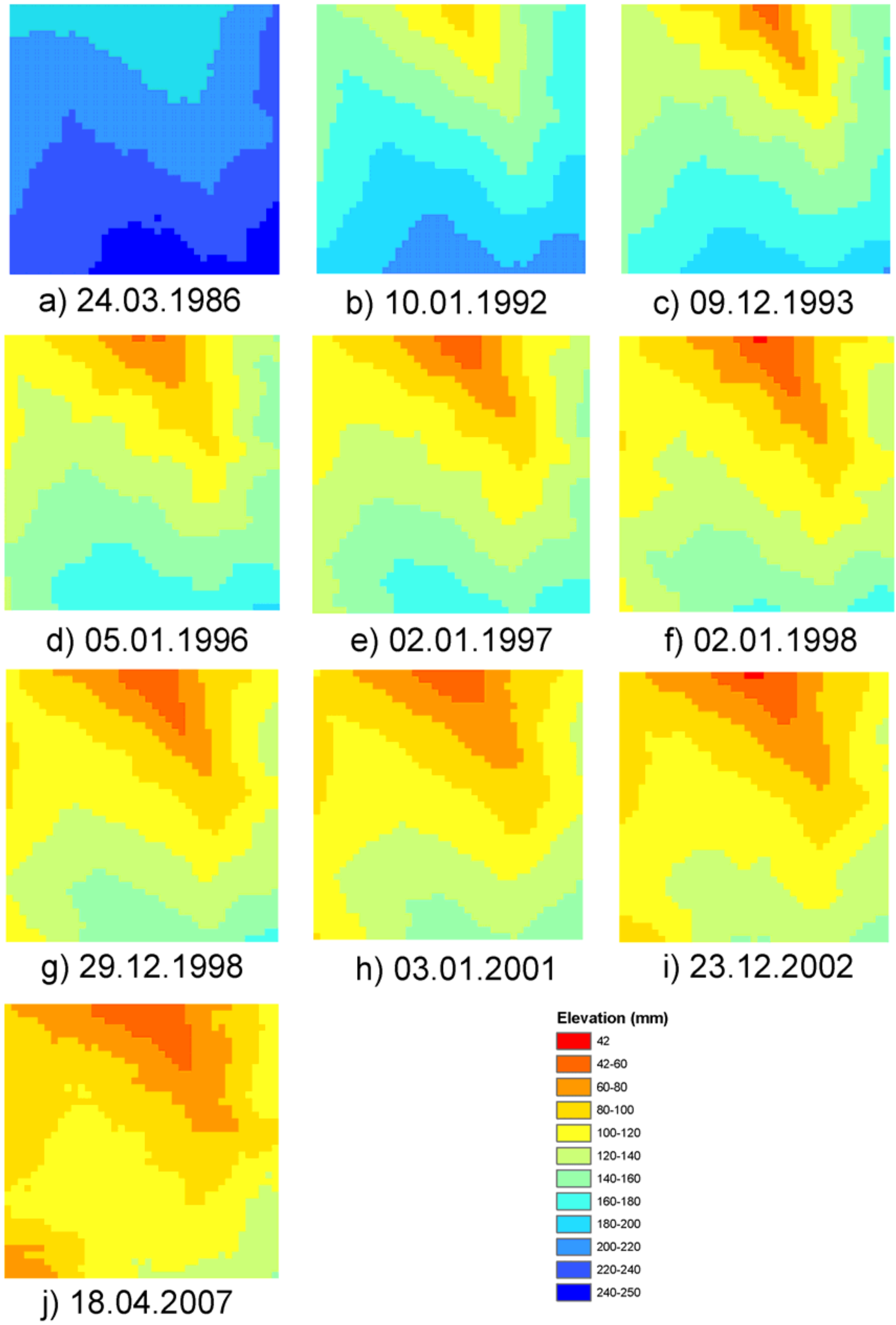

Figure 5. MicroDEMs surveyed from 1986 to 2007, with identical elevation classes shows the significant lowering and changing shape of the micro-landscape. MicroDEMs d,e,f,g,h,j and another Small survey (13/4/2002, not shown) were used in the comparisons with erosion pins.

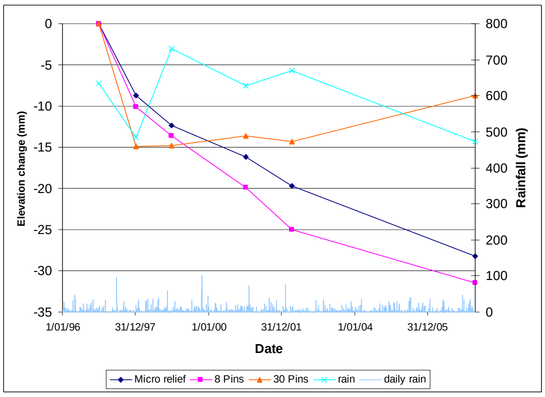

Figure 6. Comparison of cumulative erosion (mm) from 2/1/1997. Bars show daily rainfall for the entire period.

6. DISCUSSION

Tables 1 and 2 and Figure 6 show similar erosion rates over time for the microDEM and the 8 erosion pins in salt scald. The average erosion rates over the 30 pins is quite different, with significant net deposition in some periods. These differences are not surprising since the microDEM has absolutely no cover compared to the semi scald and grass areas that change seasonally and may have some cover when the extreme events occur.

Measured sediment loss for the catchment in 1985/86 was 62 t/y measured from sediment traps (Bullock and Neil, 1990). Assuming a bulk density of 1.5 t/m^3 this corresponds to average lowering of about 1 mm/y across the 4.3 ha salt scald. This suggests the erosion rates on the bare area of the microDEM and the scalded areas represented by the 8 pins are significantly higher than the erosion across the entire scald.

A significant slowing of erosion between pre and post 1998 in the microDEMS is possibly associated with a number of factors including: lower than average rainfall and extreme events; the removal of the highly erodible topsoil exposing harder to erode material; the emergence of pisolith (pea gravel) armouring.

Rainfall is clearly important in erosion process but it is difficult to calculate how much the results are confounded by the other factors. From Table 1. there is a significant decrease in rainfall and intensity after 1998 which contributes to quite low erosion rates after that date. High erosion rates during the wetter pre 1998 period may have exhausted the easily erodible topsoil leaving the areas supply limited with the harder and less erodible soil horizon exposed. The last factor is the evolution of surface armouring. As the erosion continues the soil is covered with small ferruginous nodules and other gravel where coarser particles are left behind when fine sediments are eroded, forming a surface armoured against further impaction and erosion.

Other unpublished data from measurements taken on 24/3/1986 and 21/9/1989 for the microDEM and the original set of 80 erosion pins (removed after 1989) showed a mean surface lowering of 30mm and 29mm respectively (about 8.6 mm/y). This level of agreement supports the results from the smaller erosion pin comparisons.

Data density is an important consideration. Like the erosion pins, some points in the microDEM vary markedly while others are reasonably stable. Having more erosion pins add information and reduces the uncertainty in erosion measurements for the whole landscape. Similarly, the high density of measurements in the microDEM improve the confidence in that estimate. Taken as a single average there is higher confidence in the estimate of erosion given that erosion and deposition occur in different places and times in the same quadrat.

The microDEM is interesting in how well it seems to mimic the form of the larger study area catchment. The microDEM clearly shows evolution of structures analogous to valleys, hillslopes and ridges but at a much finer scale and much faster rate than the whole landscape.

This suggests that similar erosion processes operate across a wide range of scales, both spatially and temporally, in this location. It is unlikely that this scaling would hold as well in many other locations in the study area, such as on a hilltop or in a vegetated site. Most landscapes show no evidence of catchment structures evolving at the 1 m^2 scale as in the microDEM described here.

7. CONCLUSION

The results show good agreement between very fine resolution microDEM and the coarser scale erosion pin surveys, particularly the 8 salt scald pins.

The microDEM is useful here because the processes are structured at a very fine scale. We think this is an uncommon situation and is unlikely to be as useful in many other landscape positions and particularly sites with vegetative cover.

The microDEM is like a scale model of the study area catchment, having tributaries draining into the main channel located approximately through the middle. This study raises interesting questions about how a set of erosion pins located in the microDEM site in the same relative position as they are the study area would compare. The agreement in erosion rates also suggests that the micro DEM is also scaled in time.

An advantage of using a microDEM is that it averages many elevation changes over a reasonable area, ie is data rich. Depending on position some points vary markedly and others very little so choosing a single point can introduce more uncertainty. Selected representative microDEMs could be targeted to provide more useful information in appropriate sites and selected point surveys could target other less appropriate landscape / landcover sites. These would include areas where a microDEM is unlikely to mimic the broader landscape or simply be too hard to measure through vegetation cover.

The main disadvantage of the microDEM is the data collection time. A more cost effective technology such as remote sensing, could be very useful in capturing a larger number of representative sites (landscape positions) in a catchment rather than the one available for this study.

Most importantly it shows that applications dependent on fine resolution DEMs with high vertical accuracy require frequent resampling.

8. REFERENCES

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