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THE MURRAY VALLEY: ITS HYDROLOGIC REGIME AND THE EFFECTS OF WATER DEVELOPMENT ON THE RIVER

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INTRODUCTION

The hydrologic regime of a river basin is the result of the interaction of many natural influences, such as geology and soils (discussed in other papers in this Symposium) and climate, including precipitation and evaporation. In addition, man's development of the land and water resources of a basin for his own purposes has a major impact.

The Murray-Darling River Basin is Australia's largest river system (Fig. 1). It is fed mainly by rainfall over the inland slopes of the Great Divide which form the eastern and southern borders of the Basin. Rainfall in these headwater catchments is generally reliable and the main rivers are perennial. The principal river is the Murray, which through its tributaries, drains the whole Basin. Flowing through dry country in their lower reaches the major rivers have allowed, through irrigation, intensive agricultural development in places where cultivation would not otherwise be possible. In its lower reaches the River Murray provides a major part of the water supply for Adelaide and towns to the east and north of the South Australian Gulf.

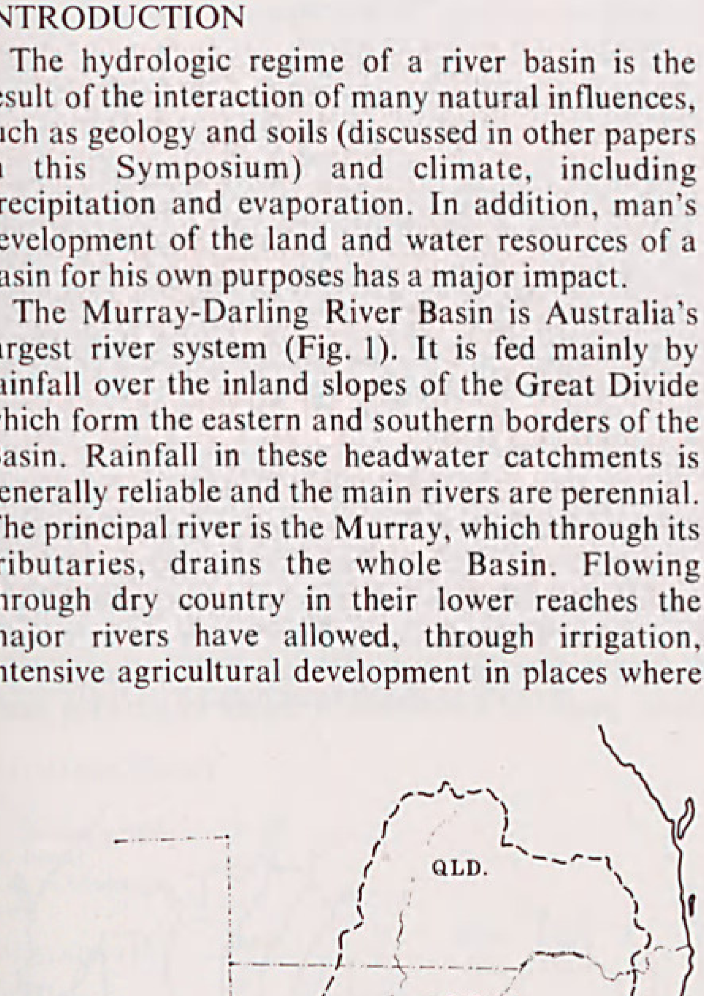

FIG. 1 — Murray-Darling Basin.

Three main groups of rivers can be identified within the Basin. The Darling and its tributaries drain the northern regions. Rainfall in their headwaters occurs predominantly in summer. Flows in this group of rivers are highly variable and the Darling itself has ceased to flow in some dry years. Although the Darling system drains over half the area of the whole Basin, its contribution to flow in the River Murray is relatively small.

The Murrumbidgee and its tributaries drain central and southern New South Wales. Median annual rainfall in the headwaters reaches 1500 mm in places, under the influence of winter low pressure systems, and the Murrumbidgee River at Gundagai has never ceased to flow over the period of record.

The River Murray itself and its tributaries upstream from the Murray-Murrumbidgee junction drain central and northern Victoria and parts of southern New South Wales. Runoff from the headwater catchments is fairly reliable and in spring includes some snow melt. Streams in this system contribute the bulk of flow to the lower reaches of the Murray.

There are other rivers in the southwest of the Basin, but they flow only intermittently.

The rivers of the Murray-Darling Basin are generally meandering and slow on the low gradients of the inland plains. The Murray and many of its tributaries have formed extensive alluvial flood plains which support the principal irrigation districts of Australia.

The flow of many rivers is regulated, especially in their upper reaches. The Murray is regulated at intervals from the Hume Dam upstream of Albury-Wodonga to the salt water barrage on Lake Alexandrina at its mouth, a distance of 2,200 km.

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TABLE I
PRINCIPAL STORAGES IN THE MURRAY-DARLING RIVER BASIN

NAME	RIVER	GROSS CAPACITY ($m^3 \times 10^6$)	PURPOSE
Dartmouth*	Mitta Mitta River	4000	Irrigation and hydro-electric
Eildon	Goulburn River	3390	Irrigation and hydro-electric
Hume	River Murray	3038	Irrigation and hydro-electric
Menindee Lakes	Darling River	1794	Irrigation and water supply
Burrendong	Macquarie River	1680	Irrigation and flood mitigation
Blowering	Tumut River	1628	Irrigation and hydro-electric
Copeton	Gwydir River	1364	Irrigation
Wyangala	Lachlan River	1220	Irrigation
Burrinjuck	Murrumbidgee River	1026	Irrigation

**Under construction.*

Table 1 shows the principal water storages in the Basin and their uses (WRC, N.S.W. 1971). There are many other smaller storages and overall 91% of the exploitable surface water resources of the Basin are now committed (DNR Review 1976).

This paper will deal only with the surface water hydrology of the Basin, since groundwater is covered in other papers. After a brief review of the hydrologic regime of the entire Murray-Darling System the effects of man's development of the water resources of the Murray River will be discussed.

PRECIPITATION

The Murray-Darling Basin experiences a wide range of climatic conditions. Median annual rainfall is shown in Fig. 2. To the east and south-east, where the headwaters of the major streams rise in the Great Dividing Range, median rainfalls are as high as 1500 mm but in the far west they decrease to 200 mm. In the north, rainfall is heaviest in summer; in the south, winter low-pressure systems bring the rains.

EVAPORATION

Mean annual evaporation for the Basin is shown in Fig. 3. Evaporation is high over most of the area (in excess of 1500 mm) and the trend is that as rainfall decreases, evaporation increases. In almost the whole Basin, average evaporation is greater than average rainfall. High evaporation means that losses, such as transmission losses in streams and

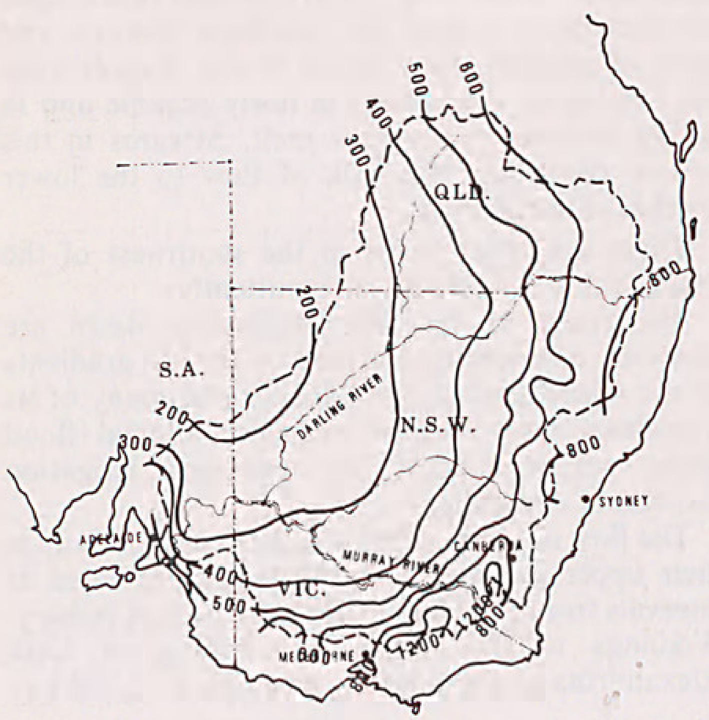

FIG. 2 — Median annual rainfall (mm).

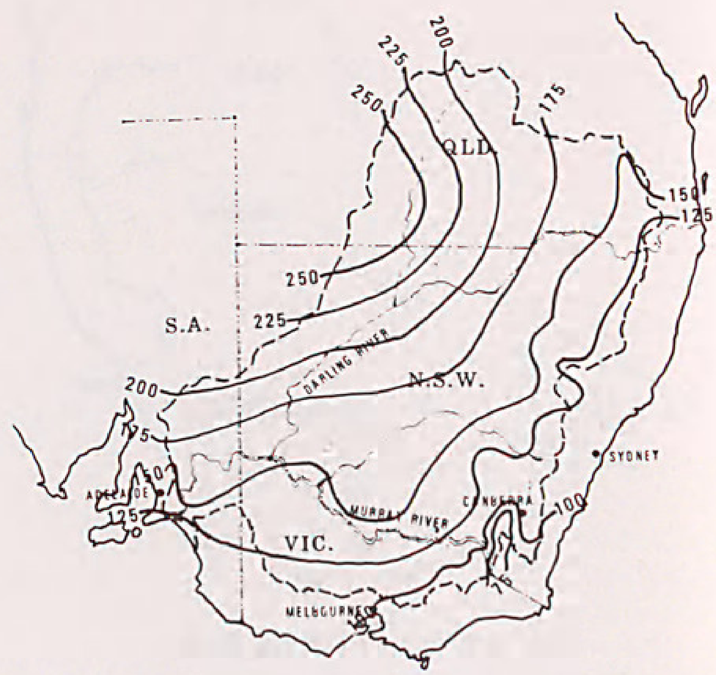

FIG. 3 — Average annual evaporation (cm).

evaporative losses from impounding reservoirs, are important factors to be considered when designing water-use systems.

STREAMFLOW

Variations in landscape, vegetation, geology and climate throughout the Murray-Darling Basin produce a variety of streamflow characteristics, varying from partly snow-fed mountain streams to ephemeral rivers. As would be expected, areas of high runoff occur where high precipitation occurs. Two of the most important factors characterising streamflow are average runoff and variability of runoff. Fig. 4 shows regions within the Murray-Darling Basin with similar runoff characteristics in terms of their amount of runoff and its variability (DND, Map Series, in prep.).

Most of the Basin has low runoff with high variability (see Fig. 4, 5d). Flows in the Murray itself are variable, but they do not reach the extremes of many of the northern rivers. At Albury the range of annual flow volumes in the Murray has varied in the ratio of about 14 to 1, from a little less than 25% of average to slightly more than three times average. The variability of monthly flows is greater, with the largest measured monthly flow at Albury being nearly 1,200 times the smallest. The average annual flow in the Murray just above Wentworth (Fig. 5) is about 9,000,000 Ml (WRC, N.S.W. 1975). At this point the total drainage area amounts to about 310,000 km^2 and the runoff is equivalent to a catchment depth of 29 mm.

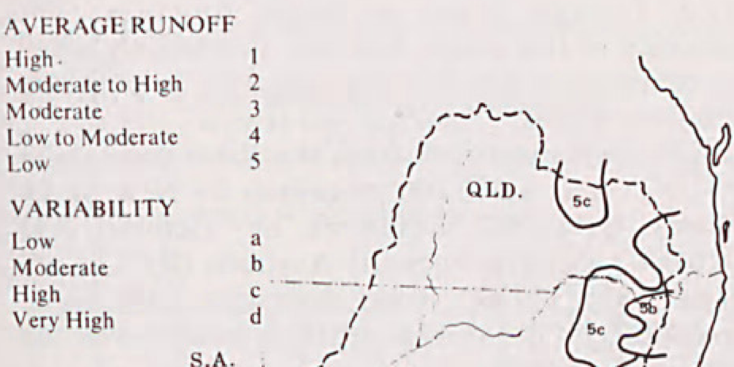

FIG. 4 — Runoff characteristics.

FLOODING IN THE MURRAY VALLEY

The degree and magnitude of flooding along the Murray River is largely controlled by the predominating terrain of each section of the valley. In the upper Murray Valley above Hume Reservoir it is confined to relatively narrow alluvial flats bordering the river along the valley floor. Below Hume Reservoir the terrain is flatter and floodwaters spill over the channel banks and inundate surrounding country. In the region between about Albury and Tocumwal, the inundation of flat land adjacent to the river channel is not uncommon. Flood flows are often swelled by contributions from the Kiewa and Ovens Rivers, which drain large areas of northern Victoria.

Near Tocumwal, a complex system of effluent creeks and anabranches leaves the Murray and carries floodwaters away from the main stream to the north. The principal streams in this system are the Edward and Wakool Rivers. Floodwaters from both the Murray and Murrumbidgee Rivers flow into the effluent system and it carries more water in times of major floods than the parent streams. This area becomes a vast inland sea during the passage of major floods and because of the slow velocities of floodwaters, periods of inundation are often lengthy.

Floods are most frequent in the winter and spring months. Table 2 shows the monthly distribution of floods recorded in the Murray River at Albury since 1865.

TABLE 2
MONTHLY DISTRIBUTION OF FLOODS

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	0	0	0	0	0	13	15	12	18	9	1

WATER RESOURCES DEVELOPMENT

The development and regulation of the water resources of the Murray River are controlled by the River Murray Commission, which was established in 1917.

The Commission administers the River Murray Waters Agreement. This provides for the construction of works at the joint expense of New South Wales, Victoria, South Australia and the Commonwealth, and the allocation of water between the

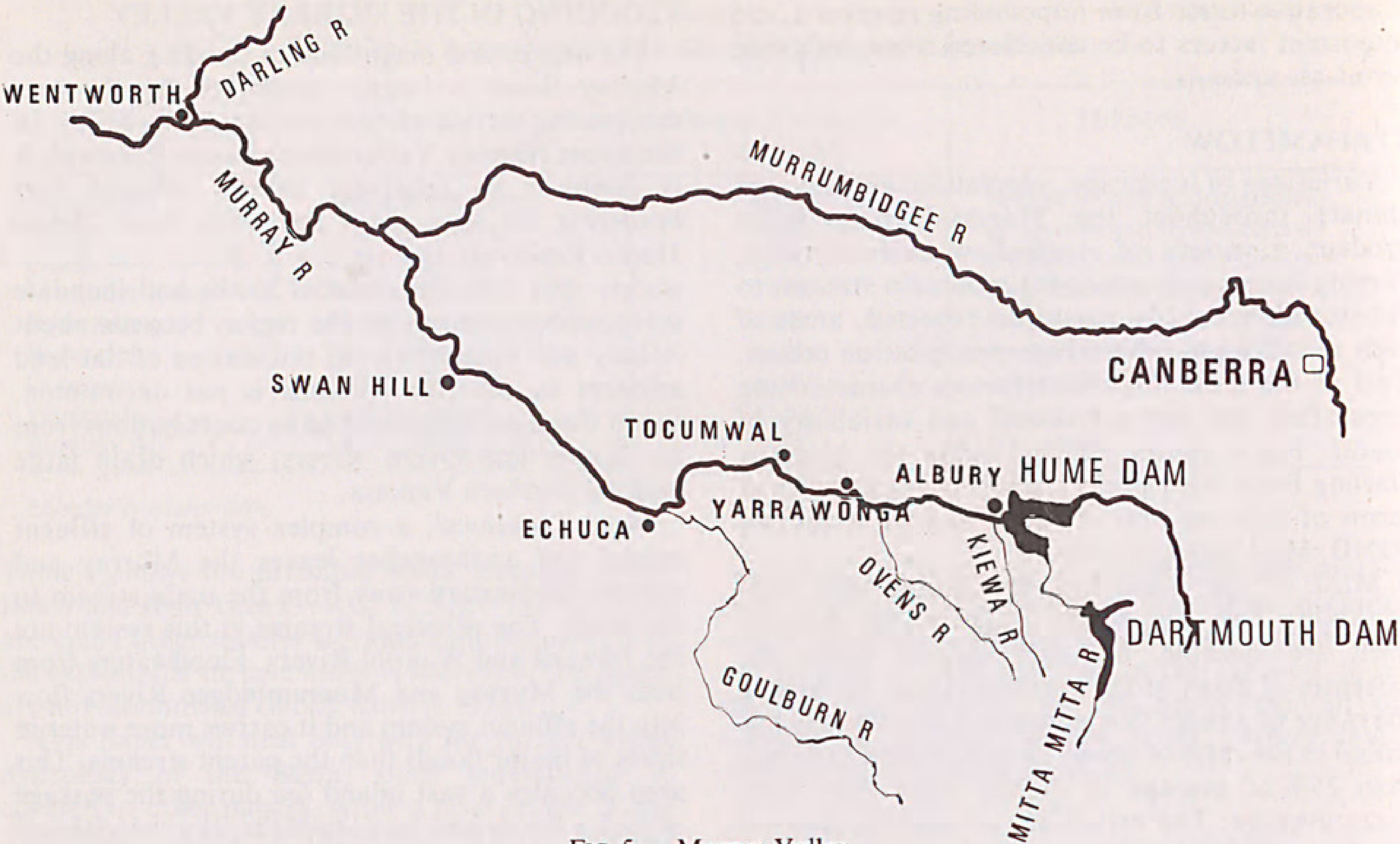

FIG. 5 — Murray Valley.

three States. The allocation entitles South Australia to receive not less than a certain volume from the upper river each year, while New South Wales and Victoria share equally the flow passing Albury, subject to provision being made for South Australia's entitlement. Each State is entitled to free use of its tributary flows entering the Murray below Albury.

The largest of the major works to date is the Hume Dam. It was first completed in 1936, was enlarged in the nineteen fifties, and now has a capacity of about 3,000,000 Ml. Dartmouth Dam, a major storage on the Mitta Mitta River, is at present being constructed and is due for completion in 1979. It will have a capacity of 4,000,000 Ml. Releases from the Snowy Mountains Scheme to the Murray River provide an additional regulated water supply.

There are very large areas in the Murray Valley, away from the main river, where topography and soils have lent themselves to large scale irrigation development. In these areas, water is brought some distance from the river in large canals for distribution into irrigation areas and districts. This type of irrigation enterprise constitutes a large part of the development in the Valley, but in addition a substantial aggregate area is irrigated by private pumping from the river.

Murray River water is also used in urban centres, the principal such usage being in Adelaide and the Iron Triangle towns in South Australia. The quantity of this usage, however, is relatively small in comparison with the total usage for irrigation in the three States.

The total diversions from the River Murray in 1974/75 were 1,560,000 megalitres by New South Wales, 1,540,000 megalitres by Victoria, and 396,000 megalitres by South Australia (RMC Ann. Rept. 1975, (1976)). These diversions are close in magnitude to the average yearly diversions over the previous ten years.

EFFECTS OF WATER RESOURCES DEVELOPMENT

Reservoirs modify the natural river regime to meet development needs. The operation of Hume Dam for irrigation has reduced winter and spring flows in the Murray and increased flows in summer and autumn. The use of water by abstraction from the river obviously reduces the long term average flow. Although a proportion of the water abstracted eventually finds its way back into the river, most of it is used consumptively. Three main aspects of the effects of water resources development, through river regulation and water abstraction, will now be discussed.

Flooding

In providing regulated flows in the summer and autumn months, the storage in Hume Reservoir is drawn down, so that in most years space is available to store inflow during the winter and early spring months. Floods in June, July and August are often completely stored, but in the process the storage may be filled so that in years when major floods occur in the September-October period, these floods pass through the reservoir with little reduction in their peak flows.

Fig. 6 illustrates the effect that Hume Reservoir has had on the incidence and magnitude of peak flood heights on the Albury gauge in the years 1970-1975 (RMC Rept. 1977). In this period the incidence of flooding was the greatest on record. Actual peak heights are compared with those which would have occurred if Hume Reservoir had not been there.

The altered regime of river flow is also illustrated in Fig. 7 which demonstrates, by means of flow duration curves for actual and estimated natural conditions, how the natural regime has been modified (RMC, Rept. 1977).

It is clear from these figures that the operation of Hume Reservoir to meet irrigation needs has had a significant effect in reducing the incidence and severity of flooding at least in the section of the river close below it.

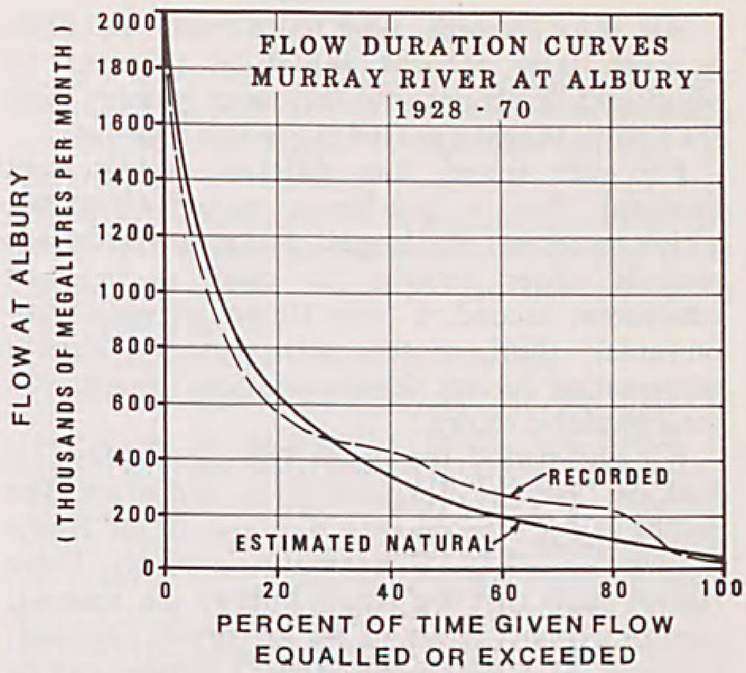

Fig. 7 — Flow-duration curves at Albury.

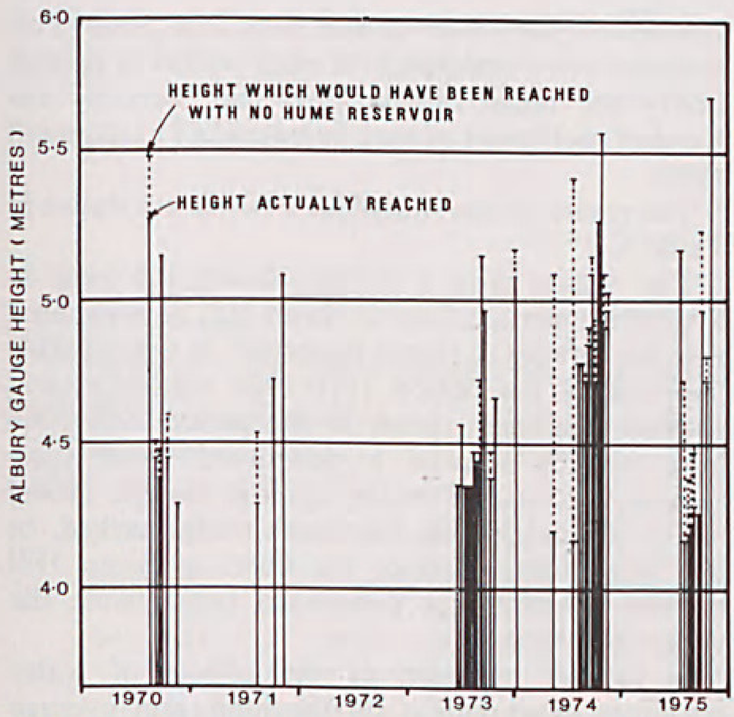

Fig. 6 — Flood heights at Albury.

It is possible to achieve additional benefits by the deliberate adoption of a flood mitigation policy in operation of the dam. Although the River Murray Commission's main responsibility under the present River Murray Waters Agreement is the supply of water for irrigation and other purposes, it does provide some flood storage in Hume Reservoir, to the extent possible without prejudicing the security of water supplies.

Seasonal Distribution of Flows

To illustrate quantitatively the effects of water resources development on seasonal distribution of streamflows and long-term average flows, monthly flow records were analysed at three points on the Murray River.

The first record was the inflow to Hume Reservoir, or, prior to 1928 before the construction of the dam, the flow in the Murray at that point. The second was the flow of the Murray River at Albury and the third was the flow of the River Murray at Swan Hill.

Inflows to Hume Reservoir in the period considered are virtually unaffected by man's activities, since water abstractions above the reservoir are small in comparison to the flows. Flows at both Albury and Swan Hill, however, are affected by the reservoir upstream, and those at Swan Hill are further affected by the large abstractions from the river in both New South Wales and Victoria. Most of these abstractions take place between Albury and Swan Hill.

All three records were taken only to 1968, because later records would be affected by significant diversions into the upper Murray from the Snowy Mountains Hydro-Electric Scheme.

For each record, four different periods were analysed: first, a 'pre-Hume' period (1910-28), which represents the longest period of concurrent records under natural (or close to natural) conditions; second, a 'post-Hume' period (1929-onwards); third, a ten year period (1959-68) representing current development; and fourth, the total available record.

For each period, the means were calculated of all January flows, all February flows, and so on. The results are plotted on Figs. 8, 9 and 10 for Hume inflows, Albury and Swan Hill respectively. These figures show that for Hume inflows the seasonal pattern is nearly the same for all periods analysed. However, at Albury a considerable increase can be seen in summer/autumn flows post-Hume. At Swan Hill, the effect of abstractions upstream can be seen.

Long-Term Average Flows

To test what impact water resources development has had on long term average flows in the Murray River, a further analysis was made of the records of Hume inflows and Swan Hill flows. Two statistics were computed for each period of record: firstly the mean annual flow and secondly the Kendall coefficient of rank correlation (τ) (Kendall 1950).

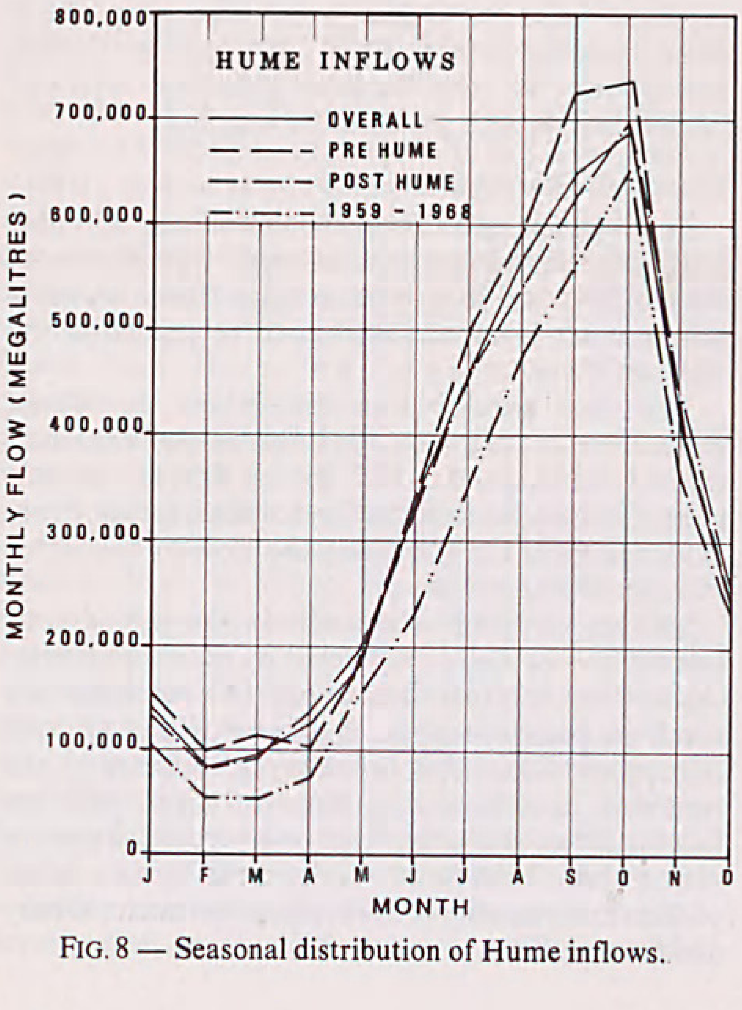

FIG. 8 — Seasonal distribution of Hume inflows.

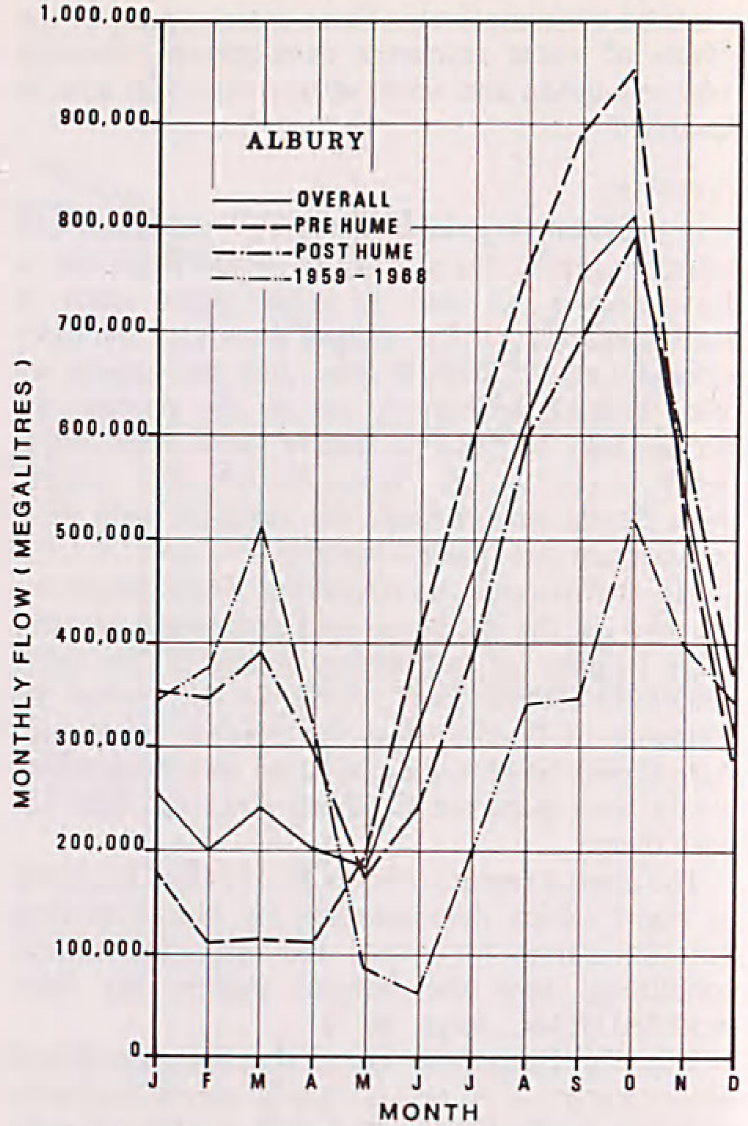

FIG. 9 — Seasonal distribution of flows at Albury.

The results of the statistical analysis are shown in Table 3.

The results show a definite downward trend in long-term average flow at Swan Hill as compared with the inflows to Hume Reservoir. It is noticeable that during the period 1910-1928 neither record showed significant trend. In the period 1959-1968 both records showed a downward trend (presumably because of the dry spell in the late 1960s) but at Swan Hill this was much more marked. In the 'post-Hume' period, the flows at Swan Hill showed a significant downward trend while the Hume inflows did not.

A further measure of the effects of water resources development on the long-term average flows can be seen by comparison of the 'pre-Hume'

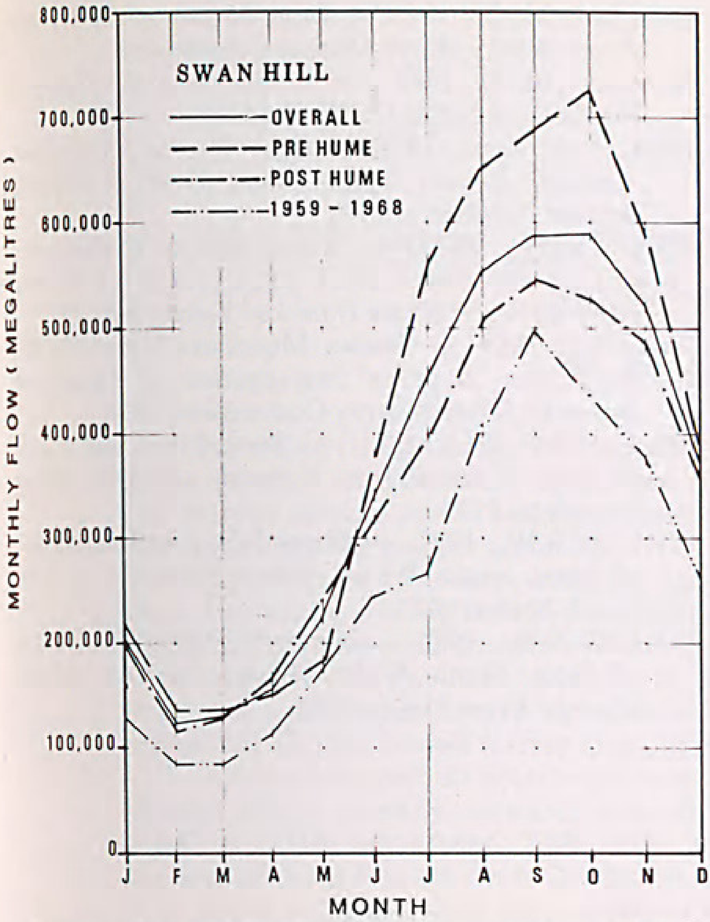

FIG. 10 — Seasonal distribution of flows at Swan Hill.

period with the period 1959-1968. At Hume Reservoir, average flow dropped to 78% of the 'pre-Hume' period during this time, while at Swan Hill the reduction was to 64%. This is clearly the effect of increased abstraction of water in the reach between Hume Reservoir and Swan Hill, and smaller inflows from the tributaries downstream of Hume, from which abstractions had also increased.

SUMMARY AND CONCLUSIONS

This paper has discussed briefly the hydrologic regime of the Murray-Darling Basin, with emphasis on the Murray River. It has then outlined the development of the water resources in the Murray River and attempted to determine quantitatively the effects of that development on the surface water hydrology of the river, by the use of simple statistical tests.

The results have shown the following:

(i) Simple statistical analyses can be used to determine, in quantitative terms, the effects of water resources development on hydrologic regime. This analysis confirms what is known qualitatively about these effects, but is difficult to assess because of uncertainties about return flows to the river, effects of groundwater and so on.

(ii) Water resources development has had a beneficial effect on flooding in the valley, by reducing the magnitude of many floods through regulation of the river flows.

(iii) Regulation and abstraction have altered the seasonal distribution of streamflow to a certain extent by relatively reducing the winter and spring flows and increasing the summer and autumn flows. The effect differs in different reaches of the river. It is very apparent close below Hume, but less marked further downstream, where tributaries add to the winter/spring flows and abstractions for irrigation reduce the summer/autumn flows.

(iv) Development has reduced the long-term average flow at Swan Hill, which is downstream of the major diversion points on the Murray River. There has been a significant downward trend in flow volumes since construction of Hume Reservoir and this trend is continuing.

TABLE 3
RESULTS OF STATISTICAL ANALYSIS

HUME				SWAN HILL			
Period of Record	Mean Annual Flow (a)	(b)	Kendall τ (c)	Period of Record	Mean Annual Flow (a)	(b)	Kendall τ (c)
1910-1928 (d)	4212	100		1910-1928 (d)	4788	100	
1929-1968	4039	96		1929-1970	3974	83	—0.054
1959-1968	3299	78	—0.093	1959-1968	3053	64	—0.162
1891-1968	3991	95		1910-1970	4228	88	—0.082

(a) Mean annual flow in Ml x 10^3. (b) Mean annual flow expressed as a percentage of that for the 'pre-Hume' period. (c) Only values significant at the 5% level are shown. (d) 'Pre-Hume' period.

BIBLIOGRAPHY

Text citations to Government Department publications are abbreviated to initials, as shown below with full references.

AWRC, 1968. — Australian Water Resources Council, *Review of Australia's Water Resources — Monthly Rainfall and Evaporation*, Bureau of Meteorology 1968.

DND, Map Series, in prep. — Department of National Development, Division of National Mapping, *Variability of Runoff* — Map series in preparation.

DNR Review, 1976. — Department of National Resources, Australian Water Resources Council, *Review of Australia's Water Resources 1975*, Aust. Govt. Publishing Service, Canberra, 1976.

DNR Stream Gauging, 1976. — Department of National Resources, Australian Water Resources Council, *Stream Gauging Information Australia 1974*, Aust. Govt. Publishing Service, Canberra, 1976.

EATON, J. H. O., 1945. *A Short History of the Murray River Works*, River Murray Commission.

KENDALL, M. G., 1950. *An introduction to the Theory of Statistics*, Charles Griffin, London.

RMC Ann. Rept., 1976. — *River Murray Commission Annual Report 1975*, Aust. Govt. Publishing Service, Canberra, 1976.

RMC, Rept., 1977. — River Murray Commission, *Report on Flood Plain Management of Murray River between Hume Dam and Yarrawonga*, 1977.

SMH-EA, 1969. — Snowy Mountains Hydro-Electric Authority, *Detailed Investigation of Dartmouth Damsite*, River Murray Commission, 1969.

SR & WSC, Vic., 1971. — State Rivers and Water Supply Commission Victoria, *Victoria River Gaugings*, 1971.

WRC, N.S.W., 1971. — Water Resources Commission of New South Wales, *Water Resources of New South Wales*, 1971.

WRC, N.S.W., 1975. — Water Resources Commission of New South Wales, *Water Resources of the Murray River Valley*, 1975.