Patterns of Spatial and Temporal Variability of Factors Affecting Nutrient Export from Chaffey Dam Catchment

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Abstract An analysis of topographical and climatic characteristics of the Chaffey Dam catchment in northern NSW provided the basis for an understanding of processes affecting spatial and temporal distribution of runoff, erosion and nutrient export in the catchment. Topographic analysis combined with GIS software was used to produce, visualise, and interpret the compound topographic attributes W (wetness index) and T (sediment transport index). The resulting maps show extensive areas in the north and west of the catchment with high W values, indicating areas with high runoff producing potential. The steeper areas of the catchment to the east and south and along drainage lines had high T values indicating susceptibility to erosion. Analysis of rain, rain intensity, and runoff data showed strong seasonal characteristics and high annual variability. The summer months had more rain, higher rainfall intensity, and lower runoff than winter months. The combination of the rainfall-runoff analysis with the topographic analysis, indicated different mechanisms for runoff production and nutrient export in summer compared to winter. The annual variability indicates that there are critical periods in the history of the catchment for the production of sediment and nutrient export. The conclusions from this have implications for land management and water quality in the Chaffey Dam catchment

1. INTRODUCTION

The recognition of the impacts of land management on water quality has lead to new demands being made of hydrological analysis. Traditional requirements of assessing water yield of catchments did not need to take account of the spatial distribution of runoff in the catchment, and simple lumped conceptual models could be used to estimate rainfall excess and route it to the catchment outlet. Water resource management is increasingly being focused on water quality issues. One of these issues is eutrophication, or nutrient enrichment of the water [Verhoeven, 1992]. Eutrophication is a chronic problem in Chaffey Dam reservoir in northern NSW, causing frequent blue green-algal blooms. The key nutrient, phosphorus, is transported from the land surface form to receiving waters by the agent of running water. This phosphorus is either adsorbed to soil particles or in dissolved form. Water quality managers require knowledge of how, where and when phosphorus is washed off the catchment surface before they can devise hydrologically sound nutrient management strategies.

Approaches for the analysis of these nutrient source areas need to account for the spatial and temporal patterns of the factors affecting export from the land surface. The export of phosphorus from the land surface is a combination of phosphorus form and availability, rainfall amount and intensities, topography, antecedent moisture index, runoff, soils, and landcover. These factors are to an extent interdependent. Methods for assessing these range from simple empirical approaches, to detailed distributed parameter modelling using models such as ANSWERS [Beasley et al., 1980] and AGNPS [Young et al., 1989]. The simplest approaches often do not consider the full range and interrelationship of the factors affecting nutrient export, whereas the detailed models take considerable time and effort to set up and run. Similar information to the detailed models can be derived using simpler means by analysing long term hydrologic data in combination with topographical analysis to assess spatial and temporal patterns of nutrient export.

2 CHAFFEY DAM CATCHMENT

The Chaffey Dam catchment of 410 km^2 forms part of the Namoi River catchment in the Murray Darling Basin. The catchment is on the western side of the Great Dividing Range, approximately 40km south of Tamworth (Figure 1). The main stream in the Chaffey Dam catchment is the Peel River, and the main population centre is is the town of Nundle.

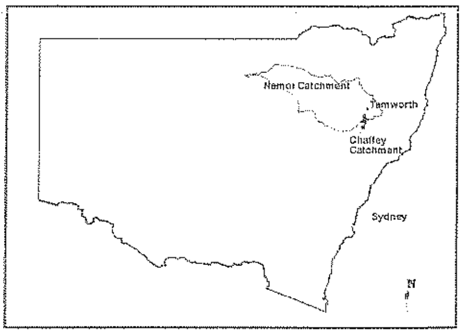

Figure 1 Location of Chaffey Dam catchment

The topography of the catchment varies from steep to precipitous on the southern and eastern boundaries, to undulating and rolling hills at lower elevations in the central and western parts of the catchment. Upstream of Nundle the physiography is characterised by narrow entrenched valleys bounded by steep cliffs. Down stream of Nundle these valleys broaden and flatten out.

The soils of the catchment are closely associated with the geological parent material. Soils with basaltic parent material are characterised by well structured krasnozems at higher elevations to the east and

Carboniferous/Devonian sedimentary geologic areas with red-brown earths, non-calcic browns and lithosols in the upland areas, and yellow solodics in the lower areas downstream of Nundle. Deep alluvial soils are associated with Quaternary sediments [Emery 1973]. The catchment has been extensively cleared since settlement in the 1800's, and the dominant land use in the catchment is improved pasture for grazing. The improved pasture areas receive regular applications of phosphatic fertilizer. Areas of native forest remain in the higher elevations of the catchment, and there is also an extensive pine plantation forest in the east. The remaining land uses are row crops along the alluvial flats and the gently sloping areas, and the Nundle urban area.

Prior to the construction of the Chaffey Dam an erosion survey of the catchment revealed that 49 % of the catchment was affected by sheet erosion, and 14 % of the catchment affected by gully erosion.

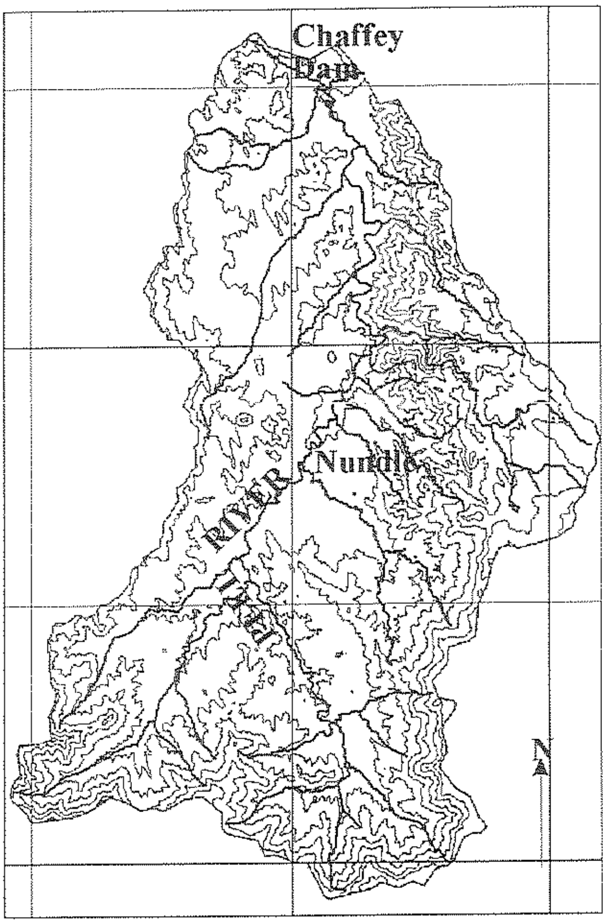

Figure 2 Topographic map of Chaffey Dam catchment grids are at 10 km spacing, contours are at 100 m intervals

3. CLIMATIC AND HYDROLOGIC ANALYSIS

The effect of the climatic factors effecting nutirent export was carried out on a seasonal and a long term basis. Rainfall records extending back over 100 years were available for Nundle Post Office, and pan evaporation records at nearby Split Rock Dam were available for the period 1972-1985. The rainfall records were gap-filled, and the evaporation records extended using statistical techniques. [DLWC, 1995]. Runoff data was based partly on historical records at a gauging station upstream of the present dam site. This record was extended to a period of one hundred years using the rainfall and evaporation data as an input to the Sacramento rainfall runoff model. An index of rainfall erosivity was also calculated (1 and 2) as a power function of the daily rainfall above a threshold rainfall amount [Neil and Yu, 1994]. This method gives a high weighting to days that have high rainfalls.

$$I = \Sigma (P-Po)^2 \quad \text{for } P > Po \tag{1}$$

$$I = 0 \quad \text{for } P < Po \tag{2}$$

Where I is an index of rainfall erosivity

P is the daily rainfall (mm)

Po is a threshold below which no erosion is assumed to have occur (mm)

A value of Po if 13 mm was adopted for this study.

The results of this analysis are presented in Figure3. There is a summer maximum in rainfall with a secondary peak in early winter. The rainfall erosivity magnifies this seasonality, with much higher values in the summer months compared to the remainder of the year. Summer has fewer rain days, but these are of a much higher intensity compared to those in winter. The runoff analysis shows that the flow in winter is much higher than that in summer, even though winter has less rainfall. This result can be explained by a higher catchment antecedent soil moisture as a result of lower evaporation and more rain days. The implications of this are that the summer months have the highest risk of erosion as sediment detachment is most influenced by rainfall intensity. However these events are only of a short duration. The winter months are less likely to detach sediment because of lower rainfall intensities, but may be important for remobilising and transporting previously detached sediment.

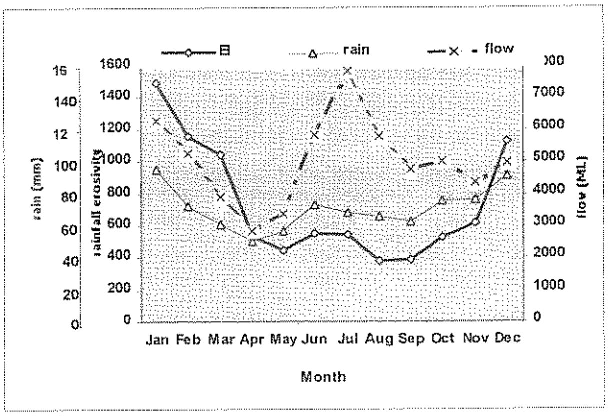

Figure 3 Seasnonal variations in rain, rain intensity, and runoff.

The annual totals of rainfall and rainfall erosivity are plotted against a residual mass curve (RMC) of runoff in Figures 4a, b, and c. Sequences of wet and dry years are shown as a rise

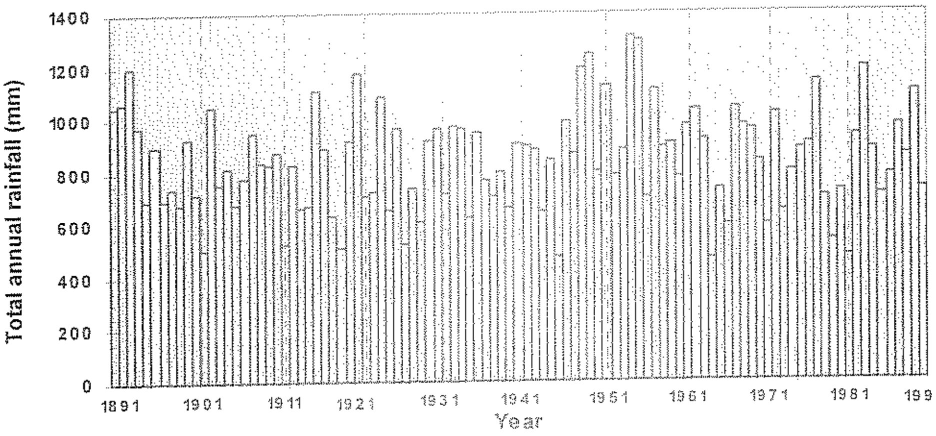

Figure 4a Annual rainfall at Nundle PO (1891-1991)

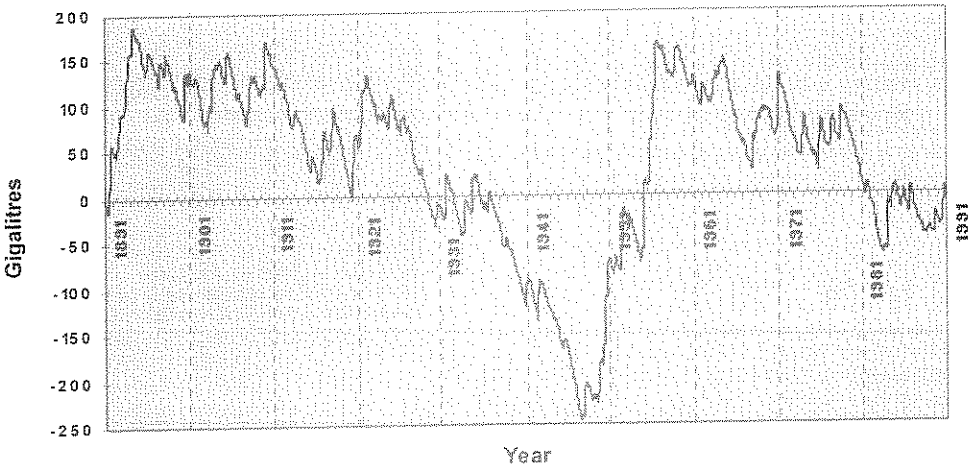

Figure 4b Residual mass curve of flow into Chaffey Dam reservoir (1891-1991)

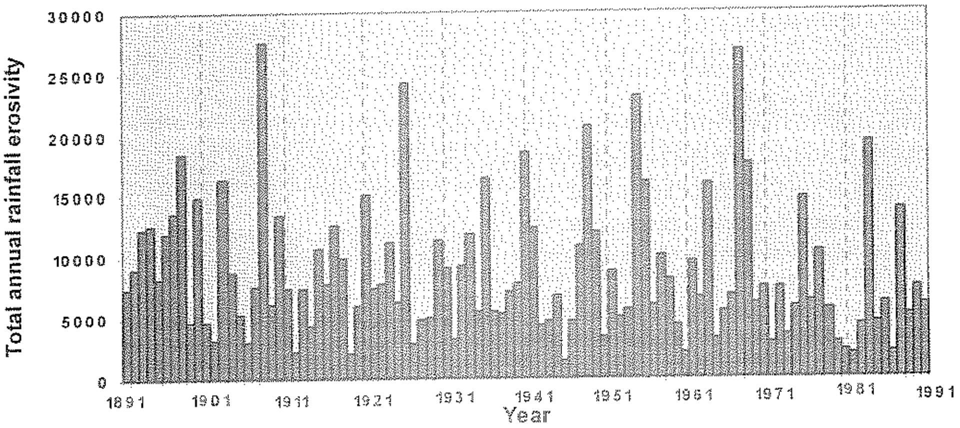

Figure 4c Annual rainfall erosivity index at Nundle PO (1891-1991)

or fall in the RMC. The prolonged drought ending in the late 1940's is a prominent feature of this plot, followed by a steep rise in the wet years of the early 1950's. The annual totals of rainfall erosivity show that there are some years that had a very high rainfall days. These are not necessarily coincident with the wet years. These years would be expected to have higher erosion and greater nutrient export than other years, especially if they occurred after a drought.

4 TOPOGRAPHIC ANALYSIS

The shape of the land surface is a key factor in the understanding of nutrient export. For example the length-slope factors in the Universal Soil Loss Equation accounts for the topographic setting of an area of land to determine soil loss. The combination of slope and length determine the power of surface runoff to detach and entrain sediment. Recent advances in the mathematical analysis of topography has produced indexes which show patterns of runoff producing areas and areas with high sediment transport potential. The first of these is the wetness index (3)

$$W = \log_e (A_s / \tan B) \qquad (3)$$

where W is the wetness index

A_s is the upslope contributing area

B is the local slope

The wetness index is a simple input/output model describing the steady state soil moisture status. [O'Loughlin, 1986]. The upslope surface area is a measure of subsurface inflow, and the local slope indicates the ability of the land to drain this water away. A sediment transport index (T) has also been formulated (4) using the same topographic attributes [Moore et al., 1992)]

$$T = 1.4 * (A_s / 22.13)^{0.4} * (\sin B/0.0896)^{1.3} \qquad (4)$$

Where T is the sediment transport index

As these both impact on nutrient export, an analysis of the patterns of these in the Chaffey Dam catchment was carried out. Digitised contours were converted to a gridded, hydrologically sound digital elevation model at 25m grid resolution using the ANUDEM program [Hutchinson, 1989]. This digital elevation data was then processed with the TAPESG program [Moore et al., 1992] to derive the primary topographic attributes slope and upslope contributing area. These were imported into the GRASS Geographic Information Sytem [USACERL, 1993] where they were operated on with the *r.mapcalc* function to derive maps of W (Figure 4) and T (Figure 5).

The bright areas of Figure 4 indicate high W values. These would on average have higher antecedent moisture index and

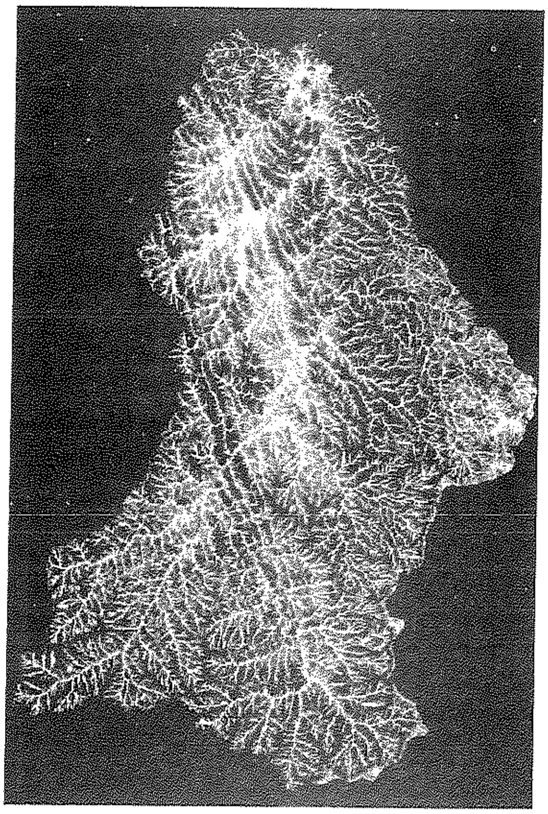

Figure 5 Distribution of W in Chaffey Dam catchment

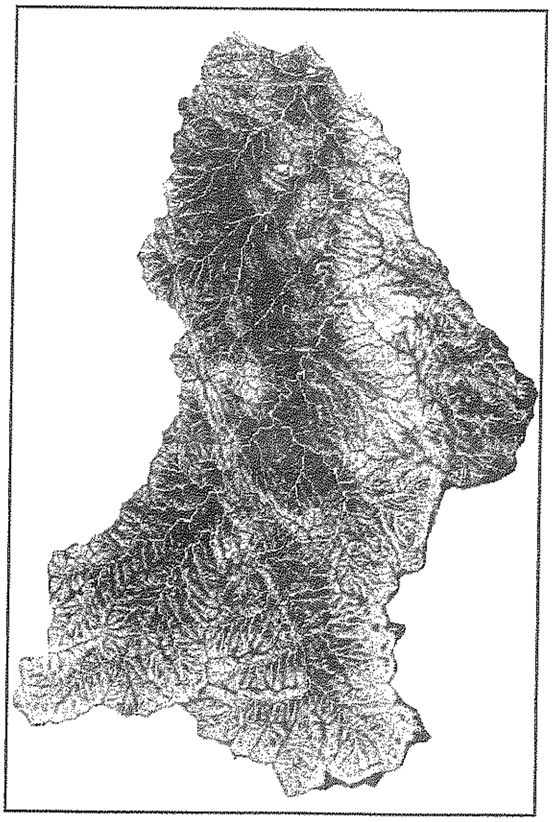

Figure 6 Distribution of T in Chaffey Dam catchment

produce more runoff. These areas are dominant in the lower parts of the catchments to the west, and near drainage lines. The distribution of sediment transport index show nearly the opposite patterns with higher values (bright areas) in the steep areas of the catchment and near drainage lines, with low values in the flatter areas.

5 DISCUSSION

The integration of the rainfall and runoff analysis with the topographic analysis suggests there are different mechanisms for runoff generation and nutrient export in the Chaffey Dam catchment.

The higher intensity rainfall in the summer months would detatch and mobilise a lot of phosphorus enriched sediment from much of the catchment, with the majority coming from the steeper areas of the catchment. These runoff events are of short duration, and a significant portion of the sediment would be deposited in low lying areas and in the channels. These depositional areas typically have higher W values, and the sediment would be remobilised and transported during the lower intensity and more persistent winter rainfall.

The practise of fertilisation in the catchment is to apply the fertiliser by aerial broadcast during the autumn months. This is prior to a period of low plant uptake, and high runoff. This suggests that there would be high availability of soluble phosphorus on the land surface. Even though there is low erosion during these months, it could be expected that there would be a significant export of dissolved phosphorus in these months.

The management practices of watering livestock in the streams ensures that there is a continous supply of animal wastes near the drainage lines. These zones have high wetness values as well as high sediment transport values. Therefore there is a high likelihood of transport of any material deposited there.

Lastly, the long term variability of rainfall and rainfall intensity suggest that there are critical period in the history of the catchment for nutrient export. This would have to be considered in assessing the representativeness of results of any monitoring program.

6 CONCLUSIONS

The rainfall, runoff, and topographic analysis carried out for Chaffey Dam catchment highlights temporal and spatial patterns in of factors affecting erosion and nutrient export from the catchment. This analysis is relatively simple, time efficient, and informative. The possible mechanisms for nutrient export discussed in the previous section may help to focus future investigations in the catchment and similar areas, as well as have a positive impact on land management in Chaffey Dam catchment. The results as presented above are qualitative. The techniques used can also be used quantitatively to improve estimates, and locate the critical areas for management [Chen et al., 1994].

7. REFERENCES

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