Climate and Hydrology in the Namoi Catchment

P F Crapper[a], S G. Beavis[b] and Li Zhang[b]
[a] CSIRO Land and Water, GPO Box 1666, Canberra, ACT 2601
[b] CRES, Australian National University, Canberra, ACT 0200

Abstract The Namoi River Basin (42,000 km^2) is located in the Murray-Darling Basin, west of the Great Australian Dividing range in north east New South Wales and includes some of the most fertile agricultural lands in Australia. One of the environmental concerns for this basin is erosion and its effects on downstream water quality. A modelling framework (Jakeman *et al.*, 1997) is being developed to determine relations between climate, land use and these concerns. Underpinning this framework are climatic (rainfall and temperature) and streamflow measurements. These measurements are examined here as a preliminary to the modelling. The residual mass technique has been used to examine the temporal variation of annual rainfalls over the approximately 100 years of available data and significant spatial variations have been found in annual rainfall trends over the catchment. Streamflow has been examined at Gunnedah and Narrabri, the only two stations on the Namoi River with more than one hundred years of record. The impact of recent large-scale irrigation operations was clearly observed. The impact of changing land use and land management on runoff ratios has been examined for eight subcatchments.

1. Introduction

In recent years the management of the water and land resources of the Namoi catchment have come under increasing public scrutiny. This has come about in part because of a wide belief that the present agricultural practices are not sustainable and in part because of a concern for the apparent deterioration of water quality. The work described in this paper is part of a larger study on the sources and transport of sediments and nutrients in the Namoi catchment. Additional information on the land and water resources of the Namoi catchment is contained in Schroder and Glennon [1995] and the Namoi Community Catchment Plan [1996].

Rainfall is probably the most widely measured meteorological parameter and is one of the major determinates of erosion. Jakeman *et al* [1997] present a framework to model and predict the effects of rainfall and land use on erosion and downstream water quality. A crucial input is accurate estimation of areal rainfall. This is not easy, as its temporal and spatial heterogeneity is high. The locations of rainfall measurement sites, within Australia at least, are generally selected for convenience, not representativeness. The Namoi Catchment is acknowledged as one with a highly variable rainfall and as having extremely variable hydrologic characteristics (see Findlayson & McMahon [1988]).

2.1 Rainfall Data

The rainfall data set for Gunnedah was examined for initial analysis. It is a composite data set from the NSW Dept of Land and Water Conservation Gunnedah Research Station and the Australian Bureau of Meteorology at the Gunnedah Post Office. This data set, as well as data sets for approximately 16,000 stations around Australia, are available on Metaccess [1996]. The data set records daily rainfall for the period 1 January 1877 to 31 March 1997. The annual rainfall for this period is shown in Figure 1 and the straight line of best fit has also been plotted. Gunnedah has in the last 120 years experienced three years with rainfall in excess of 1000 mm (1879 - 1047 mm, 1890 - 1133 mm and 1950 - 1150 mm) and one year with rainfall less than 250 mm (1946 - 247 mm). The average annual rainfall for the 120 year data set is 611.6 mm and the standard deviation is 171.1 mm giving a coefficient of variation of 0.28. The line of best fit reveals, on average, a slow

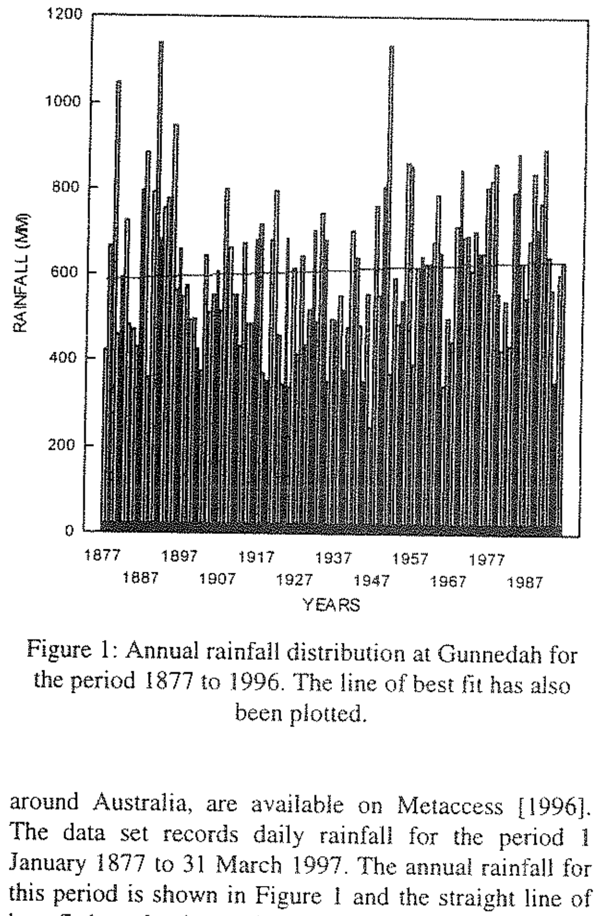

Figure 1: Annual rainfall distribution at Gunnedah for the period 1877 to 1996. The line of best fit has also been plotted.

but significant increase of about 0.4 mm/yr in average annual rainfall over this period.

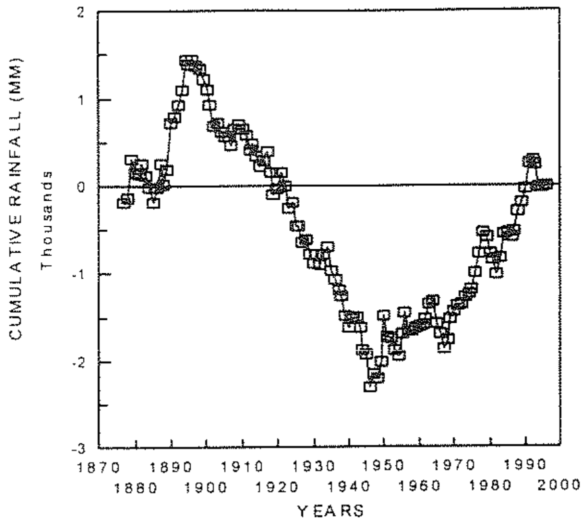

Figure 2: A residual mass plot of Gunnedah annual rainfall.

The cumulative sum (CUSUM) technique (see McGilchrist and Woodyer [1975]), also known as the residual mass technique, has been used to examine the temporal sequence of rainfall. Cumulative sum techniques have proved to be a valuable tool in detecting intermediate term changes in the mean value of a sequence of regularly spaced observations. The cumulative sum s_i can be defined as

$$s_i = \sum_{j=1}^{i} (x_i - \bar{x})$$

where x_i is the regularly spaced observation. The CUSUM distribution is a normalised distribution and it reveals runs of observations greater than the long-term mean with a positive slope and less than the long-term mean with a negative slope. Such persistent positive or negative slopes can be used to detect intermediate term changes in the mean value. The actual ordinate values are not relevant, it is the slope that is important. The CUSUM distribution for the annual rainfall at Gunnedah is shown in Figure 2. An examination of Figure 2 reveals that annual rainfalls for the 116 years of record can be treated as three distinct average rainfall periods. The first period from 1877 to 1900 consisted of a period of greater than average rainfall, with some uncertainty in the 1880s; the second period from approximately 1900 to 1945 was a period of below average rainfall and from 1945 there has been a period of average rainfall, followed by above average rainfall in the early 1970's and then in the 1980's. These trends are apparent in Figure 1 but much more difficult to discern.

Three additional raingauge stations were examined in detail. These stations were Tamworth (average annual rainfall 661mm), Narrabri (636mm) and Walgett (472mm). For periods of no record, stations within a 20 km radius were examined and the average rainfall at these stations was used. An attempt was made to show the four (ie including Gunnedah) CUSUM plots on one figure but the result was very confusing because of the vast scatter of points. Instead, a moving five year average of s_i has been plotted on Figure 3.

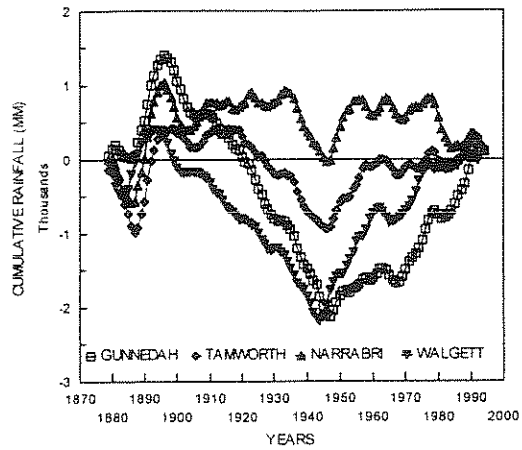

Figure 3: A moving five-year mean of s_i for Gunnedah, Tamworth, Narrabri and Walgett

The four locations show the same three major trends in rainfall, i.e., a period of above average rainfall at the end of last century, followed by a period of below average rainfall until 1945 and then a period of above average rainfall up to the present. However the durations of these periods varied for different locations.

The annual rainfall amounts presented in Figures 1, 2 and 3 conceal all within year variations. In Figure 4 the average monthly rainfall for each of the four locations for the entire record has been presented. The monthly rainfalls for each location have been normalised by the highest monthly rainfall for that location. For all locations it can be seen that; January has the highest monthly average rainfall; and with the exception of

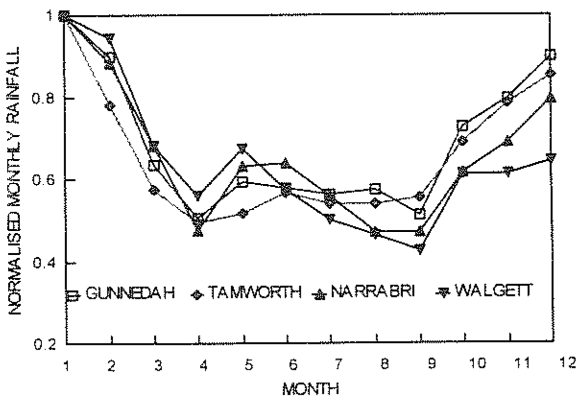

Figure 4: Long term monthly average rainfalls

Walgett in October, November and December the monthly rainfall distribution is very similar. The rainfall is very much summer dominated with January being the highest rainfall month. This was anticipated because the large summer rainfalls are associated with highly irregular inflows of tropical air masses. The average monthly rainfall from April to September is approximately uniform.

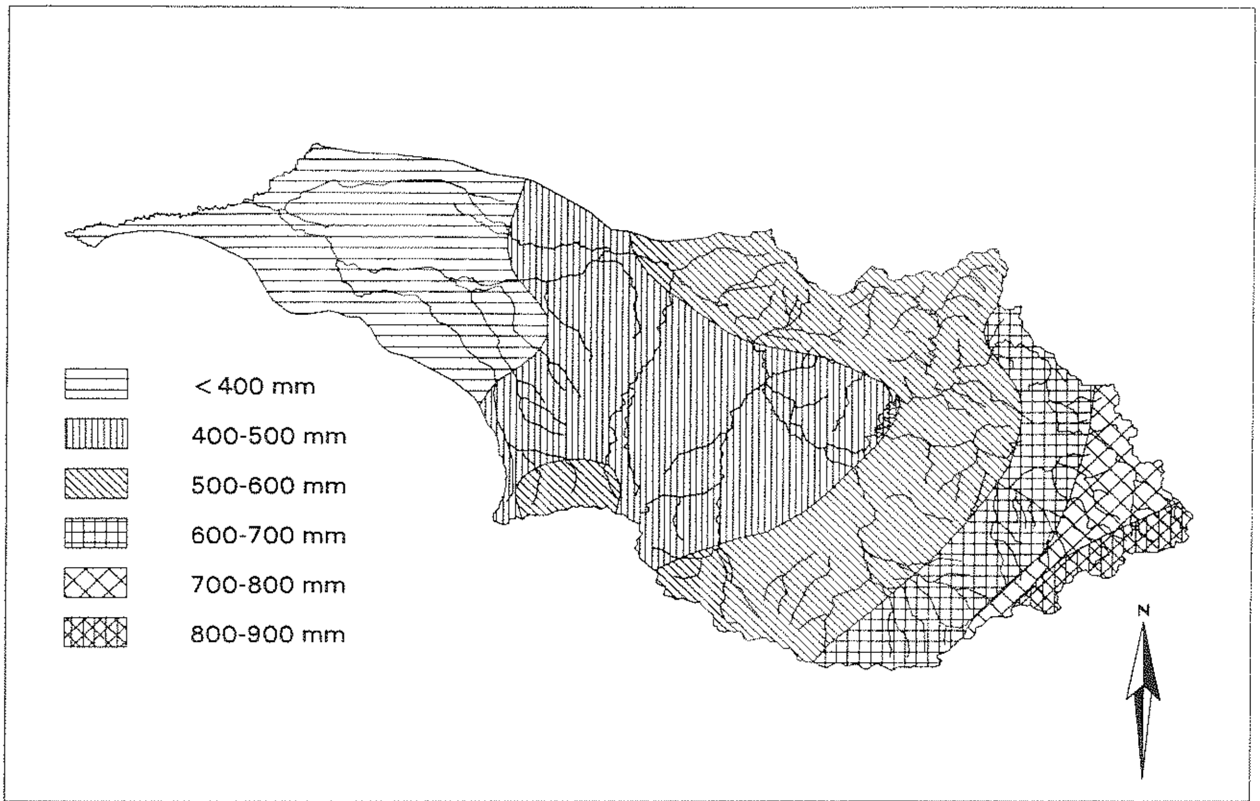

Figure 5: Rainfall contours for the Namoi catchment

Station name and No.	Area (km^2)	Annual rainfall (mm)	Annual discharge (mm)	Annual yield %	Raingauge coverage (km^2/gauge)	Longitude	Period of record
Cox's Creek at Tambar Springs 419033	1450	550	27.15	4.94	725.00	149:53:09	09/06/1965 30/06/1993
Mooki River at Caroona 419034	2540	652	24.95	3.83	181.43	150:25:47	01/01/1966~30/06/1993
Warrah Creek at Old Warrah 419076	150	930	62.27	6.70	75.00	150:38:34	15/06/1982~ 31/12/1991
Goonoo Goonoo Creek at Timbumburi 419035	503	700	52.16	7.45	100.60	150:54:55	16/06/1965~ 31/12/1990
Peel River at Piallamore 419015	1140	774	99.41	12.84	142.50	151:03:05	01/07/1936~ 14/02/1996
Peel River at Bowling Alley Point 419004	310	910	173.97	19.12	155.00	151:08:35	01/01/1940~ 31/12/1969
Mulla Creek at Goldcliff 419055	254	897	142.48	15.88	254.00	151:08:46	21/05/1974~ 09/02/1989
MacDonald River at Woolbrook 419010	829	845	156.32	18.50	138.17	151:20:45	01/01/1970~31/12/1991

Table 1: Rainfall and discharge character for eight upland subcatchments in the Namoi Basin

3. Streamflow Data

Streamflow has been measured at 87 locations in the Namoi Catchment for varying periods of time using mostly natural controls although there are some concrete structures. The daily streamflow records for all these stations (and all other streamflow stations in NSW) are available on Pinneena [1996]. Only the stations on the Namoi River at Gunnedah and Narrabri have recordings going back to last century and these stations have been considered in detail. Both of these data sets contained some periods of no record and these were set equal to zero. Narrabri is approximately 110 km downstream of Gunnedah.

The cumulative flow at Gunnedah and Narrabri are shown in Figure 6. The first feature immediately obvious from this plot is that streamflows generally exhibit similar trends until 1950 but the streamflow at Narrabri has always been less than the streamflow at Gunnedah inspite of the fact that a number of significant tributaries (Coxs Creek and Maules Creek) join the Namoi River between the two locations. In particular Coxs Creek has a catchment area of over 4000 km^2. The period of record starts at 1892, which is a long time before any irrigation or pumping for town water supplies started. The most likely explanation for this discrepancy is evaporation from the water surface and ground water recharge. A second feature obvious from the figure is that at about 1950 a change occurred and the Gunnedah streamflow increased whereas the Narrabri streamflow decreased from 1950 to 1990 (a horizontal line means no annual flow). The increased flow at Gunnedah is a result of above average rainfall from 1950 to 1990 as shown in Figures 2 and 3. The gradually decreasing gradient of the Narrabri streamflow is a result of the increasing irrigation of cotton farms that

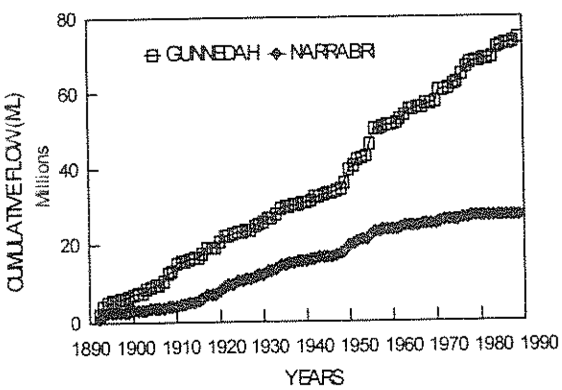

Figure 6: Cumulative annual streamflows for Gunnedah and Narrabri

occurred during that period. The final feature to note is that the major floods over the period of record occurred in the late 1940s and early 1950s.

In Figure 7 the residual mass plots of streamflow for the same period of record for Gunnedah and Narrabri have been plotted. This figure illustrates different features of the streamflow chronology than Figure 6. The first feature of interest is that, up to 1920, flows were approximately equal to the long-term average apart from slightly elevated flows in the early 1890s. However after 1920 the flow at Gunnedah was below average until the late 1940s whereas the flow at Narrabri remained approximately equal to the long-term average.

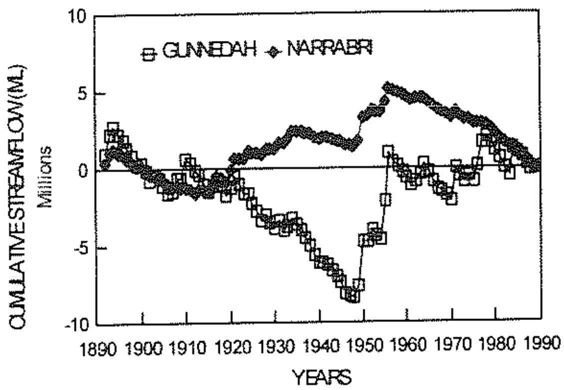

Figure 7: Residual mass plots for Gunnedah and Narrabri

This period coincides with a period of below average rainfall (see Figure 3), and irrigation pumping after 1960. If the Narrabri data set had only been examined from 1892 until 1960 then it would have shown a period of below average flow. The second feature of interest is that the highest flows during the period of record occurred from late 1940s to the middle 1950s. The third feature of note is that the streamflow at Gunnedah from 1955 to 1990 has remained approximately at the long term average, whereas the streamflow at Narrabri has been less than the long term average for the same period.

4. Effect of Land Use on Runoff

In the Namoi Basin, rainfall amount generally correlates with longitude, with the highest rainfalls occurring at the catchment boundary in the south-east and the lowest in the western section of the basin (Figure 5). Rainfall-runoff relationships have been characterised for a number of upland catchments in the Namoi Basin (see Table 1).

The data suggest that both average rainfall and catchment area are good first order predictors of average yield with correlations of 0.678 (Figure 8) and -0.741 (Figure 9) respectively.

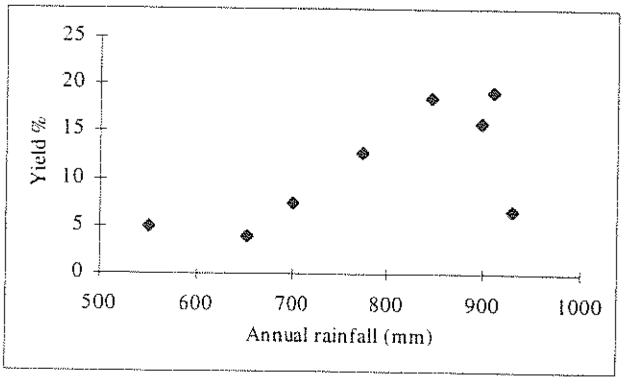

Figure 8: Annual rainfall versus yield for catchments in Table 1.

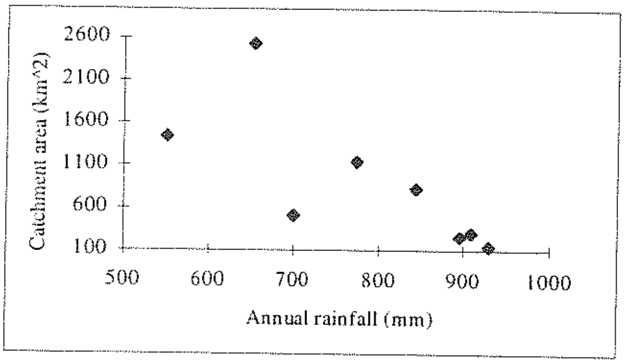

Figure 9: Annual rainfall versus catchment area for catchments in Table 1

The outlier in figure 8 represents Warrah Creek catchment which has experienced significant landuse and land management changes (Beavis *et al.*, 1997).These data suggest that factors affecting the hydrological response include:

- rainfall amount and temporal distribution;
- landscape attributes of the catchment including land cover and catchment area.

Agricultural expansion since European settlement has been associated with extensive clearing of forests and woodland and subsequent improvement of native grassland with exotic species. The application of fertilisers has also impacted on vegetation density. These land cover changes have a number of complex impacts on catchment hydrology:

- Removal of the tree canopy reduces interception losses (Langford *et al.*, 1982; Ruprecht and Schofield; 1989) and increases surface runoff;
- Replacement of deep rooting native pasture by shallow rooting improved pasture reduces the extraction of soil moisture by plants, particularly during dry periods, leading to aquifer recharge (Boughton, 1970);
- Introduced plant species transpire moisture at greater rates than native species, thereby reducing runoff (Ring *et al.*, 1984);
- Improved pasture increases groundcover density and reduces runoff (Ring and Fisher, 1985); and
- Water storages, including farm dams, reduce streamflow particularly during low flow conditions (Ockenden and Kotwicki, 1982; Cresswell, 1991; Good, 1992).

This complexity is compounded by the inverse relationship between infiltration rates and intensity of grazing as a function of soil compaction. Furthermore, the percentage groundcover in cropping conditions, which varies temporally, is significant: bare or fallow ground creates the most runoff, whilst closely grown crops result in least runoff (Ring and Fisher, 1985).

In response to land degradation problems, often initiated by clearing and inappropriate management practices, farmers have been encouraged to construct contour banks, grassed waterways and farm dams to form integrated erosion control networks. These structures modify catchment surfaces, impede the movement of water within a catchment, and ultimately reduce streamflow. In a catchment with conservation treatments including perennial pasture, three-year crop rotations and extensive contour banking, a 24% reduction in runoff was measured, with the figure almost doubling to 43% for drier periods (Moore and Morgan 1969). Furthermore, the diversion of water for irrigation reduces downstream flow, and can contribute to potential conflicts between users. Consequently, whilst the initiation and development of erosional networks is associated with changes in landcover (Beavis *et al.*, 1997a), sustainable land management practices also impact on the erosional drainage network by reducing runoff (*ibid.*).Beavis *et al* [1997b] illustrate, for the Chaffey catchment the effect of changes in land cover and use on runoff.

5. Conclusions

Climatic parameters are highly variable and vary with many apparently different timescales. Whether these timescales are real or an artefact of the time series analysis technique is a question more related to philosophy than science. Nyquist's theorem, from the field of signal processing, states that to observe a signal of period T, you need a minimum data set of 2T. Thus with 120 years of rainfall and 40 years of temperature data, it is not possible to make any statistically significant statements about long term trends (> 100 years). However it is possible to state that shorter-term trends (up to 50 years) were evident in the rainfall data. No trends were visible in the temperature data. The streamflow data exhibited shorter-term trends due to changes in land-use.

8. Acknowledgments

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