Erosional History of Selected Upland Subcatchments in the Liverpool Plains, New South Wales

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Abstract Since European settlement, considerable changes in landcover and land management have occurred in Australia, and particularly in the Liverpool Plains, as a response to agricultural expansion and development. Hydrological responses to decreased landcover and soil structural changes imposed by land clearing and grazing include decreased infiltration and increased runoff, sediment mobilisation and transport. As a consequence, erosion gullies have been initiated and subsequently have developed into extensive networks. In the Warrah subcatchment, these networks produce a number of on-site and downstream impacts including reduced farm access and land productivity, sediment loss and reduced water quality downstream as a function of increased sediment and phosphorous loads. Streams, erosion gully networks, rills, landcover and land management have been mapped and digitized onto a GIS using a number of aerial photographic time slices. Information derived from the GIS-generated maps include: (a) measurement of temporal and spatial changes in the fluvial and gully networks, and landuse and land management practices; (b) assessment of changes in the connectivity of gullies to streams; and (c) identification of channel responses to hillslope erosional processes. These analyses will form the basis for a number of 'what if' scenarios to determine erosion drainage density responses to landcover/management changes, which will ultimately provide stakeholders with a powerful strategic planning tool for best management practices.

1. INTRODUCTION

Responses by Australian rivers to changes in the hydrologic regime and/or sediment delivery have been well documented (Erskine, 1986; Cornish *et al.*, 1989; Brizga and Finlayson, 1990; McMahon *et al.*, 1992; Brooks and Brierley, 1997). However, these studies are generally concerned with channel metamorphosis and avulsion. Furthermore, climate is viewed as the dominant control on channel responses, either in terms of catastrophic events (Henry, 1977; Nanson and Hean, 1985; Erskine, 1994; Erskine and Melville, 1983), or flood and drought dominated regimes (Warner, 1987, 1994; Erskine and Warner, 1988; Erskine and Bell, 1982).

Studies on river regulation (Riley, 1981; Warner, 1984), gravel extraction and point sources of sediment supply (Warner, 1984) have provided some understanding of direct anthropogenic controls on channel form. Broader scale human activities including deforestation or modifications to the riparian zone have been addressed largely in the context of logging practices in native eucalypt forest and pine plantations (Cornish, 1993; Moran, 1988; O'Shaughnessy *et al.*, 1995). In contrast, the impacts of landcover and land management changes at a catchment scale have received little attention, despite vegetation cover being a primary intrinsic control on sediment and water supply to a stream (Brooks and Brierley, 1997).

Since European settlement, broadscale clearing of timber and the development of agriculture has involved removal of virtually 100% of the canopy followed by practices to discourage or prevent regeneration. In addition, catchment surfaces have been modified by the construction of farm dams, contour banks and other conservation works. These landscape modifications impose long term impacts on the hydrologic regime, as demonstrated by changes in the erosional network and channel metamorphosis. Whilst previous research has been concerned with channel form responses (Brooks and Brierley, 1997), this study quantifies the impacts of 'diffuse anthropogenic disturbance' on erosional networks in an upland catchment of the Liverpool Plains. The methodology provides the basis for developing a predictive tool, with management applications.

2. REGIONAL SETTING

Warrah Creek is an upland subcatchment (150 km^2) of the Mooki River in the Liverpool Plains, New South Wales (Figure 1). The subcatchment above the stream gauging station at Old Warrah is a narrow valley bounded by sandstone ridges comprising Triassic Digby Conglomerate to the east and west, rising to precipitous slopes of the Liverpool Ranges in the south, with elevations up to 1232 metres. Basalts of the Tertiary Liverpool Range Beds comprise the parent material of the upper catchment and as cappings on the sandstone ridges. Soils are heavy textured uniform to gradational profiles ranging from black earths and euchrozems to prairie soils and non-calcic brown soils.

3. LANDUSE HISTORY

In 1832, the early explorations of Sir Edward Parry (April 1832) and of the Surveyor-General, Dangar (December 1831-January 1832) in the Liverpool Plains and Peel River area were drawn up by Dangar (Noel

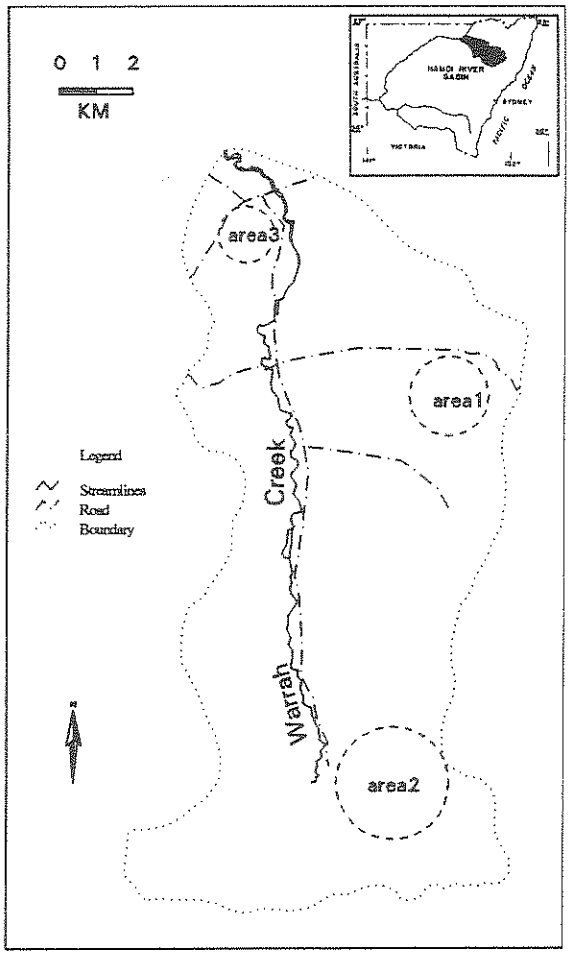

Figure 1. Location map of the study area

Butlin Archives Centre, 1/452/C/2). Notations on the map describe the upland catchments of the Liverpool Plains as "successions of fine valleys, and good forest ridges extending towards the dividing range". The eastern section of the Warrah catchment is described as "elevated inferior sand" and the plains downstream of Warrah homestead are "extensive rich plains but without permanent water and occasionally very wet."

In 1833, the Warrah catchment was taken over as a part of the Australian Agricultural Company's (East) Warrah Estate. Limited sheep grazing was practised until 1861 when major development of the property commenced. Development included running significant numbers of sheep and cattle and the enclosure of the Estate by wire fencing. Two dams were built in the Warrah catchment together with a series of washpools on or immediately adjacent to the creek for washing sheep prior to shearing. Although the "forests of Warrah were not particularly extensive" (despatch Merewether to Court, 21 October, 1862, in Robertson, 1960), they were sufficient to supply the fencing needs of the Company. "Practically all the fencing timber was sawn from trees growing on Warrah" (Merewether to Court, 27 March, 1868, in Robertson, 1960).

Contemporary maps and surveys of the catchment indicate that Warrah Creek was a meandering, entrenched stream (Noel Butlins Archives Centre, 1/453/2a, 1/453/2b) with a number of major tributaries. Two discontinuous gullies are apparent, including one system which incises the inherently unstable slope located in Area 1, discussed below. Further downstream, approximately 5 kilometres east-northeast of Warrah Homestead, the creek "meandered along a barely defined watercourse" (Robertson, 1960).

After 1885, exotic weeds had become problematic, and by 1903 rabbits had arrived in the area. Severe droughts occurred in 1885 and in 1901-2 with the latter being "the worst season since 1838" (Wilson, 1930). Surveys of the upper catchment, completed in 1912, depict a number of ephemeral gullies in the upper and middle sectors of the catchment, suggesting that land degradation in response to land clearing, total grazing pressure and drought was manifest by this date (Noel Butlin Archives Centre, 1/453/2c). Furthermore, the main channel downstream of the homestead had become entrenched.

Rainfall and streamflow data for the region indicate droughts for 1911, 1916-17, 1921, 1928, 1931, 1934 and 1936. Very wet years occurred in 1924, 1933 and 1941-42. Clearing of timber continued in the catchment until 1926, when the supply of mature timber was exhausted and the sawmill, that had been operating in the middle catchment, was closed (Wilson, 1930).

The earliest aerial photography for the catchment was taken in January 1943. These photographs show a highly degraded catchment almost devoid of timber. Extensive gully systems comprising deep incisions with abundant secondary offshoots occur throughout the catchment. These gullies are often associated with multitudes of rills which are oriented generally in the direction of slope. The condition of native pasture is poor with large areas subjected to sheet erosion. Grazing is the primary landuse, although very limited areas of cropping are restricted to small holdings adjacent to the creek in the middle to lower parts of the catchment.

Aerial photography for 1984 and 1994 reflect hydrologic response to climate and landuse practices. Between 1943-1994 droughts were recorded for 1949, 1952, 1962-4, 1974-5, 1982 and 1985. Wet years occurred in 1968 and 1989. In terms of landuse, in the same period since the 1943 photography the evidence suggests that regeneration of forest and woodland has occurred in the upper catchment, and to a limited extent, on crestal slopes of the sandstone ridges. Grazing on the midslopes and lower slopes has continued, and cropping has expanded to include the alluvial flats and slopes of the lower part of the catchment. Land management has included the construction of dams and contour banks, pasture improvement and management of total stocking rates. At a catchment scale, the erosion network appears to have retracted in response to these management practices. However, detailed study of selected subcatchments indicates that smaller scale erosional responses continue to be very sensitive to site conditions and local management practices (Table 1).

These variations have implications for management at both catchment and subcatchment levels.

4. METHODOLOGY

Aerial photographs were interpreted and mapped to record the status of drainage density of the gully erosion network and land use/land management for three specific time slices: January 1943; 25.5.84; and 17.9.94. Information from the contact prints was copied directly onto clear overlays to form a mosaic, which took into account peripheral distortion. Two maps for each time slice were constructed, comprising erosion drainage density and landuse/land management, by tracing the relevant details from the mosaic onto drafting film. Erosion drainage density maps record major drainage lines, continuous and discontinuous erosion gullies, rills, and sheet erosion. Landuse/land management maps record areas of dry schlerophyll forest, scattered timber/native pasture, improved pasture, continuous cropping, strip cropping, and define contour banks, farm dams and windbreaks. Field checks were undertaken to verify the accuracy of interpretation of the 1994 photography.

5. GIS DEVELOPMENT

Maps based on aerial photographic interpretation were digitised, using Tosca, an Idrisi based GIS software package. Control points were found by matching aerial photograph layout features, such as road intersections, significant dams and fords. Distortion effects were minimised by:

- Ground truthing;
- Selecting control points located in the central regions of aerial photographs; and
- Using the GIS maps for comparative analyses based on ratios, rather than absolute measurements.

Once digitised, the data were dissected into various layers, converted to ArcInfo compatible formats and then generated in ArcInfo using Sun workstations. In the ArcInfo environment the calculations on areas were made, in addition to lengths of gully systems, rilling and contour banking. These data were tabulated and compiled in Excel spreadsheets. Maps for presentation and analysis purposes were also created using Arc Tools and ArcView. Using this approach, the acceptable root mean square error for reference transects, including roads, stream segments and gullies, was generally <25m.

6. STATISTICAL ANALYSES

Changes in the erosional networks were examined initially at a catchment scale. The data derived from the 1943 photography indicate an intensely degraded catchment characterised by a relatively high erosional drainage network and a low proportion of the catchment covered with woodland. Over time, general patterns of change in landuse are apparent (Table 1). However, whilst regeneration of woodland is steadily increasing, fluctuations in other landuse practices occur. These patterns of change may reflect sensitivities to socio-economic factors such as commodity prices, drought or land ownership. At the catchment scale, the data also demonstrate a general decrease in total erosion drainage density (ie, the sum of continuous and discontinuous gullying and rilling).

In order to determine whether the most salient variables controlling erosional drainage density were extrinsic (climate) or intrinsic (landuse/land management change), more detailed analyses were undertaken at a finer scale. Within the Warrah catchment, where climate was assumed homogeneous, a number of 'representative sites' were selected for detailed study based on distinct patterns of landuse and land management practice. These sites are described below:

- Area 1: an erosionally unstable slope of 3°-3.5° which has undergone increasingly intensive landuse since the 1940's. Contour banks were constructed prior to 1984, but have been poorly maintained, and are generally absent by 1994.
- Area 2: a drainage network, with slopes 8°-14°, in the upper catchment where regeneration of forest and woodland has replaced extensively cleared, actively eroding native pasture.
- Area 3: a slope of 3.2°-3.5° where landuse has been relatively static over the period of the photographic record, but with a significant increase in contour banking.

The erosion and landcover data derived from mapping these sites, together with the total catchment, are given in Table 1.

7. DISCUSSION

Whilst the general trend in Table 1, at a catchment scale, indicates that erosion is stabilising, at a local scale sensitivities to landuse and land management are evident. It is notable that in the highland area (Area 2), conservative landuse associated with regeneration of woodland and a reduction of landuse intensity is associated with stabilisation of gully systems and contraction of the erosion network.

Furthermore, the construction of contour banks has a positive impact on controlling erosion (Areas 1 and 3), regardless of landuse intensity. However, it is clear that this management practice is not effective when the structures are not well maintained (Area 1). Where soils are susceptible to erosion, reduction of the total erosional drainage network is largely a function of the sensitivity of rilling to changes in slope length. Here, the *character* of the erosional network changes, with stabilisation of transitory erosional features accompanied by an extension of the continuous system. The concurrent reduction of discontinuous gullies and extension of the continuous gully network suggests that

Year	Dry schlerophyll forest	Scattered timber	Improved pasture	Cropping	Contour banks	Cont. Erosion density	Discont. erosion density	Rill density	Total erosion density
	% area				Km	km km^{-2}			
Total catchment (150 km^2)									
1943	22	66	6	6	0.8	0.91	0.79	0.85	2.45
1984	22	49	12	18	49.1	0.84	0.42	0.16	1.42
1994	38	42	9	15	48.6	0.67	0.47	0.001	1.14
Area 1 (6.8 km^2): Subcatchment with inherently unstable slopes and increasingly intensive landuse									
1943	5	95	0	0	0	2.9	1.7	1.9	6.5
1984	0	52	31	17	11	3.1	1.2	0.4	4.7
1994	2	30	68	0	2.6	3.6	0.9	1.6	6.1
Area 2 (10.5 km^2): Highland subcatchment experiencing regeneration									
1943	36	64	0	0	0	2.4	3.7	0	6.1
1984	63	37	0	0	0	0.7	0.5	0	1.3
1994	77	23	0	0	0	0.6	0.1	0	0.7
Area 3 (9.0 km^2): Subcatchment with static landuse and increasing contour bank network									
1943	10	74	0	16	0	1.4	0.8	3.9	6.1
1984	0	71	12	17	12.6	0.5	0.8	0.2	1.5
1994	2	76	10	12	16	0.1	0.8	0.1	1.0

Table 1. Temporal changes in erosion and landuse/land management in selected areas of Warrah Creek catchment

linkages have been made between the two systems over time. This increased connectivity between systems may have significant, local impacts on the delivery of sediment and flow to the fluvial network.

These results indicate that the landscape is stabilising within an historic context, but that at a local level sustainable management practices have significant impacts on further development or retraction of erosional networks. Furthermore, changes in channel form and pattern recorded in historic documents and aerial photography suggests diffuse anthropogenic disturbance within the catchment continues to have geomorphic impacts (Green *et al.*, 1997).

The results from this study are being extended using comparable data for the Coxs Creek catchment, in the western section of the Liverpool Plains. In addition to the quantification of landuse/management and erosion network changes, these analyses are a fundamental component in the modelling of sediment delivery in upland catchments. The integration of these analyses into the modelling framework is described in Jakeman *et al.* (1997). Spatio-temporal landscape analysis supports the modelling by providing an interpretative basis for catchment dynamic response characteristics including quickflow hydrograph peak and runoff ratio. In addition, rainfall-runoff modelling provides predictive relationships between (mapped) landscape attributes and catchment dynamic response characteristics. These outcomes can then be used to modify parameters of the rainfall-runoff model IHACRES (Jakeman *et al.*, 1990; Jakeman and Hornberger, 1993) in order to run a number of 'what if' scenarios to simulate the impacts of landuse/land management on daily runoff. Moreover, estimated soil losses can be compared with simulated suspended sediment concentrations and loads, providing inputs to the in-stream process model (Jakeman *et al.*, 1997).

8. CONCLUSIONS

By 1943, agricultural and pastoral development of Warrah catchment had imposed an extensive erosional network in the landscape. Stored sediment from diffuse landuse changes over the previous 100 years was mobilised as erosion networks developed.

Over the last fifty years, the significant role of conservative land use and sound management practices in the stabilisation of erosional networks, has been demonstrated. Future research will involve further analyses of the erosional effects of other subcatchments of the Liverpool Plains, as the basis for determining best management practices for erosion mitigation, channel stabilisation and water pollution control.

It is hoped that this approach will provide stakeholders with a powerful predictive tool for management.

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