# Predicting channel incision of low relief landforms

**Summerell G K**

**Department of Natural Resources, E-Mail: gregory.summerell@dipnr.nsw.gov.au**

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**EXTENDED ABSTRACT**

Water movement processes through the landscape to the stream requires an understanding of run-off, lateral flows and groundwater processes. The conceptualisation of how these processes interact in the landscape plays a vital role in the development of water and solute movement models. The development of such models are used to inform management decisions. These decision are becoming more focused at the whole of catchment scale as apposed to just addressing issues at a hillslope. Therefore there is a need to develop robust methodologies to represent hydrological processes at the catchment scale.

At the catchment scale the most common element of a landscape that represents major changes in soil properties and water movement processes is the 'landform'. Landforms are defined as areas within a topo-sequence identified down and across slope by the land surface shape and pattern. A topo-sequences in this study reflects a regular pattern of soil down slope as soil-forming processes, soil profile drainage and sometimes parent material change.

Recent publications have indicated the importance of low-relief, colluvial and alluvial landforms as these features connect the streams to the landscapes. Within these low-relief landforms more complicated processes of water movement occur, and therefore additional understanding of these processes is needed for model development. One important driver for water movement within these landforms is depth of incision by streams. The level of incision influences groundwater depths, seepage faces, evaporative concentration zones and depth of the unsaturated zone. Using a combination of the Multi Resolution Valley Bottom Flatness index (MRVBF) and FLAG landforms, areas of alluvial flats are delineated. By determining the average slopes within these units an indication of whether the unit is incised or not can be determined. Examples are given of field evidence demonstrating that areas identified as valley bottoms with a high slope average are incised along the channel networks. Hillslope cross sections are also presented. The method is dependent on DEM resolution but provides a simple yet effective way of determining channel incision within flat low lying alluvial and colluvial landforms. This research provides the initial framework for more detailed studies.

## 1. INTRODUCTION

Recent studies have identified the importance of alluvial areas for catchment hydrology. Herron and Wilson (2001) illustrate the importance of these areas in terms of buffering capacity and complex impacts on hydrological connections between catchment and stream. A field study focused on salinity processes in the Livingstone Creek of southern NSW Australia (Summerell 2004) demonstrated how alluvial landforms are major sources of lateral flow to streams during rainfall events. It was also shown that channel incision through the alluvial landform increases the unsaturated zone depth, thereby increasing the volume of easily mobilised salt stores. This conclusion is supported by Schilling *et al.* (2004) who indicated that channel incision lowered the water tables from the stream edge resulting in a considerably larger unsaturated zone. Summerell (2004) also showed that, during rainfall events, stream isotopes had an old water signature when the stream water passed though alluvial landforms, indicating a dominance of soil water contributions.

McGlynn and Mcdonnell (2003) showed that riparian runoff from small alluvial landforms dominated the rising limb of the stream hydrograph and hillslope runoff dominating the falling limb. In the Livingstone Creek study the impact of the alluvial landform soil water contributions continues into the falling limb and even during base flow. This may be because the alluvial landform is a much larger body then just the riparian zone studied by McGlynn and Mcdonnell (2003). Therefore the size of alluvial area also determines what hydrological impacts these landforms have on stream water contributions. Siebert *et al*. (2003) also showed that water table response in the riparian zone is often separate and independent from those positions upslope. Burns *et al.* (2001) similarly concluded that hillslope waters are chemically and isotopically distinct from riparian zone waters.

McGlynn and McDonnell (2003) also showed results from groundwater well fluctuations where riparian zones responded more quickly to precipitation events then hillslope areas. Similar observations where made by Summerell (2004) in locations of buried paleao-channels in the alluvial landform. Two important features of a alluvial landscape need to be understood in order to correctly account for the connections from the landscape to the stream.

- The first, requires an understanding of the size and location of alluvial landforms,
- And secondly, is the alluvial landform incised.

These questions are easily addressed at the hillslope and small catchment scale however at the larger catchment scale (>50km$^2$) this question is a lot more difficult to answer. This is because commonly used GIS spatial analysis tools that are used to define these features are dependant on Digital Elevation Models (DEM). At this scale the quality of the DEMs is much lower, and features such as the incision of alluvial areas is much harder to define. This paper demonstrates the use of a simple terrain analysis method that is able to detect incised alluvial areas at the large catchment scale using average quality DEM's. With advances in computer technology and the increased availability of high resolution DEMs, simple terrain-based modeling techniques are becoming more widely used at larger catchment scales.

This work provides the foundation for further research and development into methods for identifying incised alluvial landscapes at the large catchment scale.

## 2. METHODS

This study was conducted in the Bombala and Delegate catchments, which are sub catchments of the Snowy catchment in the Snowy Monaro region, NSW. The combinded catchment area is ~2500km$^2$. These catchments have diverse geologies ranging from basalt, granites, sediments and alluvial landscapes. Landuses include grazing for cattle and sheep, and a large proportion of the catchment is under native trees or plantation forestry. Rainfall ranges from <600mm/year to >900mm/year with snowfall common on the ranges during winter.

Terrain analysis was applied to the Bombala and Delegate catchments using the 25m digital elevation model (NSWLIC 1999). DEMS of this resolution are more common across eastern Australia. The DEM was then used to derive a six category landform delineation of the landscape called "LF6". The terrain landforms – LF1, LF2, LF3, LF4, LF5 and LF6 are described in Table 1. The terrain anaylsis method uses digital elevation data to delineate major landforms of catchments. For hillslope areas the FLAG landforms methodology is used to define landscape topo-sequences with concave and convex breaks of slope (Summerell 2004). At these locations in the topo-sequence, a significant difference in soil properties commonly occurs due to impact of the hydrological balance on pedogenesis. These breaks of slope significantly affect contributing cells in the accumulation algorithms used by FLAG landforms. FLAG landforms uses these points to delineate four major landform types: (a) the ridge tops and upper slopes, (b) mid slopes, (c) lower slopes and (d) infilled valleys and alluvial depositions (Summerell 2004, Summerell *et al.* 2003). In this study further definition of valley bottoms features were delineated using the multi-resolution index of valley bottom flatness, MRVBF (Gallant and Dowling, 2003), an index specifically designed to map depositional areas within landscapes using digital elevation data. Combining the strengths of both methods, MRVBF in valley floors and FLAG landforms in the hillslopes, creates an overall better landform delineation procedure. The procedure creates 6 landform categories "LF6" which generally represent a hillslope catena (Table 1). Using the combined MRVBF and the FLAG landforms, classes "4 and 5" are additional to those landform features identified by FLAG landforms. Class 4 is the area where MRVBF identifies a valley floor and the FLAG landforms doesn't. Class 5 is areas where FLAG landforms identifies a valley floor feature and MRVBF doesn't. The areas identified as "6", large expanses of infilled valleys and alluvial depositions are of main interest for this study. The landform "6" class is the area where both MRVBF and FLAG landforms agree there is a valley floor.

**Table 1.** LF6 landform classes and generalized descriptions for a catena sequence

| **Landform class** | **Description** |
|---|---|
| LF1 | Ridge tops and upper slopes |
| LF2 | Mid slopes, |
| LF3 | Lower slopes, |
| LF4 | Valley fill in upland landscapes |
| LF5 | Rises in lowland alluvial fill or long gentle sloping foot slopes |
| LF6 | Large expanses of infilled valleys and alluvial depositions. |

The study area was then classified into major geological groups that exhibit different landscape formation. These terrain attributes relate to erosion potentials. The major geological groups identified were Basalts, Adamellite, Basalt Alluvium, Granites, Meta-Sediments/Sediments, Alluvium and Tertiary Sediments.

The slope was calculated for the entire DEM. For each geological category, the average slope for the LF6 class was then calculated. Areas of category "6", large expanses of infilled valleys and alluvial deposition, that also had average slopes of >2 % were then further investigated to determine what landscape features represented by the DEM were producing the higher slope values.

## 3. RESULTS AND DISCUSSION

The average slope angles of the LF6, class "6" are presented in Table 2. Results showed that the Adamellite and Alluvial geological groupings have average slopes values >2%.

The class "6" category of the Basalts and Basalt Alluvium landscapes consisted of well structured black clay, prairie soils. Gullying was therefore not common. A cross section of this landscape showing all the LF6 classes is shown in Figure 1.

**Table 2.** Average slope of the LF6 class 6 (large expanses of infilled valleys and alluvial depositions) for the major geological groups.

| **Geological group** | **Slope % for LF6 class "6"** |
|---|---|
| Basalts | 1.3 |
| Adamellite | 5 |
| Basalt Alluvium | 1 |
| Granites | 1 |
| Meta-Sediments/Sediments | 1 |
| Alluvium | 5 |
| Tertiary Sediments | 1 |

The Granites, Meta-sediments/sediments, and Tertiary Sediments landscapes all have sodic soils in the class "6" categories. These areas have minor gullying, which is usually very narrow and shallow. These features were not present in the DEMs. Hence the average slope of the class "6" category was 1%. Gullying is usually a minor feature of the overall landscape. Figure 2 shows a typical Meta-sediments landscape. Very stony shallow soils occur on the ridge tops at class "1" and long upper slopes consisting of classes "2 and 3", which often grade directly into a class "6", dominate in this landscape.

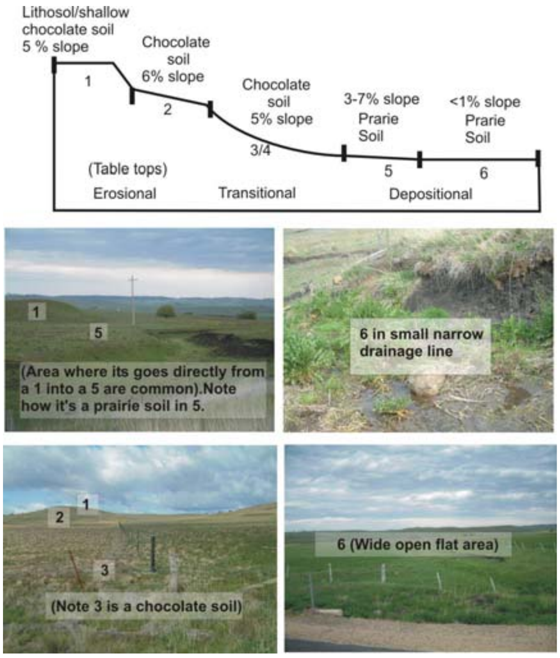


**Figure 1.** Typical cross section of a Basalt landscape showing the location of the LF6 classes 1 through to 6 within the toposequence. Photos are also given to show the terrain. The numbers on the photos reflect the LF6 class.

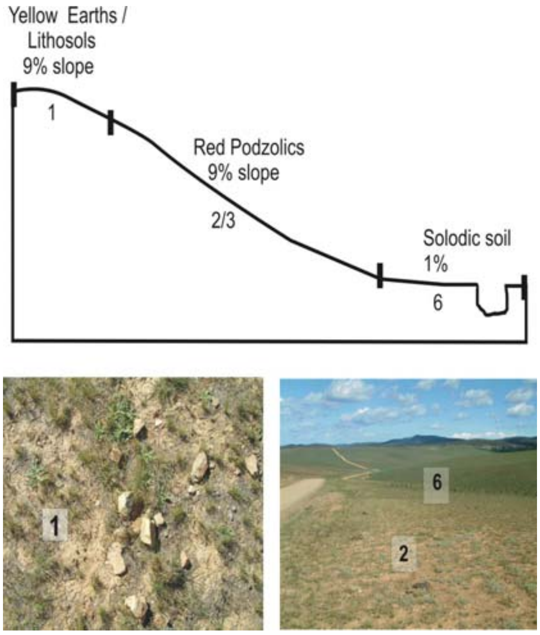


**Figure 2.** Typical cross section of a Meta-sediment landscape showing the location of the LF6 classes 1 through to 6 within the toposequence. Photos are also given to show the terrain. The numbers on the photos reflect the LF6 class.

The Alluvial geological group also contained areas of sodic or sandy soils that are strongly incised by major creek lines and gullies. These incisions were represented in the DEM, and therefore high slope values were reflected in the average slope estimates (Table 2). The Adamellite geological group also showed a high average slope for class "6", dominated by well structured black clay prairie soils, which were also deeply incised. The reason for the deeper channel incisions is that very steep, shallow rocky, sandy and well drained soils occur on the upper slopes of LF6 classes "1, 2, 3". These upper slopes then grade very steeply into the lower 4/5 and 6 classes. The energy of water running off this steep upper landscape into the lower landscape is eroding the lower class "6" landforms. Figure 3 shows a typical cross section of this landscape.

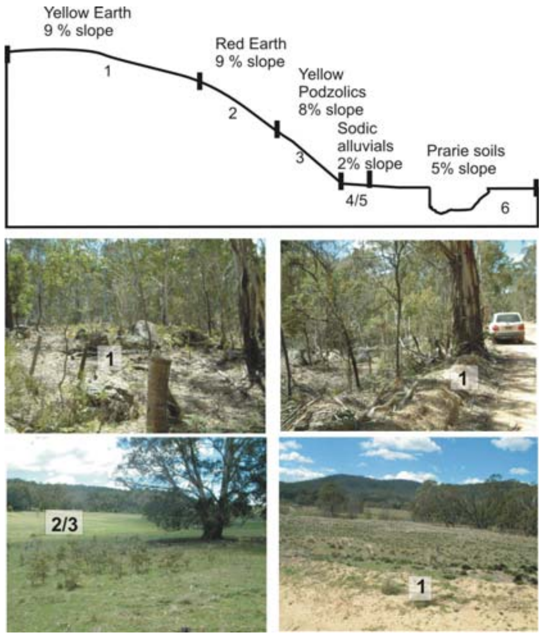


**Figure 3.** Typical cross section of a Adamellite landscape showing the location of the LF6 classes 1 through to 6 within the toposequence. Photos are also given to show the terrain. The numbers on the photos reflect the LF6 class.

Figure 4a and b shows an area of class "6" in the Alluvial geological group. The stream is defined by the darker colours indicating lower slope values. However, on the edges or banks of the creek line there are very steep sections (indicated by lighter colours). These lighter colours indicate the incised banks. The same features are also expressed in Figure 5a and b which represented an area of class "6" in the Adamellite geological group, which has areas of deeply incised prairie soils.

This identification of incised alluvial areas will greatly improve our representation of hydrological systems operating within a landscape. Specifically for salinity studies this method will identify landscapes that are not likely to express large areas of land salinisation or water logging as the incision provides a control for groundwater seepage. These landscapes may however be major contributors of lateral flows of more saline water into the streams during events, due to the increased unsaturated zone and bank incision (Summerell, 2004). For riparian zone management the level of incision will provide an indication of the groundwater or perched water table boundaries as well as areas of gullying. Therefore better vegetation management decisions can be made. Finally from a water quality perspective the incised areas are also likely source locations for sediment loads into creeks.

## 4. CONCLUSIONS

- The extent and size of valley floor deposits (alluvial or infilled) can be defined by terrain analysis tools such as MRVBF, and the representation of the complete hill slope toposequence can be obtained by combining MRVBF with FLAG landforms giving the LF6 landform delineation method.
- The effects of incision within valley floors deposits needs to be classified by geological groupings to create areas of likeness to identify the processes that have caused landscape incision. Once this classification is made, an average slope for a valley fill deposit above 2% indicates high levels of incision that will influence hill slope and catchment hydrological processes.
- The 25m DEM used in the study does not have the accuracy to represent minor incisions at the hillslope scale but is able to represent major incisions, at a level detailed enough for catchment scaled hydrological modeling.

## 5. ACKNOWLEDGMENTS

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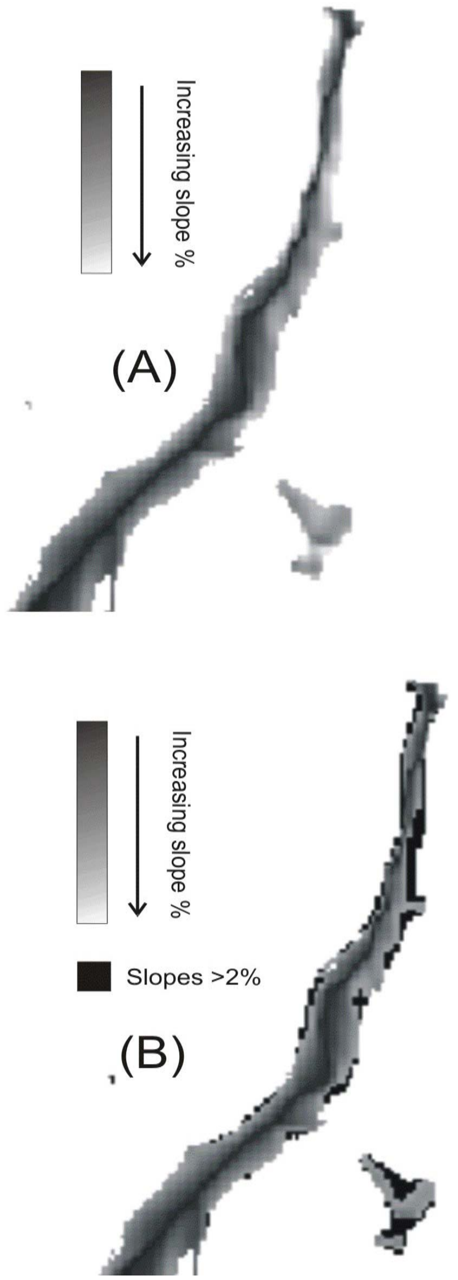


**Figure 4.** (A) Slopes in an area of class "6" in the alluvial geological group. The stream line is easily depicted by the darker lower sloped pixels. Steep slopes are shown by lighter colours. (B) The same area except slopes >2% have been classified separately and shown in black. These are the areas of high incision leading into the stream

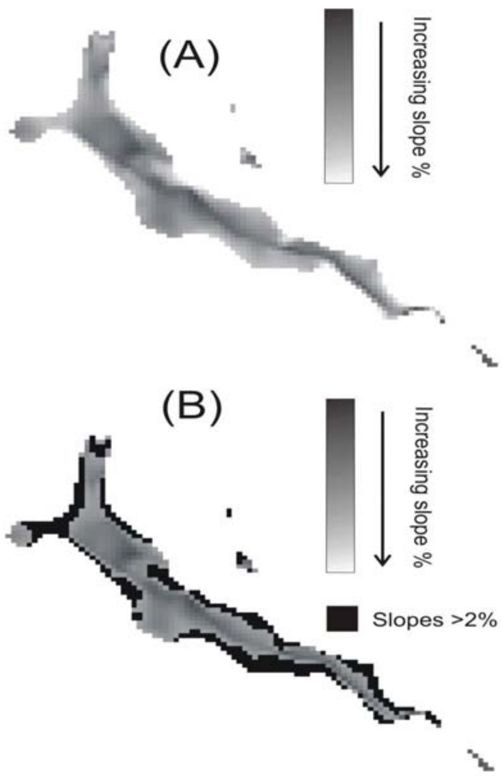


**Figure 5.** (A) Slopes in an area of class “6” in the Adamellite geological group. Steep slopes are shown by lighter colours. (B) The same area except slopes >2% have been classified separately and shown in black. These are the areas of high incision leading into the channel.

## 6. REFERENCES

Burns, D.A. McDonell, J.J. Hooper, R.P. Peters. N.E. Freer, J.E. Kendall, C and Beven, K. (2001) Quantifying contributions to storm runoff through end-member mixing analysis and hydrologic measurements at the Panola Mountain Research Watershed (Georgia, USA). Hydrological Processes **15** 1903-1924.

Dowling, T.I. Summerell, G.K. and Walker, J. (2003) Soil wetness as an indicator of stream salinity. Environmental Management and Software **18** 587-593.

Gallant, J.C. and T.I Dowling (2003) A multi resolution index of valley bottom flatness for mapping depositional areas, Water Resources Research **39/12** 1347-1360.

Herron, H and Wilson, C (2001). A water balance approach to assessing the hydrological buffering potential of an alluvial fan. Water Resources Research. **37/2** 341-351.

McGlynn, B.L. and McDonnell, J.J (2003) Quantifying the relative contributions of riparian and hillslope zones to catchment runoff. *Water Resources Research*. **39/11** 1310.

NSW LIC (1999) Statewide digital elevation model data NSW Land Information Centre Bathurst NSW Australia.

Schilling, K.E. Zhang, Y.K and Drobney P (2004) Water table fluctuations near an incised stream, Walnut Creek, Iowa. Journal of Hydrology **286** 236-248.

Seibert, J. Bishp, K. Rodhe, A. McDonnell, J. (2003) Groundwater dynamics along a hillslope: a test of the steady-state hypothesis. Water Resources Research **39/1** 2-1-2-9.

Summerell, G.K (2004) Understanding the Processes of salt movement from the landscape to the stream in dryland catchments. PhD Thesis, The University of Melbourne.

Summerell, G.K. Vaze, J. Tuteja, N.K. Grayson, R.B and Dowling, T.I (2003) Development of an objective terrain analysis based method for delineating the major landforms of catchments. MODSIM, (Ed. DA Post) p.496-501 Townsville Australia.