Hydrological impact of water use and regulation in the Barwon - Darling River

*Neeraj Maini * and Hugh Cross**

ABSTRACT: *The flow regime of the Barwon-Darling River has changed markedly over the last century, and especially the last 30 years, through construction of weirs, regulation of streams upstream and a continued increase in water abstractions. A model developed by the Hydrology Unit, Water Resources, of NSW Department of Land and Water Conservation was used to compare simulated natural flows at five stations with simulated current conditions which corresponds to irrigation development in 1993/94. New and infrequently used hydrological methods are developed to analyse the impact of water abstraction on the riverine environment. Water Resource development has significantly reduced daily and annual volumes of flow. Increases in rates of fall, or a steepening of the recession limb of flood hydrographs, have occurred for events that occupy up to 50% of river channel capacity. Further, the frequency and size of in-stream flood flows have been significantly reduced at all stations. These hydrological changes have had a profound impact on ecology and the long term utility of the river as a resource.*

1. INTRODUCTION

The Barwon-Darling River is a large low land river draining most of the semi-arid inland of NSW north of the Lachlan valley, and southern inland Queensland up to Charlesville (Figure 1). Despite the river and its tributaries draining an area of 650,000 square kilometres, the Darling contributes, on average, less than 10% of the mean annual flow of the Murray River at Wentworth. Climatic variability, especially rainfall, is a feature of the catchment with occasional periods of intense rainfall over much of the catchment interposed by periods of long drought. This is reflected in long term variations in mean annual flow volumes at Bourke which can range from 6.34 % to 286 %.

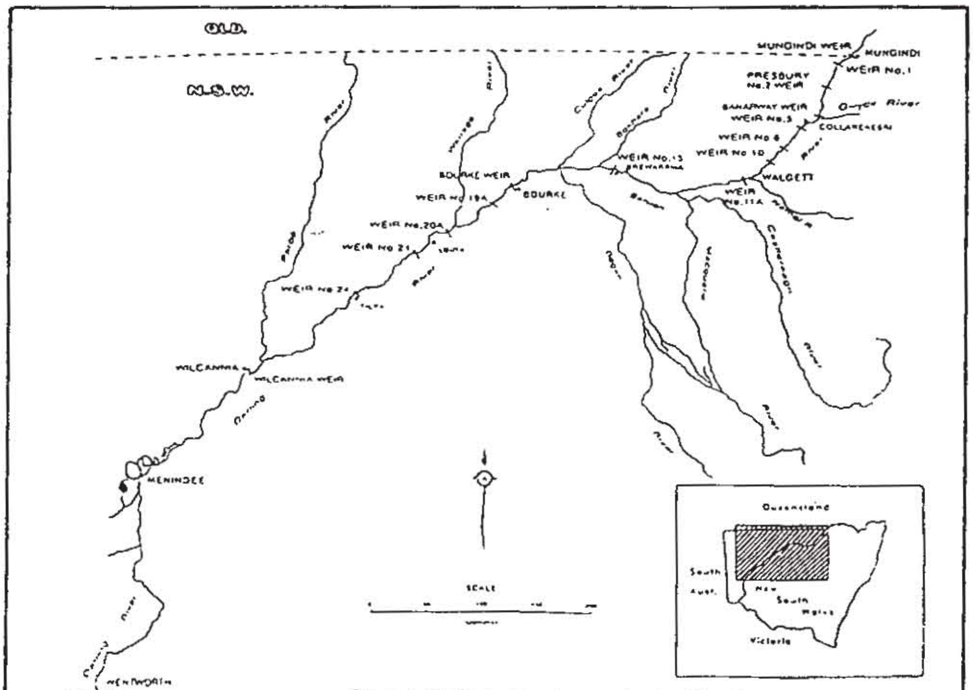

Figure 1 The Study Area Barwon-Darling River System

* Ecological Services Unit, Water Resources, NSW Department of Land and Water Conservation, P.O Box 3720 Parramatta 2124. Telephone: (02) 895 7471 Fax: (02) 895 7867

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The purpose of this paper is to analyse the change in specific hydrological variables that have resulted from flow regulation and water use. These results were used by the Barwon-Darling Expert Panel to investigate changes to the flow regime and assumed linkages with ecological and geomorphological processes (Cross *et al.* (in press) ; Thoms *et al.*, (in press)). The approach differs substantially from that used in the study of six regulated rivers of the Murray-Darling Basin by NSW Fisheries and the former NSW Department of Water Resources (Swales and Harris, 1995).

The study area covered the unregulated section of the Barwon-Darling River, from Mungindi at the Queensland border, to the upstream end of Lake Wetherill at Menindee. The Barwon-Darling River upstream of Menindee is highly impacted by water extraction, both from regulation of upstream tributaries and from pumping of unregulated flows along the river. For example, the median monthly flow at Mungindi is now only 40% of its natural value. Seventeen weirs constructed between Mungindi and Menindee over the past 100 years which now impound about 40% of the length of the river in this reach. The resulting changes in the flow regime from all these changes has significantly contributed to in-stream environmental deterioration reflected in declining fish populations (Harris, 1992) and an increase in the frequency and severity of algal blooms, especially blue-green blooms (Blue-Green Algal Task Force, 1992).

2. METHODS

To analyse the impacts of water abstraction on the riverine environment we have used new and infrequently used hydrologic "tools". In particular, the frequency, duration and recession limb slope of individual flow events appeared from the panel's assessment to be critical to ecological functioning. Water resource elements having an influence on ecosystem components (fish, invertebrates, macrophytes, trees and geomorphology) were identified as: total discharge; flood frequency; frequency of drought; flow duration; seasonality; velocity; frequency of stage height variation and rate of rise and fall. Hydrological data were analysed for annual and mean daily volumes, peak flows, duration of flows, event duration and rate of rise and fall. The panel conducted their own analysis of the frequency of stage height variations in a separate study.

Simulated data were used for five key sites along the river at Mungindi, Collarenebri, Walgett, Bourke and Wilcannia. Simulated data for pre- and post development (natural and current) conditions between 1966 and 1992 were obtained from output of NSW Department of Land and Water Conservation's Integrated Quantity/Quality Model (IQQM). The IQQM is a daily time step, generic river basin flow simulation package and was configured to simulate different processes and water management rules in the Barwon-Darling system (Black et al., in press). Simulated natural (ie. pre development) data refers to flows in the river in its natural state without any regulation or abstraction, and the simulated current (ie. post development) data refers to water resource development conditions existing during 1993/94.

The following methods were used in the assessment of hydrological changes in the River system:

2.1 Flow Duration Curve (FDC) Analysis

FDC analysis was performed to compare the percentage of time during which specified discharges were equalled or exceeded in simulated current and natural conditions. Monthly flow duration curves are derived by simply ranking the daily flows from all the months of that particular month, and extracting the flow values corresponding to exceedence values of 1%, 2%, 3%-------98%, 99%. This approach was used to derive monthly FDCs for all months from simulated flow data (1966 to 1992) under current and natural conditions. The major limitation of these curves is that they do not give any indication of the length of individual events. The percentile values plotted were selected by the panel to represent the range of most commonly occurring flows, that is low flows.

2.2 Flood Frequency

Flood frequency analysis is based on the annual exceedence series (Chow, 1964). It would be, in fact, more appropriate to use partial-duration series. For instance, in this series the recurrence interval is the average interval between floods of a given size regardless of their relation to the year or any other period of time. But in the annual series the recurrence interval is the average interval in which a flood of given size will recur as an annual maximum. Modelled data for the period 1966-1992 was used for this analysis.

2.3 Flow Exceedence Frequency Duration Analysis

The flow exceedence frequency duration is derived by scanning the daily flow record and noting the number of times and the length of period during which the streamflow exceeds the four given thresholds (ie. 80%, 50%, 25%, 10%) of mean daily natural flow recognised by the Panel as important in-channel threshold flows. These frequencies are then accumulated to provide information on the number of times that the flow exceeded the given thresholds for periods of 10 day intervals 1 - 10, 10 - 20, 20 - 30,----------,190 - 200 days and greater than 200 days.

2.4 Rates of fall and rise

This analysis attempts to quantify any changes in slope of the rising and the falling limbs of individual flow event hydrographs. Simulated data for the period (1966-1992) were used for this analysis.

2.4.1 Rates of fall

The number of days for which daily discharge dropped by greater than 100, 500 and 1000 ML/D from the preceding days was calculated for various flow ranges. These flow ranges were selected by the expert panel on the basis of surmised interactions between river flows and geomorphic processes. The percentage occurrence of discharge dropping by more than the nominated rates of flows in each range, was determined by dividing the number of days flow dropped by more than 100, 500 and 1000 ML/D by the total number of days that the flow dropped within that range.

2.4.2 Rates of rise

The rates of rise were calculated in a similar manner to the rate of fall for nominated daily changes up to 500, 1000 and >2000 ML/D for all flow events at Bourke. Flows were not directed into the flow ranges used for the falling limb analysis due to the panel's conclusion that ecological and geomorphic processes are less sensitive to changes in the slope of the rising limb.

3. RESULTS AND DISCUSSION

The results presented in this paper have been limited to Bourke for some analysis due to space constraints.

3.1 Flow Durations

Table 1 shows discharges for 80, 50, 25 and 10 percentile flows at each site. Figure 2 gives flow exceedence values for all months at Bourke. This analyses demonstrates that in all months simulated current FDCs for all five stations are below the simulated natural curves except for the 97th to 100th percentile flows which are now higher. This indicates an overall reduction in total flow value and the cumulative duration at all but the very lowest flows in the Barwon-Darling River. The difference is more noticeable for larger flows that occur less than 25 percent of the time. Seasonal variability is also seen by a reduction in flow durations which are more prominent during the summer months, corresponding to higher water demand in summers. This shows that current conditions are affecting seasonal distribution (magnitude of flows in different seasons during a year) and 'seasonality' (the relative variation of flows from one season to the next).

3.2 Flow Exceedence Frequency Duration

Results are reproduced in Table 2 as the ratio of the number of simulated current and natural flows events exceeding threshold levels. The percentage of natural events exceeding each flow threshold for different durations were also calculated. The duration ratios for the 80th and 10th percentile flows are presented in Table 3.

Table 1: Flow duration analysis (simulated data ; 1966-1992)

Station	Discharge in ML/D for different flow percentiles							
	10%		25%		50%		80%	
	Natural	Current	Natural	Current	Natural	Current	Natural	Current
Mungindi	5250	3250	2250	1000	510	340	110	70
Collarenebri	8750	6250	3250	1500	720	550	180	160
Walgett	14500	9000	5500	2250	1390	590	370	200
Bourke	24500	20000	9750	5500	2930	1350	780	510
Wilcannia	25250	21000	10500	6000	2600	670	500	240

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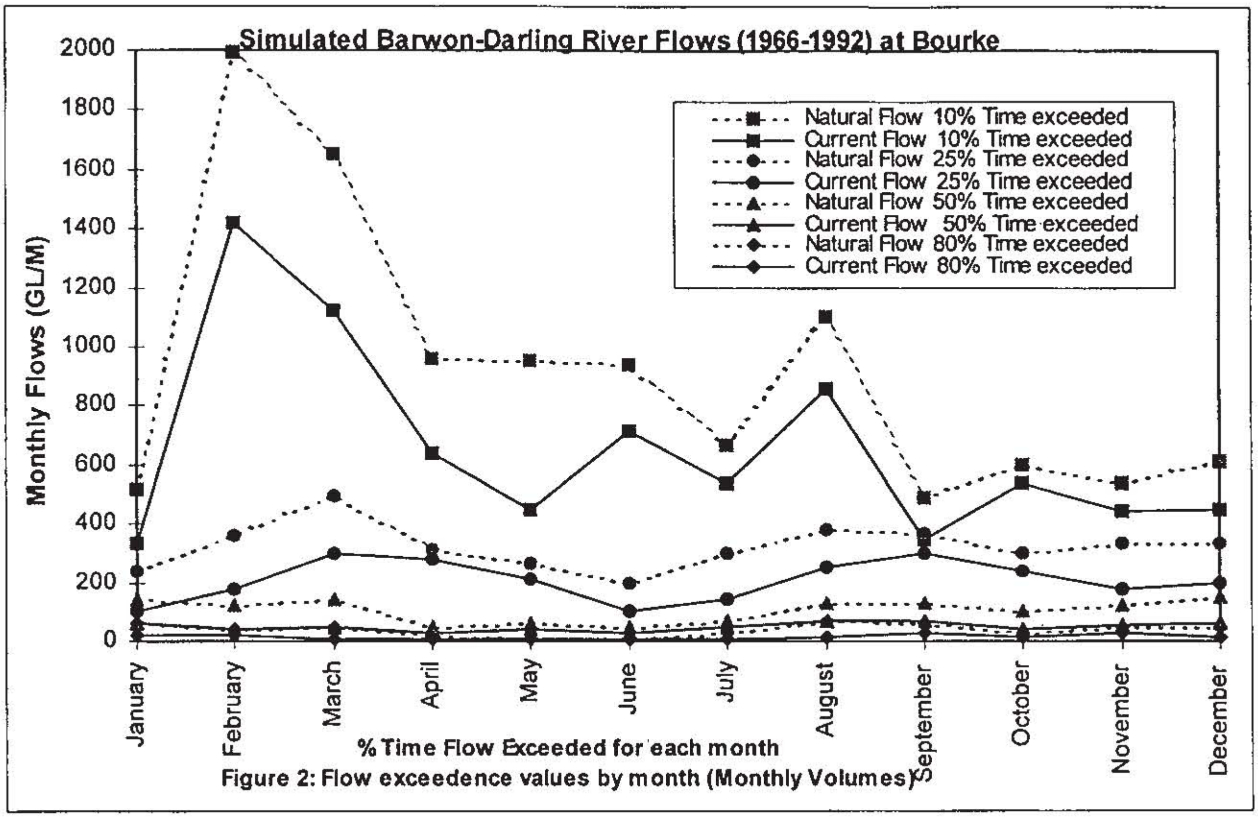

Figure 2: Flow exceedence values by month (Monthly Volumes)

Table 2: Ratio of the number of simulated current and natural flows

Station	The number of events exceeding the following flow percentiles (expressed as a ratio of simulated current: natural)			
	80 th	50 th	25 th	10 th
Mungindi	2.13	1.88	0.63	0.71
Collarenebri	1.16	1.19	0.88	0.74
Walgett	1.47	0.88	0.63	0.72
Bourke	1.29	1.57	0.78	0.97
Wilcannia	1.40	0.60	0.71	0.81

Table 3: Duration ratios for the 80th and 10th percentile flows.

Station	The number of events with the following durations (expressed as a ratio of simulated current: natural)									
	1-10 days		11-20 days		21-30 days		31-40 days		----->120 days	
	80th	10th	80th	10th	80th	10th	80th	10th	80th	10th
Mungindi	2.62	**0.69**	3.89	**0.72**	1.28	**0.70**	4.50	**1.00**	0.61	**0***
Collarenebri	1.25	**0.68**	1.23	**0.57**	1.60	**0.82**	0.80	**1.50**	2.43	**0***
Walgett	1.46	**0.92**	1.83	**0.60**	3.60	**0.50**	0.50	**1.00**	0.70	**0***
Bourke	1.44	**0.66**	2.00	**1.20**	1.83	**0.66**	0.37	**0.86**	0.82	**0***
Wilcannia	2.00	**2.00**	1.60	**0.25**	8.00	**3.00**	0.70	**0.50**	0.66	**0***

* No events greater than 120 days

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Table 2 shows that the frequency of events exceeding higher flows (ie. 25th and 10th) is less than natural by up to about 35%. This is consistent with the reduced flow durations under current conditions for same thresholds observed using the FDC analysis (Table 1).

The lower flow events (ie. 80th and 50th percentiles) display a contrary trend, ie. they have increased in frequency despite the FDC analysis showing an overall decline in flow duration under current conditions for all flows. The apparent contradiction is a result of fragmentation of events under current conditions relative to natural conditions, ie. single large events have been broken up into a number of smaller events that intersect the flow thresholds more frequently but for less total time.

The duration analysis of each threshold exceedence shown in Table 3 indicates that the greatest changes have taken place for events of 30 days duration or less, for 80th percentile flows these changes have been positive, whilst for higher flows (ie. 10th Percentile) the frequency has decreased. Longer duration events generally correspond to higher flows which have been less impacted by flow regulation.

3.3 Flood Frequencies

Table 4 shows changes in flood flows for various average annual recurrence intervals at Bourke. Flood flows up to the 5-10 year return interval have been significantly reduced at all stations under current conditions. Reductions generally decrease with an increase in the average return interval. The size of flood flows and reduction in their frequency are greatest at Bourke. This shows that water resource development has reduced the frequency and size of in-stream flood flows in the Barwon-Darling River system, up to events of about 1 in 10 years average recurrence interval.

Table 4: Changes in flood flows for different ARI at Bourke

ARI (years)	Natural	Current	% Change
1 in1	18,000	10,000	-44.00
1 in 2	30,000	20,000	-33.30
1 in 5	110,000	70,000	-36.40
1 in 10	180,000	180,000	0
1 in 20	200,000	200,000	0

3.4 Rates of fall

A comparison of the number of days the river fell by nominated rates of flow at Bourke is presented in Table 5. Comparing the two indicates whilst number of events have fallen considerably the relative proportion of steep events to total number of falling days has remained almost the same. This is further confirmation of the fact that the significant reduction in flows has been achieved without any significant change in rate of fall.

3.5 Rates of rise

At Bourke the rates of rise (Table 6) in daily flows have generally decreased under current conditions. A reduction in flows upstream will have tendency to reduce rate of rise (and fall) at downstream locations due to channel routing effects. Under certain circumstances this effect could be compounded by progressive increase in pumping rates during the rising limb along the Barwon-Darling River.

Table 5: Frequency of days exceeding nominated rates of daily reduction in discharge at Bourke. The number of days and the percentage of occurrence are given.

Number of days exceeding nominated rates of fall at Bourke at each flow stage								
Nominated rates of fall	0 - 1000 ML/D Natural	Current	1000 - 3000 ML/D Natural	Current	3000 - 10,000 ML/D Natural	Current	10000 - 30,000 ML/D Natural	Current
> 100 ML/D	30 (13%)	83 (7.9%)	235 (62.5%)	284 (58%)	586 (94.5%)	329 (81%)	333 (96.3%)	243 (91.4%)
> 500 ML/D	0	7 (0.7%)	5 (1.4%)	30 (6.2%)	134 (21.6%)	136 (33.5%)	211 (61%)	193 (72.6%)
> 1000 ML/D	0	3 (0.3%)	0	4 (0.8%)	36 (5.8%)	49 (12.1%)	105 (30.4%)	132 (49.6%)

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Table 6: Number of days exceeding nominated rates of daily increases in discharge (ML/D) at Bourke:

Nominated rate of increase in daily flow	Number of days (simulated data 1966-1992) Natural conditions	Current conditions
Up to 500 ML/D	2876	3174
500 - 1000 ML/D	656	472
> 2000 ML/D	291	234

4. CONCLUSIONS

The analysis shows that daily flows have been significantly reduced for flows having an average annual recurrence intervals less than about 1:10 years and that this reduction is greatest for flows in the 25 to 50th percentile flow range. For example, at Bourke these flows which equate to 9750 and 2930 ML/D respectively, have been reduced on an average by 56% to 46% respectively. Although the changes has been less dramatic for flows less than the 50% flow on a cumulative basis, the effect on individual flow events has been to fragment larger events into smaller ones with respect to the flow thresholds. This has led to a reduction in the duration of individual flow events even though the total number of events is generally now greater.

The Barwon-Darling Expert Panel have addressed the ecological and geomorphological significance in detail (Thoms *et al.*, in press). The analysis of the above results by the Panel, together with other data, such as, water quality, fish and field observations, indicates that the reduction in peak flows and flow fragmentation are likely to have contributed substantially to the observed deterioration in river health. These impacts occur via direct (first order) effects on biota such as via velocity and depth and also via indirect (second and third order) effects. The latter occur by ecological changes to processes, such as changes in competition or predation, and through geomorphic and structural habitat changes.

The rate of fall analysis does not seem to conclude that the observed hydrological changes are likely to increase bank erosion arising from more rapid or frequent steep drawdown in river flows. However, similar more powerful analysis might be performed using stage-height data which may more directly reflect the relevant mechanism of bank erosion by mass failure. It may also be appropriate to repeat the above analysis using shorter or longer time scales than the daily rates used here.

5. ACKNOWLEDGMENTS

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