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Influence of recent climate on sedimentation in Burrinjuck Reservoir

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Abstract Rainfall, runoff and peak discharge data were used to attempt to explain a declining sedimentation rate in the Burrinjuck Reservoir. A statistically significant increase in rainfall was observed for the period after 1948 compared to the pre-1948 period. Runoff and peak discharge data did not indicate any significant increase in mean. The behaviour of the drainage basin with regard to wetness and potential vegetation was simulated using a simple water balance model and the computer program GROWEST. The drainage basins were slightly wetter in the latter period and a significant increase in growth index was observed for the same period. A slight increase in the stream power was observed, but the increase was not statistically significant. The observed decreased rate of sedimentation in the reservoir since 1948 is attributed to a relatively wet drainage basin in which erosion of the land surface was unchanged but in which tributary channels have become progressively less important sources of sediment.

INTRODUCTION

The rate of sedimentation (as measured from the core samples taken during the 1982 drought) in Burrinjuck Reservoir, on the southern tablelands of New South Wales (Fig. 1), has declined markedly (Fig. 2) since about 1950 (Wasson & Clark, 1985; Wasson *et al.*, 1987). Although the past and present sedimentation rates are not a threat to the storage capacity of the reservoir, this decline in the sedimentation rate is of interest because it may be an indicator of drainage basin condition or of climate change. The value of the sedimentary record in the reservoir is therefore as an integrator of processes within a large drainage basin. In this paper we explore the possibility that climate change has modulated the complex processes of erosion, deposition, re-entrainment and re-deposition to produce the net result observed in the sediments of the reservoir. This hypothesis may appear to be counter-intuitive, given that rainfall has increased since 1945 in south-east Australia (Pittock, 1975). But it is this coincidence in timing that is worth exploring.

Other possible explanations of the changed sedimentation rate are: better land management; increased numbers of farm dams and small town reservoirs storing sediment; and re-equilibration of small channels and gullies after an initial period of very active erosion following land use change.

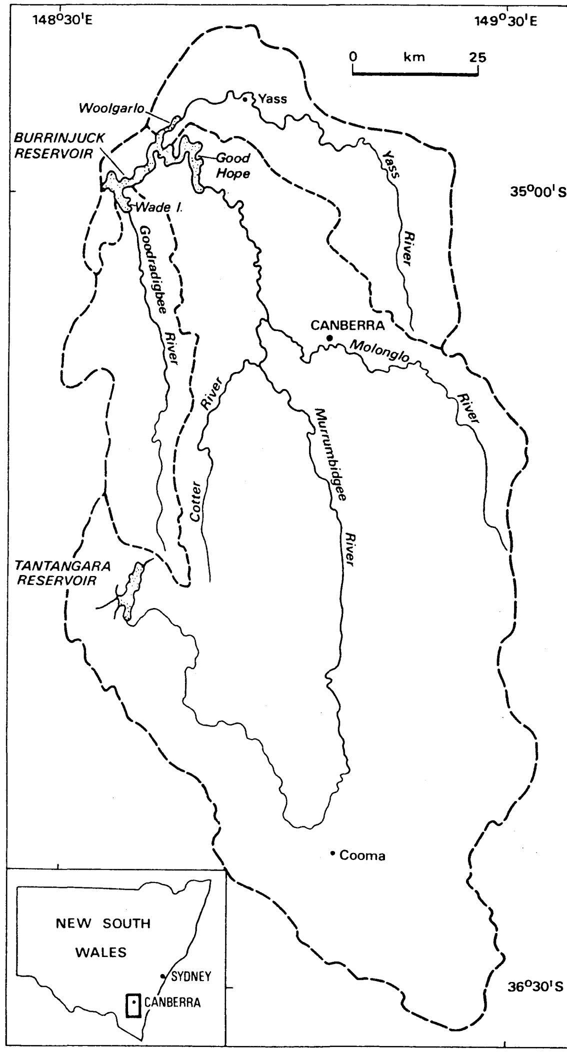

Fig. 1 Location map of Burrinjuck drainage basin.

DESCRIPTION OF BURRINJUCK DRAINAGE BASIN

The drainage basin for the Burrinjuck Reservoir is located in the southeast of New South Wales (Fig. 1). The area of the drainage basin is 13 500 km^2. The drainage basin lies just west of the Great Divide and forms part of the Murray-Darling Basin. The dominant relief is a rolling lowland between 500 and 1000 m above sea level with hills and mountains up to 1000 m or higher. The natural vegetation of the lowlands was originally dry sclerophyll woodland, most of which has been cleared for grazing and some limited cropping. There are some natural grasslands on the plains. Parts of the high ground carried wet sclerophyll forest which is still largely intact. The Burrinjuck drainage basin is divided into three major sub-drainage basins, namely, Goodradigbee,

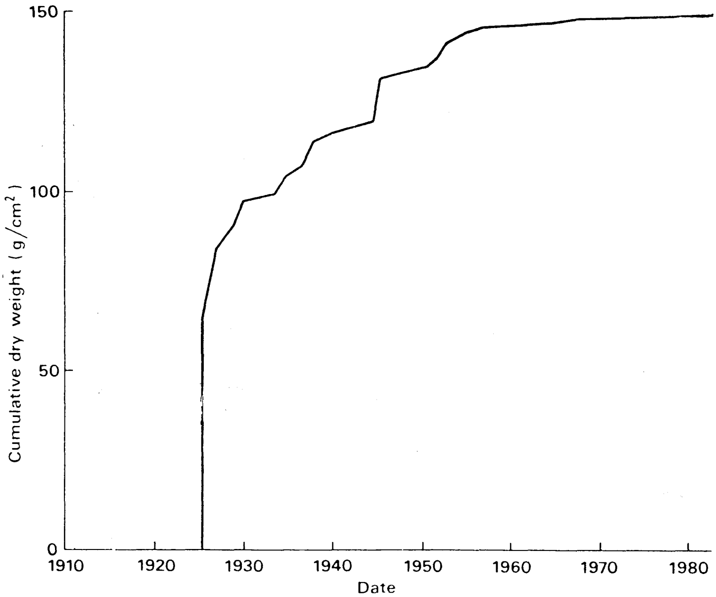

Fig. 2 Sedimentation rate at Burrinjuck Reservoir (Wasson & Clark, 1985).

Yass and Murrumbidgee drainage basins each feeding into separate arms of the reservoir. The topography of the Yass drainage basin (area 1680 km^2) is undulating with a maximum relief of 300 m. Most of the slopes are gentle or moderate. The Goodradigbee drainage basin (area 1260 km^2) consists of a number of mountain ranges with steep slopes and is mainly forested. The Murrumbidgee drainage basin (area 10 320 km^2) occupies over 75% of the total drainage basin area. The southern part of the drainage basin consists of mountainous ranges while the northern part is predominantly undulating land.

RAINFALL AND RUNOFF DATA

Monthly rainfall data were obtained for a number of stations lying within the drainage basin boundary and in the neighbourhood of the drainage basin. The locations of the 50 rainfall stations, selected as having more than 60 years of record, are shown in Fig. 3. Although the Goodradigbee, Yass and Murrumbidgee rivers supply water to the Burrinjuck Reservoir, inflow data at the points of entry are not available. Instead, daily runoff data from the upstream gauging stations were used (Table 1). From this, monthly and annual runoff volumes and peak annual discharges were extracted for the analyses described later. The Goodradigbee and Yass Rivers have broken records. As the Yass River record has a large gap (about 12 years), runoff volume data have been supplemented with data at Yass Railway Weir which is a few kilometres upstream of Yass. Since the characteristics of flood peaks change considerably over short distances, the gap in the annual flood data was not filled.

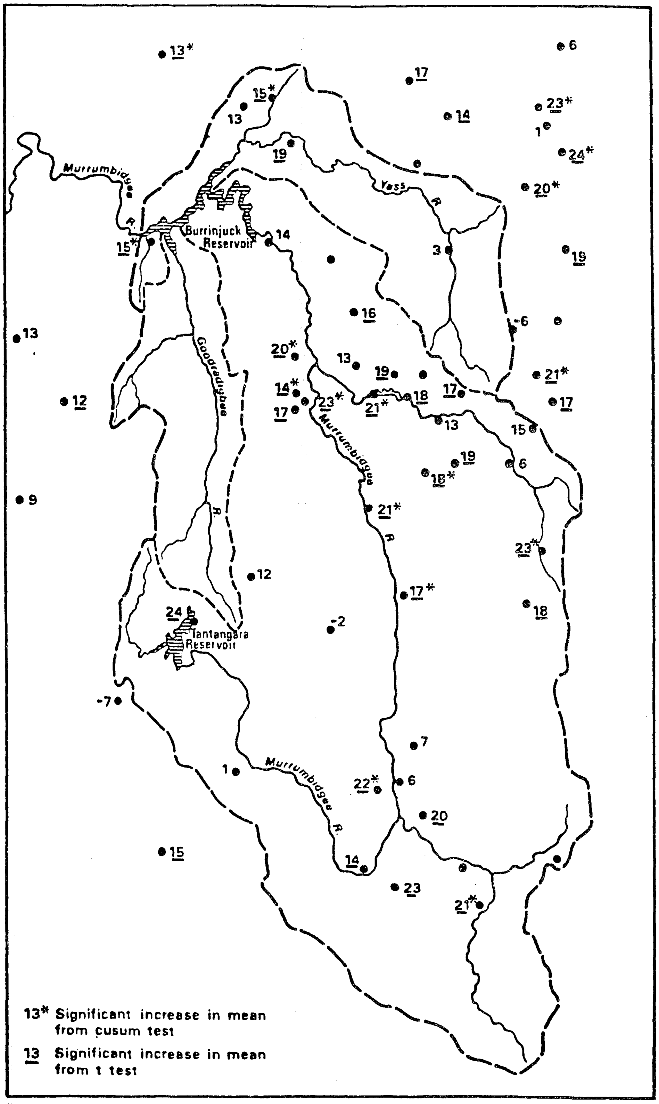

Fig. 3 Locations of rainfall stations and the results of statistical tests.

Table 1 Details of runoff data.

River	Gauging station	AWRC number	Area (km^2)	Data: Period	Length (years)
Goodradigbee	Wee Jasper	410 024	1260	1915-81	62~
Yass	Yass	410 026	1230	1916-84	68~
Murrumbidgee	Cotter	410 035	6600	1928-79	52

~ broken record.

THE HYDROLOGIC REGIME

As it has been claimed that rainfall has increased in southeast Australia since the late 1940s (Pittock, 1975; Cornish, 1977), the rainfall and runoff data were tested for a change in the mean value. Two cases were considered. In the first case, the change point was assumed to be not known and in the second case prior knowledge of the change point was assumed. If the change point is assumed to be known, a more sensitive test can be applied to estimate its significance.

Change point not known

McGilchrist & Woodyer (1975) developed a distribution free technique known as CUSUM to detect changes in the mean value of a sequence. This test was applied to the rainfall and runoff data. Seventeen of the 50 rainfall stations showed an increase in mean rainfall and these 17 rainfall stations are marked by asterisks in Fig. 3. Neither the runoff volumes nor the peak annual discharge data indicated any change.

Change point assumed known

Based on the definition of flood dominated and drought dominated regimes (Warner, 1987) and the results from the CUSUM technique, 1948 was taken as the change point. With the change point assumed, the standard t test can be used to test the equality of means provided that the variance remains unchanged. However, if the variance changes, it is necessary to use the modified t test (Yamane, 1967) to test the equality of the means. Hence, the F test was first applied to test the equality of variance. Based on the outcome of this test, the standard or modified t test was used to test the equality of means.

The tests were applied to station rainfall data which were divided into two parts; the first part contains pre-1948 data while the second part consists of post-1948 data. The differences in means and the ratio of variances were tested for significance. Excluding 9 stations which did not have at least 10 years of data after 1948, 41 stations showed an increase in variance and 35 stations indicated an increase in mean. The percentage changes in mean are shown in Fig. 3. The underline shows statistically significant increased means. Based on this figure, one can conclude that the Burrinjuck drainage basin received more rainfall after 1948 than before 1948.

Runoff from the Yass and Murrumbidgee Rivers indicated significant increase in variance while only the Yass River showed a significant increase in mean. Peak annual discharge data did not indicate any significant change in mean or variance. In addition, the empirical distributions of peak annual discharges were compared.
Three cases were considered:
(a) using all available data,
(b) using the pre-1948 data,
(c) using the post-1948 data.
Peak annual discharges were plotted against the probability of exceedances and these figures (not presented due to lack of space) confirm the earlier finding that peak annual discharge data are consistent throughout the whole period of record.

DRAINAGE BASIN WETNESS

The sources of sediment for a reservoir are the drainage basin and the river channel. The moisture status and the vegetative cover condition of the drainage basin affect the rate of land erosion and the amount of runoff for channel erosion. A moisture accounting model enables an assessment to be made of the wetness state of a drainage basin. A simple water balance model (Fig. 4) was used to model the drainage basin on a monthly time interval. It has three parameters, namely, the maximum soil moisture capacity, S_{max} and two coefficients K_1 and K_2 for baseflow. The model equations are:

$$S(t) = S(t-1) + R(t) - ET(t) - DS(t)$$

$$SRO(t) = S(t) - S_{max} \qquad \text{if } S(t) < S_{max}$$

$$= 0 \qquad \text{otherwise}$$

$$DS(t) = K_1.S(t-1)$$

$$BF(t) = K_2.DS(t)$$

$$RO(t) = SRO(t) + BF(t)$$

where

$S(t)$	soil moisture content at the end of month t,
$R(t)$	rainfall in month t,
$ET(t)$	actual evapotranspiration in month t,
$BF(t)$	base flow in month t,
$SRO(t)$	surface runoff in month t,
$RO(t)$	runoff in month t,
$DS(t)$	infiltration in month t,
S_{max}	maximum soil moisture,
K_1, K_2	coefficients in base flow equations.

The potential evapotranspiration (PET) was obtained by multiplying pan evaporation by 0.7. Since pan evaporation data was available only at one location, a scaling factor,

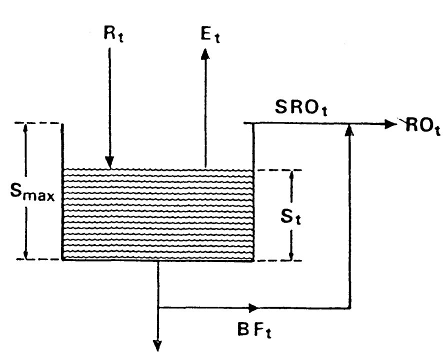

Fig. 4 Schematic representation of monthly water balance model.

Table 2 Parameters of the water balance model.

Catchment	S_{max}(mm)	K_1	K_2	K_3
Goodradigbee	306	0.289	0.673	1.221
Yass	217	0.079	0.318	0.750
Murrumbidgee	247	0.110	0.677	0.750

Table 3 Observed and simulated mean runoff volumes (mm).

Month	Catchment: Goodradigbee: Obs.	Sim.	Yass: Obs.	Sim.	Murrumbidgee: Obs.	Sim.
January	9.04	6.89	1.61	0.97	5.34	6.64
February	6.44	4.76	1.43	0.69	5.15	4.86
March	7.35	6.21	1.17	0.73	9.04	6.09
April	7.80	8.77	2.38	1.55	9.46	7.30
May	11.31	15.66	3.71	3.61	9.38	9.82
June	18.21	25.65	6.31	7.14	15.95	17.81
July	32.41	32.93	6.54	5.81	16.18	17.19
August	41.06	35.32	6.36	6.56	19.11	17.89
September	37.25	35.83	4.18	4.51	17.48	16.27
October	33.05	29.94	6.16	5.64	18.14	16.06
November	21.97	23.42	2.33	2.24	11.69	12.86
December	12.93	14.78	0.80	1.60	7.02	10.25
Annual	238.8	240.1	43.0	41.1	143.9	143.0

Table 4 Mean monthly soil moisture.

Catchment	Period: < 1948	≥ 1948
Goodradigbee	107	112
Yass	101	111
Murrumbidgee	123	136

K_3, was used obtain the PET for the three drainage basins. Actual evapotranspiration was obtained from PET using a linear relationship with the soil moisture. The model parameters were estimated by minimizing the sum of squares of the differences between observed and simulated runoff volumes, and the estimates are given in Table 2. Table 3 shows that the model simulates the runoff volumes reasonably well. Mean monthly soil moisture is given in Table 4.

Monthly estimates of soil moisture were aggregated to obtain the annual soil moisture, and the annual values were tested for change in mean value. The CUSUM technique indicated no change in mean value.

VEGETATION

The amount of vegetation in the drainage basin in terms of dry matter production is directly related to a growth index (Nix, 1979). Cumulative growth index values were estimated using the computer program GROWEST. Very briefly, GROWEST involves transformation of the non-linear responses of plants to the major light, thermal and water regimes into dimensionless ratios on a scale of zero to unity. The mean annual growth index values for the two periods are given in Table 5. A slight increase in the magnitude for the latter period is observed in this table. The annual values were tested for trend using the CUSUM technique. The results indicated an increase in the mean value for the Yass and Murrumbidgee drainage basins at the 5% significance level and for the Goodradigbee drainage basin at the 10% level.

Table 5 Mean annual growth index.

Catchment	< 1948	> 1948
Goodradigbee	14.5	15.1
Yass	7.56	8.67
Murrumbidgee	7.15	7.78

STREAM POWER

Sediment transport in a river is a complex process. The amount of sediment transported by a river is related to many variables such as water discharge, flow velocity, stream power, energy slope, shear stress, water depth, particle size, and sediment delivery rates. Based on published data, Yang (1977) found that the rate of sediment transport or total sediment concentration in a river is dominated by stream power more than any other variable, although he took no account of sediment delivery. Hence stream power was used in this study to estimate the ability of the rivers to transport sediments.

Yang (1972) defined stream power, w, as

$$w = rRSV$$

where:
r = specific weight of water,
R = hydraulic radius,
S = energy slope, and
V = flow velocity. Since $R = A/P$ and $V = Q/A$, the above equation can be written as

$$w = rSQ/P$$

where Q is the discharge, A the cross-sectional area, and P the wetted perimeter.

Assuming S is constant, w is proportional to Q/P. P was obtained from the rating table and cross sectional data. Using daily flows, streampower was calculated and aggregated annually. Mean annual values for the two periods are given in Table 6. The annual values of stream power did not indicate any significant change in the mean value.

Table 6 Mean annual stream power.

River	< 1948	> 1948
Goodradigbee	30.4	32.7
Yass	5.28	5.87
Murrumbidgee	32.0	38.8

DISCUSSION OF RESULTS

The hydrologic history of the Burrinjuck Catchment was investigated using rainfall, runoff and peak discharge data. An increase in the rainfall and runoff was observed for the post-1948 period compared to that of the pre-1948 period. However, only 17 rainfall stations indicated significant change in mean values using the CUSUM technique, while 35 rainfall stations showed a significant increase in mean using the t test if the time of change was assumed to be 1948. CUSUM technique did not indicate any change in mean runoff, while the Yass River data showed a significant increase in mean using the t-test. The reasons for the Goodradigbee and Murrumbidgee Rivers not indicating an increase in mean might be:

(a) Most of the high flows in 1950-1960 were not recorded for the Goodradigbee River.
(b) Increased vegetation in the drainage basins resulting in higher evapotranspiration loss.

Peak annual discharge data did not show any change in the mean value. The maximum floods occurred in the 1920s for the three drainage basins.

Simulation of the drainage basin behaviour using a simple water balance model indicated that the drainage basins were wetter in the post-1948 period than in the pre-1948 period. But the increase in wetness is not statistically significant. The vegetative cover in the drainage basin was assessed using GROWEST and the results indicated a significant increase in potential vegetative growth in the post-1948 period.

Although the stream power estimates were slightly larger for the post-1948 period, the increase was not statistically significant. This means that the rivers had the ability to transport an equal amount or more in the latter period.

While potential vegetation growth increased after 1948, so too did the average stocking rate (W. Gallagher, pers. comm.), probably resulting in little change in the average cover in the two periods. From this result we can conclude that sediment delivery from the land surface has changed little between the two periods. That the transport capacity of the major streams has not changed, despite variations in rainfall, is highly significant. If sediment delivery from the land surface in unchanged, and the transport capacity unchanged, the only other origin for the changed sedimentation rate is the stream network. There is abundant evidence that the tributary channels in this drainage basin incised soon after the European settlement (Wasson & Clark, 1985). The rate of change of the cross-sectional shapes and depths of these channels has slowed in this century, and it is postulated that they have become less significant sources of sediment. This re-equilibration of the tributary channels is probably the cause of the declining sedimentation rate in Burrinjuck Reservoir. The alternative explanation of increased storage of sediments in farm dams can be dismissed because a mass budget shows that this is a trivial amount by comparison with the total mass flux.

CONCLUSIONS

In an effort to explain the declining rate of sedimentation in Burrinjuck Reservoir since 1950, rainfall, runoff, soil moisture and vegetation growth potential were examined for as many as 68 years. More than half the rainfall stations indicated a significant increase of rainfall since 1948. Runoff did not increase however. Stream power, an indicator of sediment transport capacity, also remained unchanged. It is also likely that sediment delivery from the land surface was unchanged, leaving only one conclusion: the declining sedimentation rate is the result of tributary channels becoming progressively less important sources of sediment as they equilibrate after their initial highly erosive stage following land use change.

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