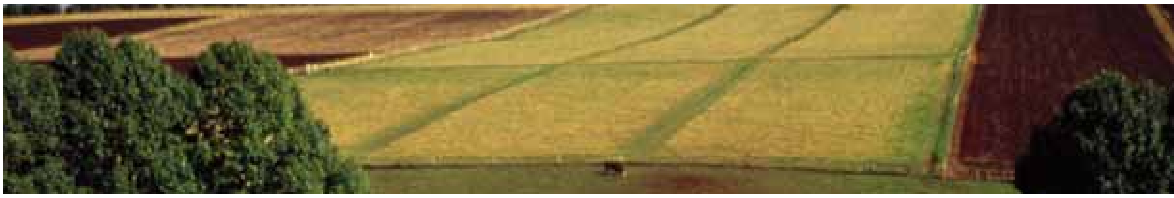
COOPERATIVE RESEARCH CENTRE FOR **CATCHMENT HYDROLOGY**

ANALYSIS AND MANAGEMENT OF UNSEASONAL SURPLUS FLOWS IN THE BARMAH-MILLEWA FOREST

TECHNICAL REPORT
Report 03/2
December 2003

Jo Chong



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Preface

The main goal of the Cooperative Research Centre (CRC) for Catchment Hydrology's River Restoration program is to provide the tools and understanding that will allow the environmental values of Australia's streams to be restored. A national priority for restoration is the Murray River with the 'Living Murray' process providing a focus for governments and the community. A clear goal is to improve the condition of icon sites along the Murray including the Barmah-Millewa Forest which is also recognised as a wetland of international significance under the Ramsar convention.

This report addresses one major threat to the forest; unseasonal flooding in the summer and autumn when the forest would normally be dry. Based on analysis of pre-regulation conditions (1908-1929) and current conditions (1980 - 2000), forest flooding has increased from 15.5% of days to 36.5% of days between December and April. In particular, small, localized floods, which inundate less than 10% of the forest, occur at least eight times more frequently now, than before regulation. Work by others has related these hydrologic changes to tree death and changes in floristic structure in wetlands. There are also economic costs because much of the water that spills into the forest is lost to downstream irrigation.

There are a range of approaches to reduce unseasonal flooding. The two solutions investigated in this report are intended to decrease the risk of flooding when there is summer rainfall which suddenly decreases the demand for irrigation water. Water from upstream that has already been released to meet irrigation orders, is not required if it rains, so remains in the river and can cause forest flooding. Creating capacity in the river to store or carry this extra flow can decrease unseasonal floods.

I am impressed with the comprehensive analysis of unseasonal flooding that has been carried out by Jo Chong and commend this report to anyone interested in improving the condition of Australia's regulated rivers.

Mike Stewardson
Program Leader, River Restoration Program
CRC for Catchment Hydrology

Executive Summary

The Barmah-Millewa Forest comprises approximately 70,000 ha of wetland habitats located on the floodplain of the River Murray between Echuca, Deniliquin and Tocumwal. The Barmah-Millewa ecosystem contains predominantly forests of river red gum (*Eucalyptus camaldulensis* Dehn), but also contains swamps and marshes, moira grasslands, giant rushlands, open waters, billabongs and streams. Together, the Barmah Forest (Victoria) and the Millewa group of forests (NSW) form the largest river red gum forest in the world, and are valued for wood products, grazing, conservation and recreation. The Barmah wetland is listed under the Ramsar Convention as a wetland of international significance.

The river red gum forests along the Murray and its tributaries have evolved in an environment characterised by natural flooding in the winter and spring months of most years, alternated with dry conditions during the summer and autumn months. (Bren 1988a, Maunsell 1992a). These natural inundations are required to sustain the ecosystem and its values.

However, the natural flow regime of the Barmah-Millewa Forest has been changed by regulation of the River Murray, since the first filling of the Hume Dam in 1934. The forest has experienced a reduction in the frequency of flows associated with partial flooding and an increase in the occurrence of small summer flows (Bren 1988a). The changing flow pattern has, in turn, changed patterns of vegetation (Chesterfield 1986). Leslie and Harris (1996) cite that permanent summer inundation of low lying forests has been far more damaging than the impacts of drought.

This project focuses on the increases in summer/autumn forest inundation. This results when flows are released from storage but not diverted into irrigation channels for distribution to farms. They occur when local rains reduce the irrigation requirement, and irrigators cancel their order for water. The released water, intended for diversion, instead passes down the river. Rain rejections occur because the River Murray is maintained at a high flow level to enable flow to pass through the "Barmah Choke", which refers to the reach of the River Murray between the junction of the Edward River and the Barmah township. This reach has the lowest channel capacity (10,600 ML/day) between Lake Hume and South Australia (approximately 1800km downstream of the forest) (Thoms *et. al.* 2000). The rain rejection flows are usually accompanied by river freshes, which are small excess flows, generated by local rainfall, in the unregulated tributaries of the Murray upstream of the forest. Together, rain rejection flows and river freshes are referred to as unseasonal surplus flows.

This project aims to analyse the extent to which an increase in system flexibility would reduce the likelihood of unseasonal surplus flows. The goals are to identify the patterns between system flexibility (eg. River Murray flows or storage air space) and unseasonal surplus flows, to quantify these relationships, and to determine the net economic impact of reducing the likelihood of unseasonal surplus flows.

The emphasis of the initial research phase (Sections 1 to 3) was to document, investigate and understand the physical, regulatory, institutional and economic environment of the problem. The information gained in this phase was used to identify and evaluate possible avenues of research, and to determine data requirements and availability.

The Literature Review (Section 2) provides a critical review of the information relevant to the problem of unseasonal surplus flows in the Barmah-Millewa Forest. The literature included information on the hydrology of the forest, changes to flooding regimes over time, the effect of these changes on flora and fauna, and the analysis and management of rain rejection events. The review considered information from both refereed journal articles and government agency publications, in acknowledgement of the scientific, regulatory and economic research conducted by various government agencies in the development of plans and strategies. The majority of independent work dealing with the hydrology of the Barmah Forest was conducted by Bren *et. al.* over the period 1984 - 1988. The literature review revealed that the most significant shift in management principles has been the move away from the idea of using rain rejection flows to water the forest (Maunsell 1992a, 1992b).

The Background Information (Section 3) documents information including location, natural resources, forest uses and resources, hydrology of the regulated system, and forest hydrology.

Section 4 (Research Methodology) outlines the research methodology which enabled an evaluation of how the frequency of unseasonal surplus flows, which affect the Barmah-Millewa Forest, is related to flow and flexibility in the River Murray system.

Section 5 (Historical Analysis) investigates changes in the patterns of summer-autumn River Murray flows (at Tocumwal) and frequency and areal extent of forest flooding. The historical analysis identified December to April as the months during which forest flooding is more frequent now (1981 - 2001) than before regulation (1908 - 1929).

Section 6 (Unseasonal Surplus Flow Events) compares the characteristics of unseasonal surplus flow events identified using three different methods. The flow at Tocumwal is evaluated as the most appropriate indicator of unseasonal surplus flooding.

Section 7 (System Flexibility) quantifies (through graphical representation) the (individual) effect of increasing airspace at Yarrawonga and reduced unseasonal flows and limiting maximum River Murray flow at Tocumwal on flooding frequency (proportion of days in season during which flooding occurs in the forest); number of events per season; event duration; and total surplus flow volume per season.

Section 8 (Economic Analysis) considers the costs and benefits of increasing system flexibility to decrease the frequency of unseasonal flooding in the Barmah-Millewa Forest (proportion of days in season during which flooding occurs) from 38.3% (current) to 15.5% (pre-regulation).

The economic analysis of the alternative strategies is not straightforward. The approach taken here is identify both market- and non-market costs and benefits, but to selectively quantify only the following costs and benefits (collectively defined as “net conservative cost/benefit”):

- benefit of irrigation water “saved” due to reduced forest flooding (both options);
- cost of irrigation water foregone due to reduced diversions (both options);
- cost of the reduction of hydroelectric generation (increasing airspace only).

The main findings of the analysis (sections 5 - 8) are described below.

Historical Analysis

There has been significant changes in the patterns of River Murray flow at Tocumwal during summer and autumn. During December to April (particularly in February and March), flows are far more likely to be above 10,600 ML/day now (36.5% of the time) than before 1908 (15.5% of the time). This means that regulation has increased the number of days in summer-autumn during which flooding occurs in the Barmah-Millewa Forest.

However, an application of the relationship derived by Bren et. al. (1987) linking flow at Tocumwal to proportion of forest flooded revealed that more extensive floods (in which over 30% of the forest is flooded) are now less frequent. This is because the construction of dams, locks and weirs has enabled mitigation of larger River Murray flows.

Consequently, there are some parts of the forest (~30% of the area) which are flooded more than twice as frequently in summer-autumn now than before 1929, which leads to tree stress and death. However, the remainder of the forest (~70% of the area) is flooded less frequently now than before 1929. Both these changes have resulted in changes to the “natural” vegetation associations and patterns in the forest.

Unseasonal Surplus Flow Events

Of three main methods evaluated the method which involves analysing daily data for flows that exceed 10,600 ML/day at Tocumwal is the preferred method in terms of a computable data set and applicability to current conditions.

The use of this method revealed that during the period 1980 - 2000, there were 82 surplus flow events (4.1 per year), which caused flooding in the forest in 38.3% of days in December-April. The average event duration was 14.1 days (median 10 days); average peak excess flow was 2211 ML/day (median 1133 ML/day); and average total flow per event was 17,833 ML (median 7960 ML).

Relation to System Flexibility

If system flexibility had been greater over the period 1980 - 2000, then there would have been significantly less frequent flooding of the Barmah-Millewa Forest. If 1980 - 2000 is assumed to represent current water demand conditions, then flooding frequency can be reduced from 38.3% to 15.5% by:

- *increasing airspace at Yarrawonga by 9100 ML (maintaining height at 124.9m, 0.195m below the maximum); OR*
- *limiting the maximum flow at Tocumwal to 9600 ML/day.*

Smaller increases in system flexibility can also have a significant impact on reducing flooding frequency, e.g. a frequency of 20% will be achieved by increasing airspace by just 5000 ML or limiting the maximum flow at Tocumwal to 9900 ML/day.

Economic Analysis

Approximately $4.4m of water (73000 ML/year) per year is currently "lost" to forest flooding during December-April. Reducing flooding frequency from 38.3% to 15.5% would reduce the total surplus volume per year to 49,000 ML (an equivalent saving of $1.4m).

Limiting the maximum flow at Tocumwal to 9600 ML/day to reduce flooding frequency to 15.5% results in a net cost of $2.5m (less water available to downstream users, but water saved from flooding for environmental flows). However, this figure is not a true indicator of net economic cost. Net economic cost will be far lower, due market (forestry and tourism) and non-market (environmental) benefits from reduced forest flooding and the potential for greater upstream use.

Increasing the airspace at Yarrawonga by 9100 ML does not limit the outflow into the irrigation areas through Yarrawonga Main Channel and Mulwala Canal. Very minor losses in hydroelectric power generation will be incurred, but they will be more than offset by the value of the water saved from flooding ($1.4m). This figure assumes a marginal value of water equivalent to the agricultural gross margin ($60/ML), which is likely to be an understatement of the value of water if it were used for environmental watering purposes. Furthermore, the $1.4m benefit does not include the value accrued from reducing flooding frequency.

Therefore, significant net benefits accrue from increasing airspace at Yarrawonga to reduce the frequency of summer-autumn forest flooding.

Finally, the research conducted in this project is not all-encompassing. Rather, this project has opened up avenues for further research, including alternative analysis/modelling methods, an extended economic analysis, or investigation of other management options.

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List of Abbreviations

BMF	**Barmah-Millewa Forum**
DCE	**Department of Conservation and the Environment (Victoria; now DNRE)**
DLWC	**Department of Land and Water Conservation (New South Wales)**
DNRE	**Department of Natural Resources and the Environment (Victoria)**
GMW	**Goulburn-Murray Water**
MDBC	**Murray-Darling Basin Commission**
MIL	**Murray Irrigation Limited**
RMW	**River Murray Water**
SFNSW	**State Forests of New South Wales**
WMA	**Water Management Area**

Glossary

Barmah-Millewa forest	is the collective name given to approximately 70000 ha of wetland habitats located on the floodplain of the River Murray between Echuca, Deniliquin and Tocumwal.
The Choke	refers to the reach of the River Murray, between the junction of the Edward River and the Barmah township, with the lowest channel capacity (10600 ML/day) between Lake Hume and South Australia.
Flooding frequency	the percentage of days (during December-April) during which flooding occurred in the Barmah-Millewa Forest (also “unseasonal flooding frequency”).
River freshes	are small excess flows (which are generated by local rainfall) in the unregulated tributaries of the Murray upstream of the forest.
Rain rejection flows	are released from the Hume Dam during the irrigation season but not diverted into the irrigation areas from Mulwala Lake.
System flexibility	the degree to which the regulated system can accommodate unseasonal surplus flows, either through airspace at Yarrawonga or flow of the River Murray below bankfull capacity.
Unseasonal surplus flows	are generated from river freshes and rain rejection flows. Also referred to as “excess flows”.

1. Introduction

The Barmah-Millewa Forest comprises approximately 70,000 ha of wetland habitats located on the floodplain of the River Murray between Echuca, Deniliquin and Tocumwal. The Barmah-Millewa ecosystem contains predominantly forests of river red gum (*Eucalyptus camaldulensis* Dehn), but also contains swamps and marshes, moira grasslands, giant rushlands, open waters, billabongs and streams. Together, the Barmah Forest (Victoria) and the Millewa group of forests (NSW) form the largest river red gum forest in the world, and are valued for wood products, grazing, conservation and recreation. The Barmah wetland is listed under the Ramsar Convention as a wetland of international significance.

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This project aims to analyse the extent to which an increase in system flexibility would reduce the frequency of unseasonal surplus flows. The goals are to identify the patterns between system flexibility (eg. River Murray flows or storage air space) and unseasonal surplus flows, and to quantify these relationships.

1.1 Objectives

The objectives of this project are to:

- conduct background research to define the unseasonal surplus flow problem, including its occurrence, consequences, and management;
- analyse how summer-autumn River Murray flows have changed with increased regulation over time;
- analyse how patterns (frequency and duration) of unseasonal flooding have changed with increased regulation over time;
- identify individual unseasonal surplus flow events;
- analyse selective costs and benefits involved with increasing system flexibility to reduce the frequency of unseasonal surplus flows.

This final report includes a literature review, documentation of background information, research methodology, documentation of analysis, conclusions and recommendations for future research.

1.2 Stakeholders and Agencies

Many government departments, rural water distribution companies, and other government and non-government organisations and associations are involved in the planning and implementation of water management and supply operations which affect the Barmah-Millewa Forest. Other stakeholders include community groups and individuals who have an interest in the value of the River Murray and the Barmah-Millewa Forest, including environmental groups like the Victorian National Parks Association (VNPA).

The MDBC (2000) acknowledges the following stakeholders in its Water Management Strategy:

- The Murray-Darling Basin Ministerial Council;
- Commonwealth and State Government agencies;
- local government agencies;
- joint community-government resource management entities in the region;
- community groups with interests in natural resource management and the regional and local economy;
- communities in the region (including Aboriginal communities) with strong cultural ties to the Forest environment;
- industries and users supported by commercial, tourist and recreational activities pursued within the Forest; and
- downstream users of River Murray water.

This section focuses on the roles of management agencies and water distribution companies. It summarises the responsibilities of these groups, and provides a brief outline of the evolving set of studies, strategies, plans and frameworks which concern water management of the Barmah-Millewa Forest. An understanding of the network of relationships between major stakeholders also assists greatly in identifying the factors which influence the likelihood of rain rejection events.

Whilst it is intended that this research project will involve a significant level of statistical analysis, a thorough approach to problem definition is considered an important component of the overall research procedure. Thus, stakeholder identification is crucial to understanding the institutional, regulatory and economic environment of the problem. It is also useful in identifying sources of data and information required for further research.

1.2.1 The Barmah-Millewa Forum

The Barmah-Millewa Forum consists of advisors from private water scheme irrigators, non-wood based and wood-based forest users, local government, environment groups and tourism operators. Membership also includes the government agencies of State Forest of NSW, Department of Land and Water Conservation (NSW), Department of Natural Resources and the Environment (Victoria), Goulburn-Murray Water and Environment Australia.

The Forum helps to implement the business plan and water management strategy for the Forest. It provides advice on the operating plans to ensure coordination between the two States, and also advises the Murray-Darling Basin Commission on general water management of the Barmah-Millewa Forest (MDBC 2001a).

1.2.2 Commonwealth Agencies

The Murray-Darling Basin Commission

The Murray Darling Basin Commission (MDBC) works in partnership with the five state governments to “promote and coordinate planning and management for the effective, efficient and sustainable use of water, land and other environmental resources of the Murray-Darling Basin.” The MDBC coordinates activities that enhance and integrate water management for the Barmah-Millewa Forest, due to its responsibilities for operating the River Murray and because of the impacts of that operation on the Forest (MDBC 2000).

The MDBC has been directed by the Murray-Darling Basin Ministerial Council to “develop water management strategies for the Barmah-Millewa Forest which enhance forest, fish and wildlife values, while not creating undue adverse affect in other areas”. The Final Report of the *Barmah-Millewa Forests Water Management Plan* was completed in January 1992. The six stages of the plan’s development were:

- identification of water management areas (WMA);
- determination of water deficits in the forests;
- evaluation of a range of projects to reduce the water deficits identified in stage 2;
- selection of the best strategies to meet water deficits for each WMA;
- assigning priorities based on costs and water stress levels; and
- developing guidelines to implement the water management plan (Maunsell 1992a).

Subsequent to the completion of the *Barmah-Millewa Forests Management Plan*, the Ministerial Council directed that 100GL per year be allocated to meet the environmental needs of the Forest, and that it should be managed as a single unit using a single allocation. The Barmah-Millewa Forest allocation was first used to augment the September 1998 flood from the Ovens River (a one in 25 year event) and extended the high flow period from 14 to 35 days (Maunsell McIntyre 1999).

River Murray Water

River Murray Water (RMW) was established by the Murray-Darling Basin Ministerial Council as in internal business division of the MDBC for the specific purposes of operating and managing the River Murray system (service delivery). RMW commenced operations on 1 January 1998 (MDBC 2001b).

The primary services provided by River Murray Water are:

- water storage and delivery;
- salinity mitigation;
- navigation;
- recreation and tourism; and
- hydro-power.

1.2.3 Victorian Agencies

The Department of Natural Resources and Environment (DNRE) and Goulburn-Murray Water (GMW) are the primary agencies responsible for managing the land and water resources of the Barmah State Forest and State Park.

Specific responsibilities related to various pieces of legislation, including:

- Forests Act 1958 (management of Forest and Forest produce);
- National Parks Act 1975 (management of the State Park portion);
- Water Act 1989 (provision of rural services and bulk water supplies); and
- Flora and Fauna Guarantee Act 1988 (protection of native flora and fauna).

In September 1992 the Department of Conservation and Natural Resources (DCNR; now DNRE) completed the Barmah State Park and Barmah State Forest Management Plan which contained a summary of resources, a review of present and future use, and plans for the management of natural resources, cultural resources, access, (economic) utilisation, recreation, tourism and visitor education, forest protection, boundaries, and resource requirements.

In August 1994 the DCNR prepared an Interim Water Management Strategy for Barmah Forest, Victoria. DNRE is currently reviewing this strategy, and expects an updated version to be complete by the end of 2002 (Ward, K.A., 2001, *pers. comm.,* 15 March). The Interim Strategy established principles and rules for regulator operation (flood initiation and duration), proposals for water management areas (including regulators, diversion and impoundment works), and general proposals such as de-snagging of the Barmah Choke.

The Goulburn-Murray Rural Water Authority (GMW; trading as Goulburn-Murray Water) was constituted by Ministerial Order under the provisions of the Water Act 1989 effective from 1 July 1994. GMW is responsible for the headworks within its region, the provision of bulk water supply, and the delivery of irrigation water, domestic and stock supplies and drainage services (GMW 2000).

GMW is responsible for servicing 1728 irrigated holdings in the Murray Valley Irrigation Area. The Yarrawonga Main Channel, which is the major supply channel for the Area, is gravity fed from Lake Mulwala (Yarrawonga Weir), 2 flow-days upstream from the Barmah-Millewa Forest. Rejected irrigation orders from within this region have the potential to cause rain rejection flows in the Barmah-Millewa forest. The Murray Valley Irrigation Area covers 128,372 hectares (88 969 hectares irrigated), and has an annual water right of 257,522 ML (GMW 2001).

1.2.4 New South Wales Agencies

The New South Wales Department of Land and Water Conservation (DLWC) and State Forests of New South Wales (SFNSW) are the primary agencies responsible for managing the land and water resources in the Millewa Forest. NSW Fisheries and NSW National Parks and Wildlife Service also have specific statutory responsibilities for native fish, wildlife, flora and cultural heritage (MDBC 2000).

In July 1996, DLWC and SFNSW completed a Water Management Plan for the Millewa Forest, which incorporated many of the technical findings of earlier forest watering reports and the ongoing community consultation process developed by the MDBC. The plan also provided a statutory framework for the planning and co-ordination of water management tasks between the various agencies with responsibilities for land, water and wildlife in New South Wales (Leslie and Harris 1996).

Murray Irrigation Limited (MIL), a private irrigation company based in Deniliquin, provides irrigation to over 2400 farms covering 716,000 hectares in southern NSW. The Mulwala Canal, which is gravity fed water from Lake Mulwala (Yarrawonga Weir), is MIL's major supply channel. MIL was established on 3 March 1995 when the NSW Government Murray Irrigation Area and Districts were privatised. The company has an entitlement of 1.445 million megalitres, which is 67% of the NSW share of Murray River irrigation entitlements (MIL 2001).

2. Literature Review

2.1 Overview

This section provides a critical review of the information relevant to the problem of unseasonal surplus flows (particularly rain rejection flows) in the Barmah-Millewa Forest. The literature includes information on the hydrology of the forest, changes to flooding regimes over time, the effect of these changes on flora and fauna, and the analysis and management of rain rejection events.

The section emphasises the information available from refereed journal articles. However, comparisons are also made with material available in government agency publications. This acknowledges the extensive scientific, engineering, regulatory and economic research conducted by various government agencies (see Section 1.1) in the development of plans and strategies for the management of the Barmah-Millewa Forest.

2.1.1 Literature

Table 2.1 and Table 2.2 list the literature reviewed in this section. The articles and publications also appear in the References section of this Report (Section 6).

2.2 Hydrology

The most extensive, independent and refereed collection of research on the hydrology of the Barmah Forest was authored or co-authored by Leon Bren (Forestry Section, Faculty of Agriculture and Forestry, The University of Melbourne) between 1984 and 1988. Other refereed research during the 1980's focussed on physiological aspects of flora and fauna (see Section 2.3), or took a broad approach to hydrological investigation of Murray River forests in general.

Table 2.1 Refereed Journal Articles

- Bren, L. 1988a, "Flooding characteristics of a riparian red gum forest", Australian Forestry, vol. 51, pp. 57-62.
- Bren, L. 1988b, "Effects of river regulation on flooding of a riparian red gum forest on the River Murray, Australia", Regulated Rivers: research and management, vol. 2, pp. 65-77.
- Bren, L. 1992, "Tree Invasion of an intermittent wetland in relation to changes in the Flooding Frequency of the River Murray, Australia", Australian Journal of Ecology, vol. 17, pp. 395-408.
- Bren, L. and N. Gibbs 1986, "Relationships between flood frequency, vegetation and topography in a river red gum forest", Australian Forest Research, vol. 16, pp. 357-70.
- Bren, L., O'Neill, I. and N. Gibbs 1987, "Flooding of the Barmah Forest and its relation to flow in the Murray-Edward River system," Australian Forest Research, vol. 17, pp. 127-44.
- Bren, L., O'Neill, I. and N. Gibbs 1988, "Use of map analysis to elucidate flooding in an Australian riparian river red gum forest", Water Resources Research, vol. 24, no. 7, pp. 1152-1162.
- Chesterfield, E.A,, 1986, "Changes in the vegetation of the river red gum forest at Barmah, Victoria", Australian Forestry, vol. 49, no. 1, pp. 4-15.
- Leslie, D.J. 2001, "Effect of river management on colonially-nesting waterbirds in the Barmah-Millewa forest, south-eastern Australia", Regulated Rivers: Research and Management, vol. 17, iss. 1, pp. 21-36.

Table 2.2 Other Publications

- Barmah-Millewa Forum (BMF) 2000, Annual Plan 2000-2001 for water operations and works in the Barmah-Millewa Forest, July.
- Department of Land and Water Conservation (DLWC) 1996, Unseasonal Surplus Flow Management - Barmah-Millewa Forest, June.
- Department of Conservation and Environment (DCE) 1992, Barmah Management Plan for Barmah State Park and Barmah State Forest, East Melbourne, September.
- Ife, D. 1998, The Hydrogeology of the Barmah Forest, Investigations Report No. 1988/32, Rural Water Commission of Victoria, November.
- Leslie, D. and K. Harris 1996, Water Management Plan for the Millewa Forests, State Forests of New South Wales, Deniliquin, July.
- Maunsell (Maunsell Pty Ltd) 1992a, Barmah-Millewa Forests Water Management Plan, Final Report, MDBC, January.
- Maunsell 1992b, Watering the Barmah-Millewa Red Gum Forest, Issues Paper, MDBC, January.
- McKinnon, L.J. 1997, Monitoring the Fish Aspects of the Flooding of Barmah Forest, Final Report to the Murray-Darling Basin Commission for Natural Resources Management Strategy Project V014, Marine and Freshwater Resources Institute, Queenscliff, October.
- MDBC 2000, The Barmah-Millewa Forest Water Management Strategy, on behalf of the Barmah-Millewa Forum, June.
- Murray Water Entitlement Committee (MWEC) 1997, Sharing the Murray - Proposal for defining people's entitlements to Victoria's water from the Murray, October.
- River Murray Commission (RMC) 1980, River Murray-Tocumwal to Echuca, River Regulation and Associated Forest Management Problems, Review Report, June.
- Thoms, M., P. Suter, J. Roberts. J. Koehn, G. Jones, T. Hillman and A. Close 2000, Report of the River Murray Scientific Panel on Environmental Flows, River Murray - Dartmouth to Wellington and the Lower Darling River, Murray-Darling Basin Commission, June.
- Ward, K.A., C. Leitch, L.N. Lloyd and B.P. Atkins 1994, Interim Water Management Strategy for Barmah Forest, Victoria, Natural Resources Management Strategy of the Murray-Darling Basin Ministerial Council, Canberra and the Department of Conservation and Natural Resources, Victoria, August.

Bren analysed the flooding frequency and duration of floods in the Barmah Forest, and examined the relationship between flooding of the Barmah red gum forests and flow in the Murray-Edward River system. Details of Bren's research included:

- Use of historic flow records and grid-cell analysis of flood maps drawn between 1963 and 1984 to determine the relationship between the extent of flooding in the Barmah Forest and the flow in the Murray-Edward River system. The study determined that the peak flow of the Murray River at Tocumwal is the best predictor of the extent of flooding (Bren 1988b; Bren, O'Neill and Gibbs 1987);
- Estimation of the mean and maximum duration of flooding in such a riparian red gum forest, considering changes in the duration of flooding attributable to regulation (Bren, O'Neill and Gibbs 1987);
- Analysis of the geographic location of points of higher flooding frequency.

Subsequent to Bren's period of research, various management agencies with responsibilities for the Barmah-Millewa Forest and River Murray have used Bren's findings to aid development of water management plans and strategies. Both Maunsell (1992a, 1992b) and Leslie and Harris (1996) cite Bren's relationship between the percentage of forest flooded and the peak monthly flow of the Murray River at Tocumwal (see Figure 2.1) in their respective management plans.

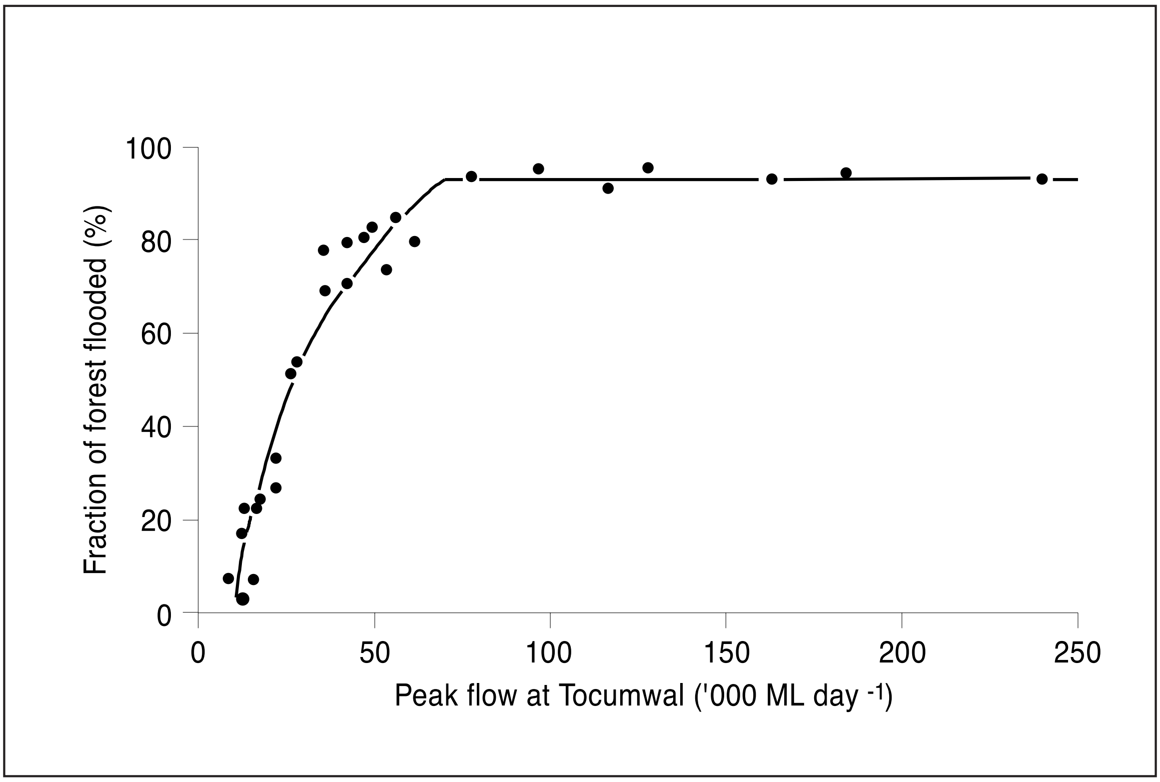


Figure 2.1 Relationship Between Extent of Flooding in the Barmah Forest and Flow in the Murray-Edward River System

The derived relation between the maximum percentage of the forest inundated (P) and maximum daily flow at Tocumwal (Q) during the flood period for all major inundations between 1963 and 1984 is:

$P = -435.40 + 47.6 \ln(Q)$ $Q<68\,500$ ML/day

$P = 93.5$ $Q > 68\,500$ ML/day

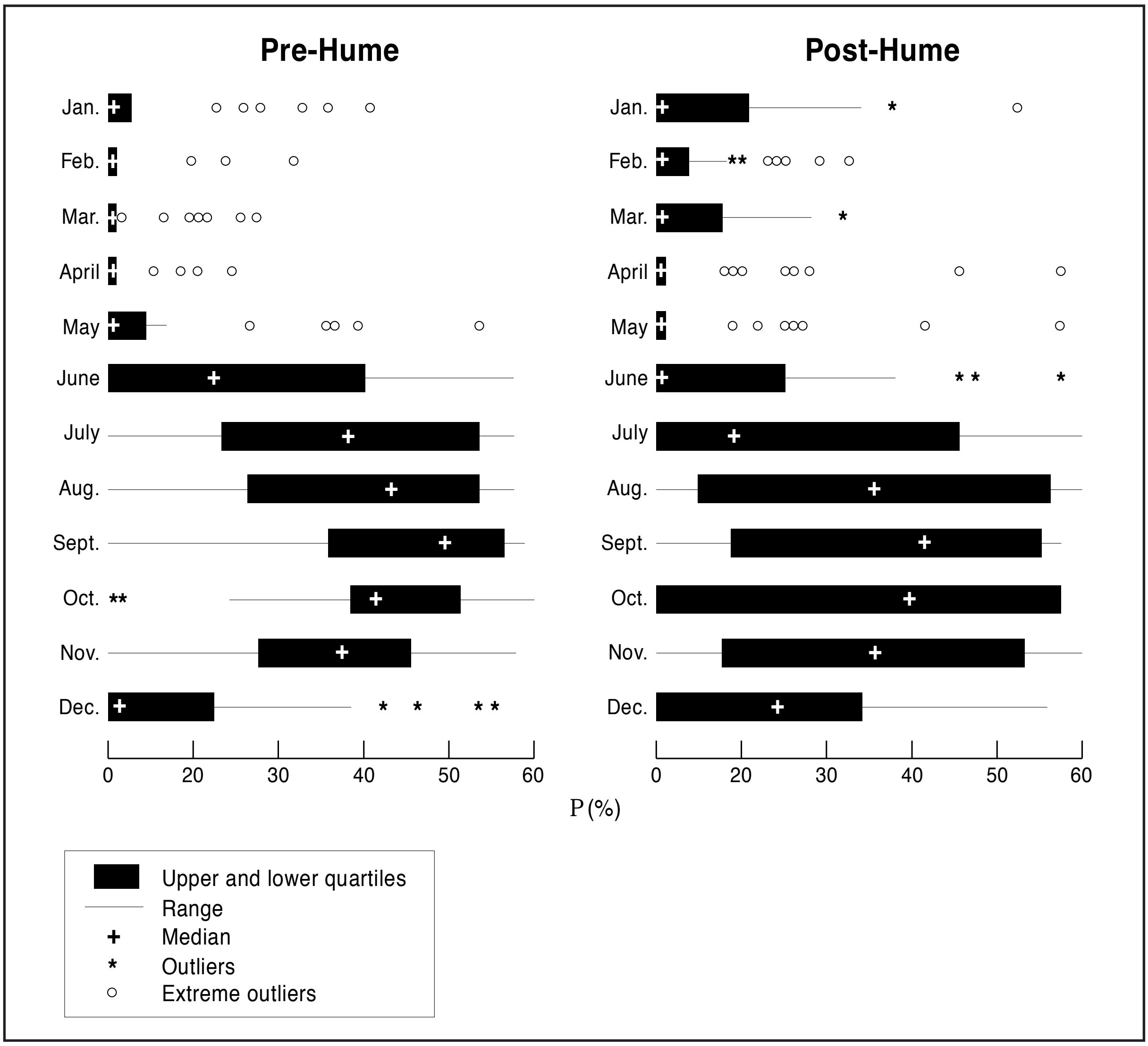
Source: Bren, O'Neill and Gibbs (1987).

Bren *et. al.* (1987) used this relationship to analyse monthly changes in the extent of flooding (see Figure 2.2) pre- and post-Hume, to illustrate the impacts of regulation. However, this analysis assumed that the relationship between flow and flooding derived for the period 1963-1984 was relevant for the period 1895-1963. It is likely that changes to the capacity of the Choke (due to activities such as de-snagging) and the introduction of raised levees and regulators in the forest have changed the threshold flow level at Tocumwal at which forest flooding commences. It is possible that the frequency of "pre-Hume" floods illustrated in Figure 2.2 is understated.

The management agencies SFNSW and DNRE provide descriptions of forest hydrology and flow patterns in their plans and strategies (Leslie and Harris 1996; DCE 1992; Ward *et. al.* 1994). As these state government agencies are responsible for managing rain rejection flows, they provided descriptions that were more detailed and included greater reference to regulators than in Bren's research.

For example, Bren (1988a) describes the river flow through the Barmah-Millewa Forest by describing the geographical layout of the Edward River, "The Choke", Lake Hume, and the Ovens and Kiewa catchments, and

Figure 2.2 Pre-Hume and Post-Hume Flooding of the Barmah Forest



Box-and-whisker plots showing the monthly statistical distributions of the percentage P of forest flooded for the pre-Hume (1895 - 1929) and post-Hume (1935 - 1984) periods.

Source: Bren, O'Neill and Gibbs (1987).

provides details of channel and river capacities. In contrast, Leslie and Harris (1996) provide hydrological descriptions of individual water management areas (WMAs) in the Millewa Forests, referring to the flows of and drainage patterns into specific creeks, swamps and lagoons.

Excluding the Barmah-Millewa Forests Water Management Plan (Maunsell 1992a), state government agencies' water management plans do not include numerical hydrological analysis. However, one older publication by the Rural Water Commission of Victoria (Ife 1988) did present the results of a hydrogeological investigation of the Barmah Forest, including hydrograph analysis of water table fluctuations.

2.3 Flora and Fauna

This section reviews a sample of literature which presents research into the flora and fauna of the Barmah-Millewa Forest. As it is not an objective of this research project to conduct a rigorous investigation of the ecological impact of unseasonal flows, this section is brief and considers only a few of the many available refereed journal articles on flora and fauna of the Forest.

Agency publications frequently refer to Chesterfield (1986) when summarising the changes in the vegetation of the Barmah State Forest due to the effect of river regulation. This article also examines changes due to reduction in frequency of burning, increased grazing by rabbits and increased domestic stock. It mentions that high summer river levels have contributed to tree death, and emphasises that, in other areas, seepage into low areas has caused some grassland to change into rushland and trees to regenerate where previously there was none.

The encroachment of moira grass plains by rushes and river red gum is also outlined in DCE (1992) and Leslie and Harris (1996). Bren (1992) used grid cell analysis to develop a model which extrapolated an almost complete extinction of extensive grass plains in the future. In certain areas, regulation causes plains to suffer less flooding in the winter-spring period, with a slightly earlier recession, which favoured survival of river red gum germinants because of the reduced depth and duration of flooding. The increased summer flooding allows young seedling to develop in the absence of moisture competition from the Moira grass. Bren's findings are reiterated by Leslie and Harris (1996), who emphasise that:

> *Drying, rather than watering, is... a critical element in wetland management in the Millewa forests, as important ecological processes which sustain the health and productivity of wetlands require a regular periodic drying phase in late summer and autumn.*

Other papers and studies examine the watering requirements of Forest vegetation, whether of a specific vegetation type such as the Moira grass plains (Ward *et. al.* 1994), or a more general summary of flora water needs (Maunsell 1992b).

Research into fauna water requirements has not been less extensive than research into vegetation water requirement. Two more recent publications which evaluate the effects of seasonal flooding on native fauna are Leslie (2001) and McKinnon (1997), who examined native waterbirds and native fish respectively.

2.4 Rain Rejection Analysis and Management

The majority of research which involves analysis of rain rejection events and opportunities for managing these flows is conducted by government agencies, due to their responsibilities in managing River Murray Flows and the Barmah-Millewa Forest. The MDBC does not currently have a publicly available working or technical paper on rain rejections. A detailed brief for a future study is expected to be finalised in April 2001, and the study is scheduled to commence during this year (Brian Lawrence 2001, *pers. comm.*, 8 March).

This section provides a chronological review of management plans and strategies that have, at various levels of detail, addressed the problem of rain rejection flows in the Barmah-Millewa Forest.

Maunsell (1992a and 1992b) proposed that watering using rain rejection flows and river freshes would be a significant way to increase spreading of water in the forest, Analysis of individual rain rejection events was presented in the *Barmah-Millewa Forests Water Management Plan* (Maunsell 1992b). The results of modelling runs indicated that rain rejection flows could be used to water the forest.

However, the rules for regulator operation presented in the Interim Water Management Strategy for Barmah Forest (Ward *et. al.* 1994) do not reflect the use of rain rejection flows for environmental purposes. Rather, the report made the following recommendations for regulator operation during the irrigation season (1 January - 12 May):

- regulators should be closed where possible;
- full use should be made of the Mulwala Canal for the diversion of rain rejection flows;
- if the MDBC directs that rain rejection flows must pass through the Barmah Forest, then flows should be diverted through numerous small channels that radiate from the Murray and feed infrequently flooded red gums, effluents which have channels rather than open wetlands, and into Giant Rush dominated wetlands.

These recommendations implicitly reflect the goal of minimising summer and autumn flooding of the forest, particularly of Moira grass plains. This goal is also emphasised in the *Water Management Plan for the Millewa Forests* (Leslie and Harris 1996), in which the authors explicitly state that, unlike in Maunsell (1992a and 1992b), there is a need for flood mitigation in summer and autumn:

> *... rain rejection flows and other minor river surpluses, due to occasional availability of short duration, low flow and possibly seasonally unfavourable river surpluses, should not form the basis of a forest watering strategy. Opportunistic river surpluses cannot be seen as a substitute for natural floods which have sustained the floodplain forests and wetlands for many thousands of years.*

In 1996 the DLWC conducted an investigation to assess the options for managing unseasonal flows affecting the Barmah-Millewa Forest. The analysis was of a preliminary nature, and since 1996 little work has been done in this area (Bryan Harper 2001, *pers. comm.,* 19 March). The current Annual Plan 2000-2001 for water operations and works in the Barmah-Millewa Forest (BMF 2000), describes the time-sharing arrangement between SFNSW and DNRE, in which 2001 is Barmah Forest's turn to receive rain rejection flows. However, the BMF has not allocated funds during 2000-2001 for research into rain rejection management.

Despite the lack of recent analysis into rain rejection management, Objective 2 of the *Barmah-Millewa Forest Water Management Strategy* (2000) is "to optimise use of river flows to enhance water management of the environment". The strategies relating to this objective are:

- Ameliorate, as far as is practicable, the impacts of river regulation exerted through high summer flows and rain rejection flows;
- Where possible, and taking into account the needs of Forest users, reinstate a more natural wetting and drying cycle by managing water flows within the river and within the Forest to benefit ecosystem requirements;
- When possible, manage unseasonal Forest flooding to minimise damage to environmental, commercial and recreational values, in that order;
- When possible, manage summer and autumn Forest flooding to protect sensitive environmental areas;
- When possible, manage summer and autumn Forest flooding to protect, as far as is practicable, access by fire control, commercial and recreational vehicles;
- Refine procedures for ordering irrigation water from Hume Dam and Yarrawonga Weir.

Furthermore, Thoms *et. al.* (2000) recommend that the management of unseasonal summer-autumn flooding should receive a "very high priority status." The following management recommendations were made:

- During the period, December 1 to end of the irrigation season, Barmah Choke should be run below channel capacity (i.e. < 10,600 ML/day at Tocumwal) in order to prevent summer flooding; and
- The [River Murray Scientific] Panel [on Environmental Flows] insists on caution in using regulators and recommends that a set of ecological, engineering and hydrological guidelines for the use of regulators to exclude high summer flows should be developed; the ecological criteria for developing these should be based on the impact of altered linkages (two-way) between floodplain and river; and on local and regional benefits or disbenefits.

These recent strategies and recommendations suggest that studies into rain rejection management might form the basis of research by management agencies in the near future. However, the issue of rain rejection management was first raised many years ago, at least as early as 1980 (RMC 1980). There is little evidence to suggest that implementation of the provisions of the current water management strategy is any more likely than the investigation of the recommendations made in previous studies.

2.5 Summary

In the mid-1980s, Bren conducted significant and extensive research into the hydrology of the Barmah Forest. His use of grid-cell analysis resulted in important findings such as a quantification of the relationship between percentage of forest flooded and the flow in the Edward-Murray river system. Bren's research is complemented by other studies which examine the consequences of changed flooding regime on flora and fauna.

From the mid-1980s to the present, government agencies have built on the findings of researchers such as Bren to develop water management strategies and plans for the Forest. Although Bren researched the hydrology of the Barmah Forest, similar hydrological relationships have been assumed for the Millewa Forest.

The most significant shift in management principles has been the move away from the idea of using rain rejection flows to water the forest (Maunsell 1992a, 1992b). Current management publications reveal a trend towards investigation of the use of environmental allocations for forest watering, and an emphasis of the need for (unnatural) summer and autumn flows to be managed to minimise impacts on the forest ecosystems.

3. Background Information

3.1 Overview

This section presents background information relevant to the analysis of unseasonal surplus flow events which affect the Barmah-Millewa Forest.

3.2 Location

The Barmah-Millewa Forest is the collective name given to the Barmah Forest and the Millewa Forests which comprise approximately 70,000 ha of wetland habitats on the floodplains of the Murray between Echuca, Deniliquin and Tocumwal. The Barmah-Millewa Forest extends approximately 40 km north-south and 40 km east-west.

The Barmah Forest covers 29,500 ha of River Murray floodplain. In 1987 the Victorian Government proclaimed 7900 ha of the forest as Barmah State Park and two Reference Areas covering 280 ha. The remaining area is classified as State Forest.

The Millewa Forest covers an area of 40,149 ha and is defined as the Millewa Group of Forests, which consists of the Bama State Forest (3092 ha), Deniliquin State Forest (365 ha), Gulpa Island State Forest (5143 ha), Horseshoe Lagoon State Forest (15 ha), Mathoura State Forest (1ha), Millewa National Forest (20,457 ha), Moira National Forest (9996 ha), Tuppal National Forest (1040 ha), and Moama State Forest (40 ha).

The easternmost boundary of the Barmah-Millewa Forest lies approximately 2 days downstream of Yarrawonga Weir, which is 4 days downstream of the Hume Dam.

See Figure 3.1 and Figure 3.2 for maps of the location of the Barmah-Millewa Forest.

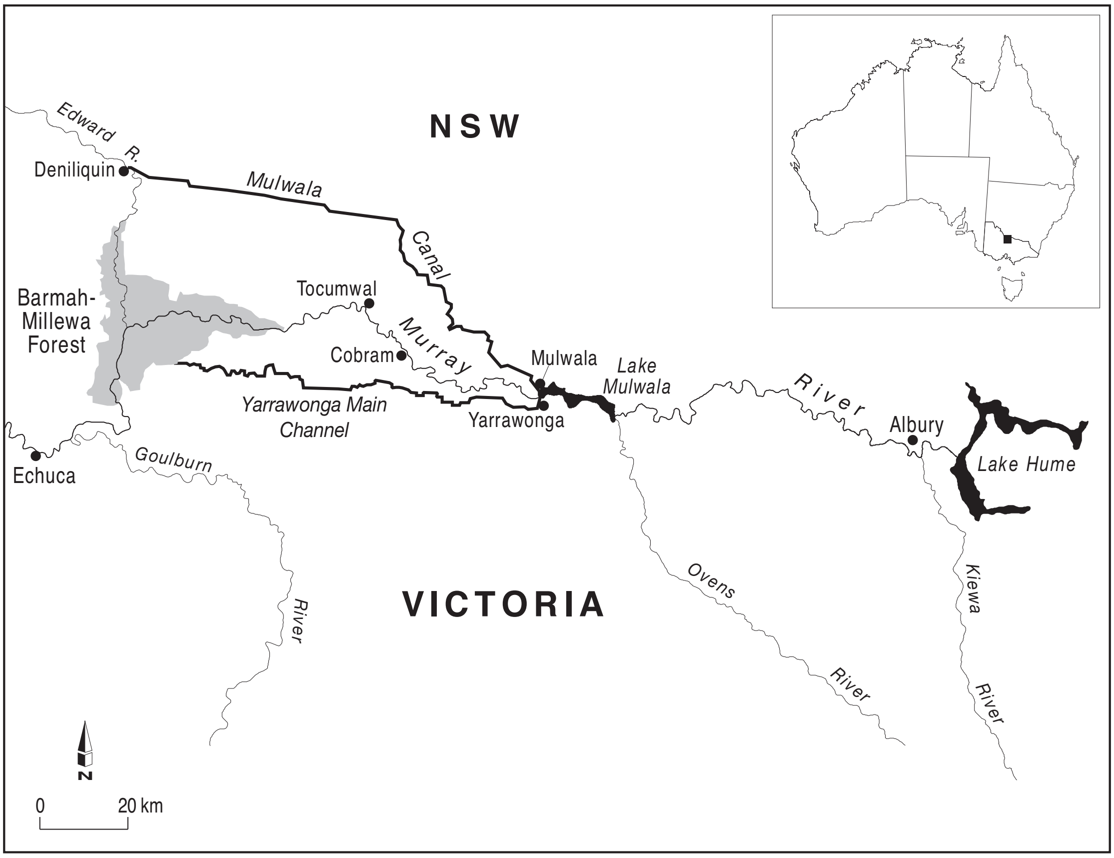


Figure 3.1 Location of the Barmah-Millewa Forest

Source: DLWC (1996)

Figure 3.2 Locality Map of the Barmah-Millewa Forest

Source: Maunsell (1992a)

3.3 Natural Resources

3.3.1 Origin of the Barmah-Millewa Forests

Approximately 25,000 years ago, an uplift of land in the southern Murray-Darling Basin created what is now known as the Cadell Tilt Block (Cadell Fault). The edge of the 12 m high block runs north/south near Deniliquin and Echuca. It influenced the course, pattern and character of about 500 km of the River Murray.

Following the uplift, a large shallow lake was created by the dammed Murray and Goulburn rivers. The Murray took a new course around the northern side of the Fault (now referred to as Wakool channel), the river bed of which is today occupied by the Edward River. For thousands of years the Goulburn River continued to feed the lake but it eventually also broke out to the west.

Around 8000 years ago, the Murray turned south, breaking through the section between Picnic Point and Barmah (taking over the Goulburn channel downstream of Echuca). This section is today known as the Barmah Choke.

During major floods, large volumes of water bank up behind Barmah Choke, flooding the former lake area. This flooding created a wetland (Barmah-Millewa Forests), which contain flora and fauna that are typical of a region which receives three times more rainfall than it does (MDBC 2001c).

3.3.2 History and Heritage

The forest's cultural landscape reflects both Aboriginal and European activities. Evidence from the Willandra Lakes area in NSW suggests that Aboriginals first lived in the region over 40,000 years ago, and that the mid-Murray area would have supported about 4800 people before European occupation. The diversity of Aboriginal site types in the area, including occupation sites, burial grounds, canoe trees, shell middens, and mound sites, gives the forests importance due to the unusual richness of these features.

Relics of early European settlement are scattered around the Barmah-Millewa Forest. However, the historical value lies in the impact of events on the forest, rather than the remains of settlement itself.

Prior to European invasion, the Yorta Yorta people occupied a stretch of territory located in what is now known as the Murray-Goulburn region. The majority of food was provided from the network of rivers, lagoons, creeks and lakes which include those in the Barmah-Millewa Forest (Atkinson 2001).

Between 1860 and 1993 the Yorta Yorta made seventeen separate claims for compensation from government agencies (Atkinson 2001). In 1994, they lodged a claim under the Native Title Act for recognition of their native title rights to, and interests in, public lands and waters in the region (Seidel 2001). However, in December 1998, the Federal Court ruled that any native title held by the Yorta Yorta (based on a continuing traditional connection the land) had been "washed away" during the 19th century. On 8 February 2001, the full Federal Court rejected the Yorta Yorta's appeal (Farrant 2001a). In March 2001, lawyers (acting on behalf of about 4000 claimants) filed an application seeking special leave to appeal to the High Court, which was subsequently granted (Farrant 2001b).

3.3.3 Vegetation Associations

The Barmah and Millewa Forests is the largest river red gum (Eucalyptus camaldulensis) forest in the world. The area is called a forest because of the predominance of red gums but it could also be termed a wetland because of its frequency of flooding and the mosaic of open water bodies, swamps, meadows, and marshes that occur within the red gum forest.

The red gum and affiliated box forests and woodlands are often associated in the vicinity of watercourses, in sites which receive regular flooding (or overlie accessible groundwater contained in sandy aquifers). These forests usually have a grass or sedge dominated understorey with the presence of shrubs being relatively rare. River red gum forests tend to have a low species diversity, due to the requirement of understorey species to survive seasonal flooding followed by moisture stress over summer, and the possible effect of toxic inhibition by red gum litter (Chesterfield 1986). In contrast, box woodlands have a comparatively rich herbaceous understorey, though the number of native species present and regeneration of shrubs may have been reduced.

The flora of the Barmah Forest consists of more than 550 species, of which approximately 30 per cent are exotics. The majority of species are herbaceous, with only about 40 species having tree or shrub habit. At least one third of the flora is associated with the box woodlands which occupy only 3.6 per cent of the forest area (Maunsell 1992a).

Vegetation Classification

There are two widely referenced classification schemes for the forests along the River Murray. Chesterfield et al (1984) identified thirteen vegetation types in the Barmah Forest based on the composition and structure of the dominant species, and a number of understorey associations. Smith (1983) classified the red gum forests according to "site quality", which was based on mature red gum height (SQ I > 30m, SQ II 21-30 m; SQ III < 21 m). In contrast, relatively little systematic information on understorey associations is available for the Millewa Forest (Maunsell 1992a). The more detailed information for the Barmah Forest cannot be directly applied to the Millewa Forest, because of significant wetland types in the two areas, and the absence of moira grass in the Millewa Forest.

3.3.4 Fauna

Forests and wetlands in the Barmah-Millewa Forests are an important habitat for wildlife, and are particularly significant as a breeding area for waterbirds. The Barmah Forest, for example, is inhabited by 31 species of mammals, 219 birds, 16 reptiles, 8 amphibians, and at least 21 species of fish (DCE 1992).

The significance of the Barmah-Millewa forest habitats are recognised in international treaties. The Barmah forest has been declared a wetland of international significance under the Ramsar convention. Two international treaties, the Japan-Australia Migratory Birds Agreement (JAMBA) and the China-Australia Migratory Birds Agreement (CAMBA) recognise that certain birds migrate between Australia and Japan, and Australia and China. Eight species of migratory birds which inhabit the Barmah-Millewa Forests in summer are protected under these Agreements (Maunsell 1992a).

3.3.5 Hydrogeology

The forest geology comprises a sequence of unconsolidated clay, silt and sand deposits derived from ancient fluvio-lacustrine environments (Maunsell 1992a). The geological characteristics include:

- a shallow system dominated by silty and clayey sediments having low hydraulic conductivities;
- channelised sand bodies interspersed within this low hydraulic conductivity system;
    - which have higher hydraulic conductivities
    - may supply water to covering forest
    - are partially or fully saturated
    - may be confined or unconfined
    - have some potential for upward leakage of groundwater (Shepparton Formation) to the shallower aquifers

The hydrogeology of the Riverine Plain has been particularly influenced by the modifications brought about by broadacre irrigation. Consequently, in order to maintain or improve the health of the trees it may be desirable to reduce the depth to the shallow water table in certain areas.

3.3.6 Sedimentology

Sedimentation in the wetland areas of the Barmah Forest appears to have increased during the last 50 - 100 years. Studies have inferred average sedimentation rates of between 1.6 - 3.8 mm/year (Maunsell 1992a).

3.3.7 Climate

DCE (1992) classified the climate of the Barmah-Millewa Forest as "temperate hot summer".

Rainfall

Rainfall across the central Murray Valley decreases from south-east to north-west as the influence of the eastern highlands diminishes. Winter rainfall is typically of low intensity, whilst summer falls are usually the result of heavy thunderstorms. Mean annual rainfall is about 400 - 450 mm.

Average rainfall statistics for Echuca, Barmah and Tocumwal are presented in Figure 3.3.

Evaporation

Annual evaporation for the region is approximately 1400 mm, almost half of which occurs between December and February, and two thirds between November and March (DCE 1992).

Temperature

The hot season commences in November and extends until March, with mean maxima and minima ranging from 31 to 15ºC in the hottest month of January. Maximum and minimum temperatures in the coldest month of July range from 13 to 4ºC (BOM 2001).

The average frost-free period lasts about 7 months from late October to mid May. Severe frosts are limited to a period of eight weeks in June, July and August (DCE 1992).

3.4 Forest Uses and Resources

3.4.1 Utilisation

Utilisation of the Barmah Forest for timber, grazing, apiary and other purposes is permitted under the National Parks Act 1975 and the Forest Act 1958 (DEC 1992). These activities also occur in the Millewa Forest.

Timber and Wood Products

Extensive logging has been carried out in the Barmah-Millewa Forests since the 1860s. It has been estimated that over 2.5 million cubic metres of river red gum logs have been harvested since that time in the Barmah Forest alone (DCE 1992). During 1999/2000, the Barmah Forest red gum timber and wood products yield comprised 4099 m^3 of sawlogs, 1012 m^3 of residual, 7866 sleepers, 355 m^3 of hewn, 350 bushsawn pieces and 5720 m^3 of firewood (Lacey 2001). A small volume of grey box (Eucalyptus microcarpa) is also cut. Yellow box (Eucalyptus melliodora) and black box (Eucalyptus largiflorens) are not harvested (Maunsell 1992a).

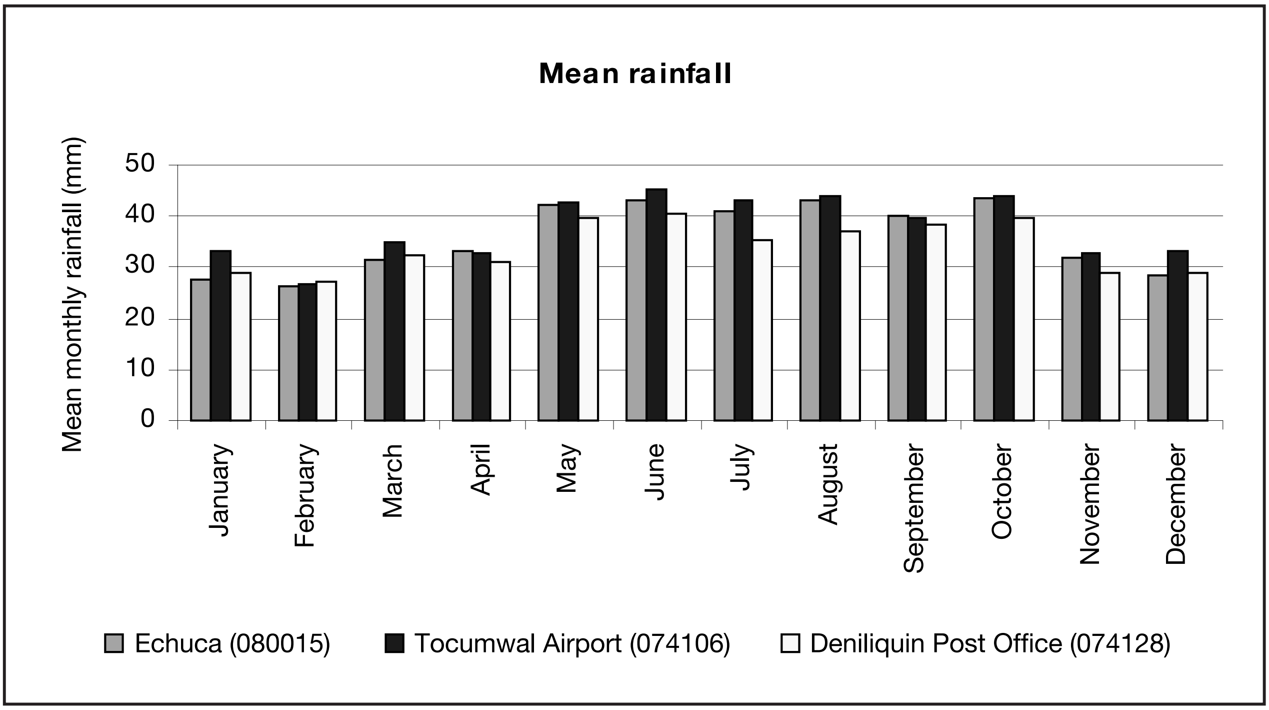


Figure 3.3 Rainfall Statistics

Source: BOM (2001).

Grazing

The Barmah Forest has been grazed by stock since 1840. Since 1885, sheep have been excluded from the forest and grazing has been restricted to cattle (DCE 1992). There are seven grazing licences in the forest and 50 agistment permit holders (Lacey 2001). Grazing currently occurs in the forest in summer and autumn, with fences used in an attempt to restrict access to sensitive environmental areas (Maunsell 1992b). In 1999/2000 the Barmah Forest was grazed by 1505 head of cattle in summer and 923 head in winter (Lacey 2001).

Apiculture

Apiary sites are held under permit allowing bee keepers to follow the flowering of red gum and box species.

3.4.2 Recreation and Tourism

The forest provides a high value recreation resource attracting hundred of thousands of people each year for camping, swimming, fishing, boating, bushwalking and other activities.

3.5 Hydrology of the Regulated System

This section describes the hydrology of the regulated system as relevant to the cause and management of unseasonal flows which affect the Barmah-Millewa Forest.

3.5.1 The Regulation of the River Murray

History

The *River Murray Waters Agreement* (1915) provided for the construction of 26 weirs with locks to ensure permanent navigation upstream to Echuca. By the time construction of locks commenced in 1922, the main purpose of weirs had changed to maintaining a supply of water for irrigation.

The other major provision of the Agreement was the construction of an upper Murray storage, so that river flow could be maintained during drought, and irrigation development greatly expanded. Hume Dam was constructed between 1919 and 1936, and enlarged in 1961 to its present capacity of 3038 GL.

Other regulation has since included (Bren 1988b; RMC 1980):

- construction of Yarrawonga Weir (1939);
- progressive raising of levees and installation and modification of regulators (1939-present);
- channel modifications through the forest;
- de-snagging of the Choke (1950's);
- Kiewa hydroelectric Scheme (1945-1960);
- Snowy Mountains Hydroelectric Scheme (1955-65);
- limited bypassing of the forest by the Mulwala Canal (1941);
- construction of Buffalo Reservoir (1965);
- construction of Dartmouth Reservoir (1973-1979).

A major aim of regulation has been the maintenance of a minimum summer irrigation flow (Bren 1998b). Except for the Kiewa and Ovens Rivers, all of the Murray's tributaries below Hume Dam are regulated. Inflows from tributaries such as the Murrumbidgee and Goulburn Rivers have been greatly diminished through regulation and use of their waters.

Flow Characteristics and Patterns

The channel capacity in the Murray through the forests can cope with a maximum regulated release of about 11,400 ML/day from Yarrawonga weir without the occurrence of significant losses to the forests, when regulators are closed (DLWC 1996). Current MDBC operational procedures allow closed forest regulators until the flow at Picnic Point exceeds the gauge height of 2.53 m, which corresponds to about 10,600 ML/day at Tocumwal.

Bren (1998a) derived flow duration curves for Tocumwal for the pre- and post-Hume periods which show the consequences of regulation:

- increased frequency of flows in the range 6000 - 10,000 ML/day
- decreased frequency of flows in the range 10,000 - 60,000 ML/day
- little effect on the frequency of flows above 60,000 ML/day

Between Yarrawonga and the Barmah-Millewa Forests the course of the River Murray travels west through the

Riverine Plain. Flows may inundated large low-lying areas in the forests, before breaking out on the north side into many anabranches, the principal of which is the Edward River. The courses and anabranches of the Riverine Plain system help to spread a large flood over a very wide area (Maunsell 1992a).

3.5.2 Unseasonal Surplus Flows

DLWC (1996) broadly identified unseasonal surplus flows as those occurring in the period November to May which exceeded the regulated flow limit (11,400 ML/day) downstream of the Yarrawonga Weir. This limit is currently under question since overbank flooding has been observed at this flow.

Unseasonal surplus flows are generated from rain rejection flows and river freshes, which often occur in combination. *Rain rejection flows* are defined as flows released from the Hume Dam during the irrigation season but not diverted into the irrigation areas from Mulwala Lake (the Yarrawonga Weir pool). These flows results when rainfall over the irrigation areas causes landholders to cancel water orders which are already in transit. River freshes are small excess flows in the unregulated tributaries of the Murray upstream of the forest (the Ovens and Kiewa Rivers), and are generated by local rainfall.

At the onset of an unseasonal surplus flow, the MDBC notifies the forest management agencies who then negotiate an outcome on how these flows will be distributed (Maunsell 1992a). A time-sharing flooding arrangement exists between SFNSW and DNRE, in which Barmah Forest and Millewa Forest accept unseasonal summer flows in alternate years (BMF 2000).

There is generally limited scope to control unseasonal flows within bank and outflows into the Barmah-Millewa forest result. When these flows occur, releases from Hume Dam are reduced to conserve water and to limit downstream impacts. The MDBC limits this rate of reduction to a decrease in river level at Doctors Point of 150 mm per day (about 1500 ML/day) to minimise the risk of bank slumping (Maunsell 1992a).

3.5.3 Yarrawonga Weir Diversions

From Yarrawonga Weir, irrigation water is diverted into Mulwala Canal and the Yarrawonga Main Channel. The Mulwala Canal supplies part of the Murray Irrigation Area (NSW), and is privately owned and management by Murray Irrigation Limited (MIL). The Yarrawonga Main Channel, which supplies the Murray Valley Irrigation Area (Victoria), and is owned and managed by Goulburn-Murray Water (GMW). The maximum operational diversions are 10,000 ML/day into Mulwala Canal and 3000 ML/day into Yarrawonga Main Channel.

GMW and MIL relay irrigators' water orders to the Weir Keeper at Yarrawonga and the MDBC who determine releases from Hume Weir. These agencies are charged for cancelled water orders which are not diverted from Lake Mulwala only if the water cannot be used along the Murray downstream, a situation which rarely occurs (DLWC 1996).

Lake Mulwala is maintained near its full supply level of 117,330 ML to achieve the maximum diversion rate necessary to each State. This limits its capacity to mitigate rain rejection flows.

3.5.4 Murray Irrigation Area (New South Wales)

Description

The Murray Irrigation Area (MIA) comprises five irrigation districts extending from Yarrawonga Weir to the lower Edward River system near Swan Hill. Along its course the channel capacity of the Mulwala Canal diminishes as flows are diverted into a network of smaller canals and supply channels (see Figure 3.4).

Operating Procedure for Water Order Cancellations

MIL reduces inflow diversions from Lake Mulwala and bars-up the regulators along the canal. Irrigators are required to take the first 12 hours of their rejected water order. Excess water in Mulwala Canal is released via escape structures into the Edward and Wakool Rivers. Operational rules for the Edward escape mean that, after 15 December, there is a 300 ML/day capacity for passing rain rejections. Further downstream, the two escapes into the Wakool River have a combined operational escape capacity of 80 ML/day.

3.5.5 Murray Valley Irrigation Area (Victoria)

Description

The Murray Valley Irrigation Area extends from Lake Mulwala to the area bordered by Broken Creek to the south of the Barmah forest. See Figure 3.5 for the location of the irrigation area and its generalised layout.

Operating Procedure for Water Order Cancellations

Diversions from Lake Mulwala into Yarrawonga Main Channel are reduced according to the volume of water orders cancelled, up to a maximum daily reduction of 2500 ML. Excess water supply already in the channel system is released into outfall channels which drain into the River Murray or Broken Creek (DLWC 1996). Runoff from landholders is carried from the irrigation

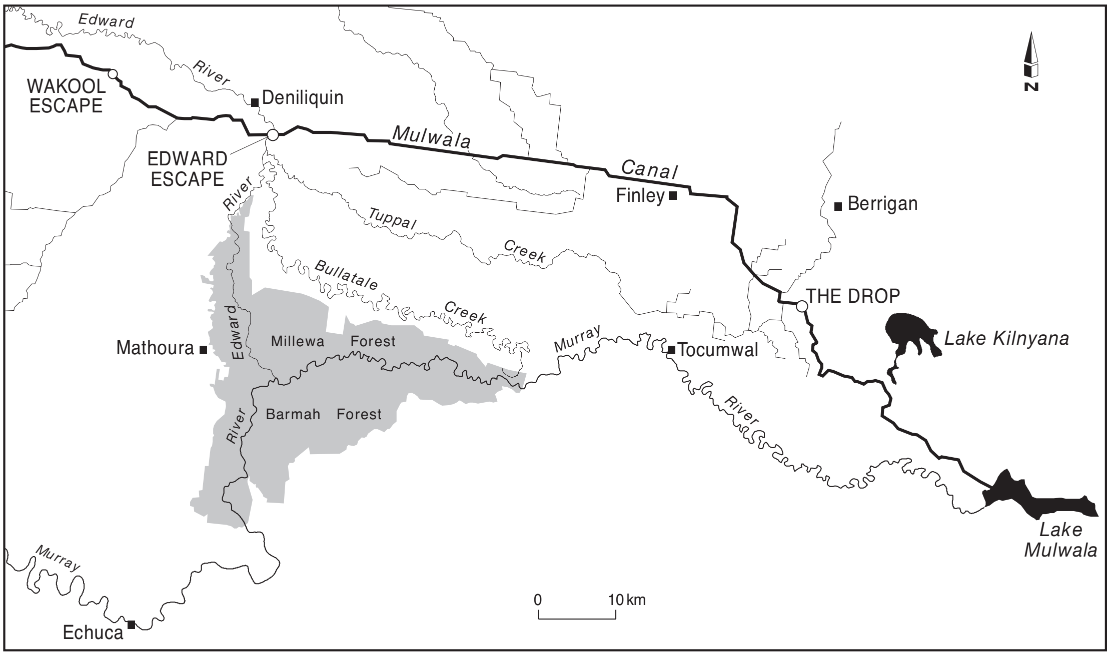


Figure 3.4 Murray Irrigation Area from Lake Mulwala to the Wakool Escape

Source: DLWC (1996)

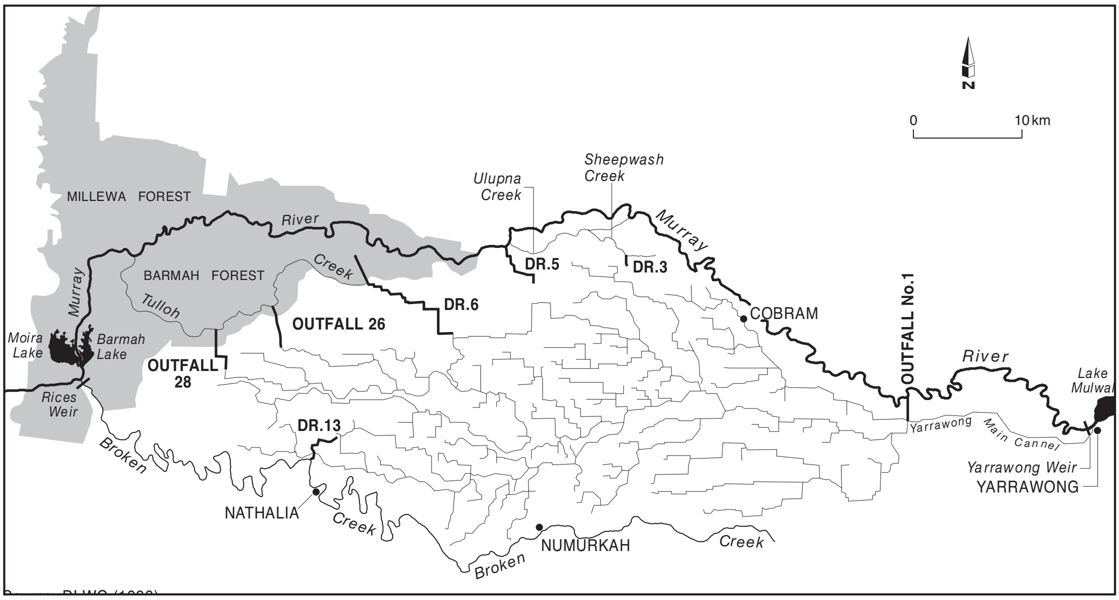


Figure 3.5 Murray Valley Irrigation Area

Source: DLWC (1996).

area by a series of channels which drain into creeks in the Barmah forest, the Murray River and into Broken Creek, and may exacerbate unseasonal flooding problems.

Overall, there is little scope to escape excess water from the irrigation area without impacting on forest flooding.

3.6 Forest Hydrology

3.6.1 Water Management Areas

The Barmah-Millewa Forests Water Management Plan (Maunsell 1992a) defined seventeen water management areas (WMAs) for the Barmah-Millewa Forest (see Figure 3.6). These subdivisions were established mainly on the basis of natural water distribution

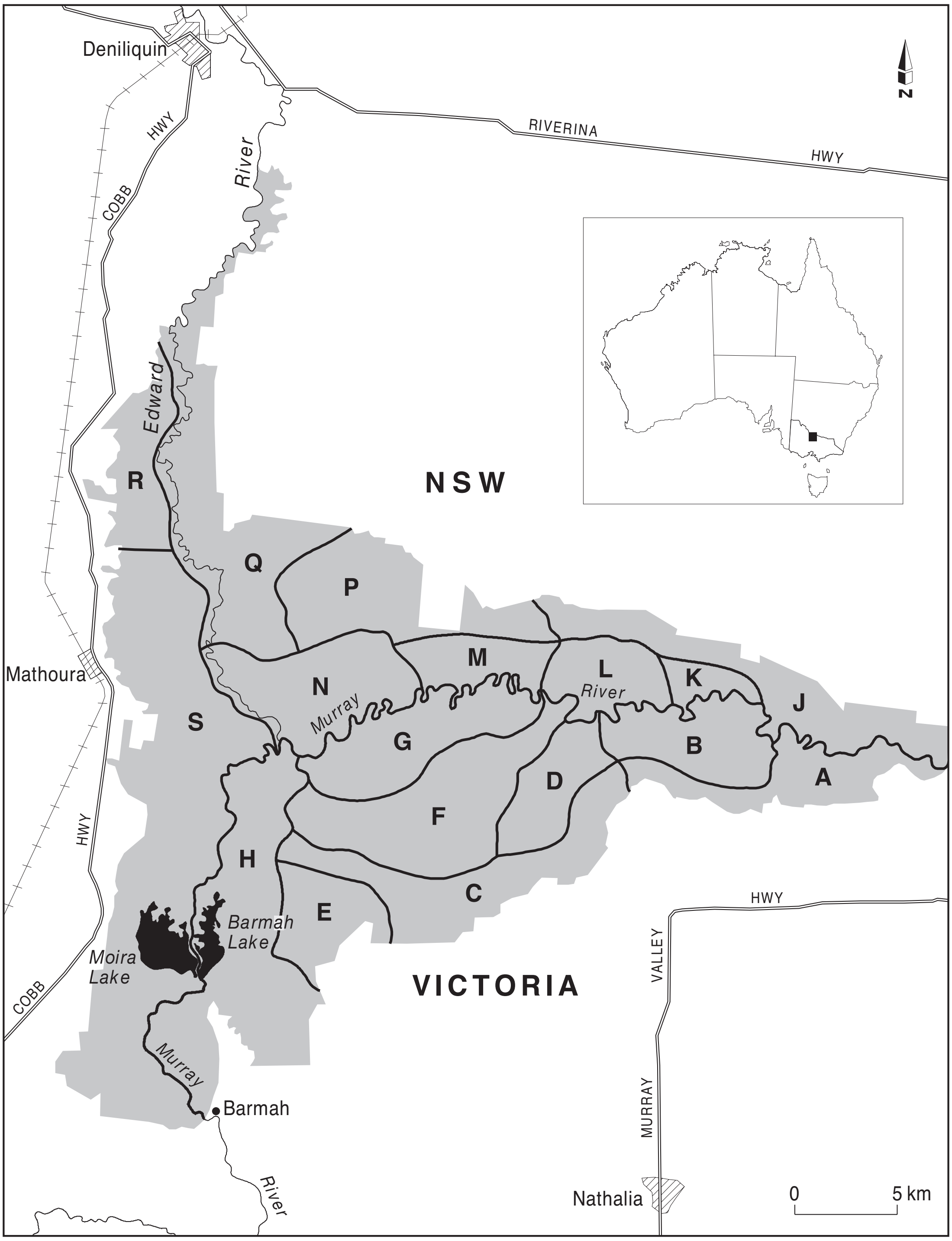


Figure 3.6 Water Management Areas

Sources: Maunsell (1992a).

networks, these natural patterns of watering dictated by the topography of the region. The purpose of distinguishing separate water management areas was to enable the prioritisation of management activities within the Forest.

3.6.2 Flow Characteristics of the Barmah-Millewa Forest

Geomorphology

The flow characteristics in the forests are dictated by the topography of the region, which has in turn been determined by the morphologic development of the river system. The flow patterns in the forest are constantly changing, as log or earth barriers alter in height or position, and silt is deposited on flooded areas. The flat terrain means that a variation of a few centimetres in a barrier across a waterway can markedly affect the location and depth of flooding (Maunsell 1992a).

Within both forests, ground levels fall generally from east to west, from 104 m AHD at the eastern limit of the Forests to 93 m AHD to the west (35 km). The gradient is uniform over the majority of the length, but flattens significantly in the lake and swamp areas to the west. The small scale topography of the forests is varied, with topographic features including ridges, depression, gullies and creeks.

Flow Characteristics

Under moderate conditions, River Murray flows in excess of 60,000 ML/day at Tocumwal bypass the forest area to the north via the overflow system of Bulltale and Tuppal Creeks. Remaining River Murray flows in excess of 25,000 ML/day leave the river channel and flood into the forests before the Black Engine Creek offtake. Flows greater than 10,000 ML/day which still remain in the channel leave the river channel and flood into the forests between Black Engine Creek offtake and Poverty Point.

There are many effluent creeks in the forests which have offtakes which cut through the levees and allow water into the forests at quite low river flows. In general, flow enters the Forests through these breaks in the natural levee, rather than by overtopping the levee. Regulators have been constructed at the offtake to many of these effluent creeks. Consequently, high regulated flows are prevented from flowing into the forests by:

- natural (and raised) levees on both sides of the River Murray;
- block banks;
- closing of regulators.

Control is loss and progressive overtopping of banks occurs for flows beyond 18,000 ML/day with the regulators open (Maunsell 1992a).

Most of the flood flow entering the Millewa forests leaves the River Murray and flows past Deniliquin in the Edward River. It then enters the Edward-Wakool system, finally returning to the River Murray some 200 km to the west at Wakool junction (Maunsell 1992b). Most of the flow entering the Barmah Forest returns to the River Murray through Lake Barmah (Maunsell 1992b).

Flow Patterns

Flows occurring in the Barmah-Millewa Forest have been divided into two main types of flow pattern (Maunsell 1992a). Channel flow is identified as dominated by flow in channels, depressions or leads), whereas broad area flooding spreads and ponds over broader areas. See Figure 3.7 for a map of broad area flooding.

Barmah Forest is watered by broad area flooding. As indicated by field observations and the relationship derived by Bren, O'Neill and Gibbs (1987), significant flooding occurs at a relatively low flow at Tocumwal (approximately 9000 ML/day). At flows greater than 68,500 ML/day, 93.5 per cent of the forest is flooded (see Figure 2.1).

The main example of channel flow in the Barmah Forest occurs in the downstream section of the Tullah Creek. Compared to broad area flooding, significantly higher river flows are required to inundate the adjacent area.

The documentation and mapping of floods in the NSW forests has not been as thorough as for Victoria. However, indications are that the dominant flow pattern to the north of the River Murray is channel flow.

"The Choke"

"The Choke" refers to the reach of the River Murray between the township of Barmah and the junction of the Edward River. This reach has the lowest channel capacity (10,600 ML/day) between Lake Hume and South Australia (Thoms *et. al.* 1998). Another 2500 ML/day can be passed through the Edward River and associated creeks bypassing the Choke.

The presence of the Choke has several effects (Bren 1998b):

- if river flow exceeds channel capacity then forest flooding occurs;
- once substantial flooding occurs the water leaves the Murray channel and passes into the Edward River system to the north; and
- because of the need to increase summer flows through this section to meet downstream irrigation commitments, channel modifications have been introduced (including raised river levees and the construction of effluent regulators).

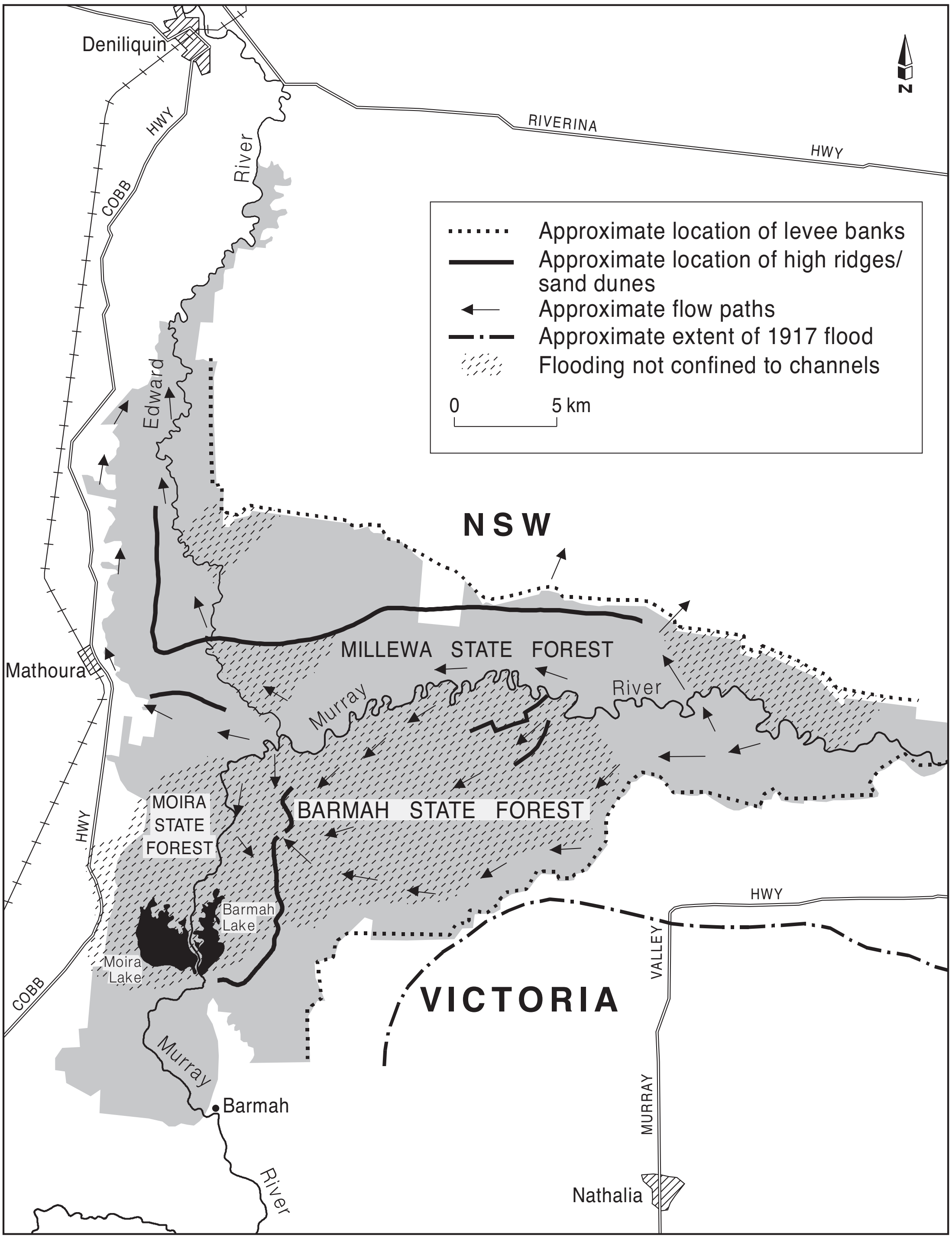


Figure 3.7 Flooding of the Barmah-Millewa Forest

Source: Maunsell (1992a).

3.6.3 Drainage Systems for Unseasonal Flows

Barmah Forest

The two major creek systems which carry surplus flows into the Barmah Forest are Tullah Creek, and Gulf Creek. These are generally carried in defined creek channels, spreading over wetland areas along their course, and draining towards the Murray River at the downstream end of the forest via Barmah Lake.

Tullah Creek passes through the length of the forest. Tullah Creek receives inflows from the Murray at its offtake (Kynmer Creek), from the unregulated Black Engine Creek / Tongalong Creek system and from the regulated Sandspit Creek.

Gulf Creek carries flows released through the Gulf regulator, and smaller downstream regulators. The wetlands along the Gulf Creek system have high ecological value. However, as the gulf regulator represents more than 50 per cent of available regulator capacity (5000 ML/day), its use is necessary when passing larger unseasonal flows into the Barmah forest (DLWC 1996).

Millewa Forest

The three drainage systems which operate in the Millewa forest during unseasonal flood events are the eastern section of the forest upstream of the Lower Toupna Creek, the section of the forest between Lower Toupna Creek and the Edward River, and downstream of the Edward River (see Figure 3.8 for drainage network).

The channel capacity of the Murray River in eastern Millewa, upstream of Lower Toupna Creek (Aratula

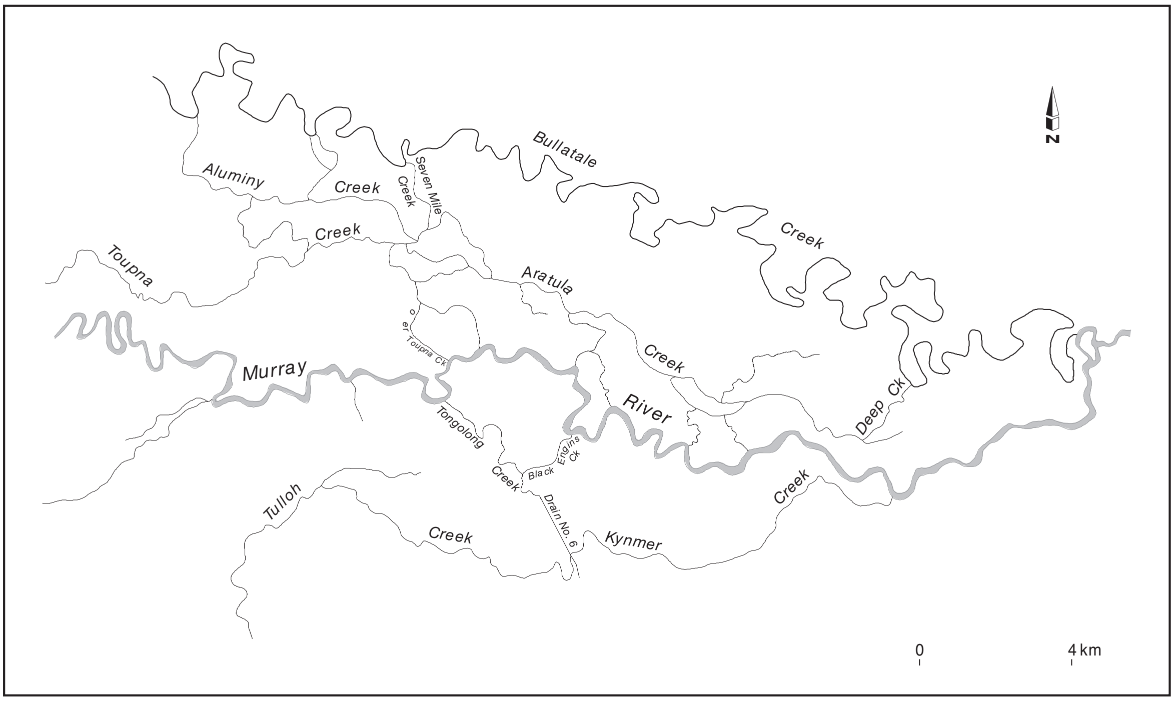


Figure 3.8 Eastern Barmah-Millewa Forest Drainage Network

Source: DLWC (1996).

WMA), is relatively large and in the range of 25,000 - 35,000 ML/day (Leslie and Harris 1996). Cancelled irrigation flows are maintained within the bank of the river and in NSW below the sill level of effluents. Consequently, only the Lower Toupna Creek in the Aratula WMA is regulated. Flows leave the forest via Seven Mile Creek and Deep Creek.

The channel capacity of the Murray between Lower Toupna Creek and the Edward River is restricted and offtake streams are regulated to prevent outflows from irrigation flows. The Mary Ada regulator (2800 ML/day) is the largest of the Millewa forest regulators and is most frequently used to divert surplus flows from the Murray. the remaining regulators have relatively low capacity (15-630 ML/day) (DLWC 1996).

The channel capacity is also restricted downstream of the Edward River. Moira Lake, a large wetland at the downstream end of the forest, is inundated during surplus flow events.

In the event that unseasonal surplus flows are to be directed into the Millewa Forest, the operational plans for flows 15,000 to 18,000 ML/day are to open the Walthours, Nestrons, Nine Panel Pinchgut and House regulators, then the top gates of the Mary Ada. The bottom gates of the Mary Ada are opened once flows exceed 18,000 ML/day (BMF 2000).

3.6.4 Unseasonal Flooding

Changes to Flooding Regime

The natural flood regime of the Barmah-Millewa Forest generally consisted of a cycle of flooding during winter and spring and a dry period during summer and autumn (Maunsell 1992a). Under natural conditions, 70 per cent of the forest flooded for an average of 2.9 months in 78 per cent of years. Since the completion of the Hume Dam, this level of flooding is only experienced for an average of 1.3 months in 37 per cent of years (Bren 1988a; DCE 1992). Furthermore, in pre-Hume period, summer flooding in January-March was effectively unknown. However, with regulation to maintain irrigation supplies, small inadvertent floods have become common (Bren 1988a).

Ecological Impacts

As introduced in section 2.3, unseasonal flooding has a significant effect on the ecology of the forest. It is degrading wetlands by interfering with the natural drying-out phase and by disrupting nutrient cycling processes. Subsequently, the productivity of the wetlands has been reduced and habitat values, particularly for waterfowl breeding, have been seriously diminished. Frequent unseasonal flooding is contributing to extensive tree deaths by overwatering, as roughly 300 hectares of red gum fringing Moira Lakes are dying from prolonged inundation, and similar effects have been identified along the Edward and Gulpa systems (Maunsell 1992a).

In addition to killing areas of forest, prolonged summer inundation is modifying the floristic structure in major wetland systems such as increasing the abundance of water milfoil and clove strip and changing some grasslands into perpetual swamps (Chesterfield 1986). The encroachment of Moira grass plains by rushland and red gum, due to the increased frequency of summer flows, is well documented (Maunsell 1992a, Chesterfield 1986, Ward *et. al.,* 1994, Bren 1992). Chesterfield (1986) estimated that since 1930, 1200 ha (30 per cent) of the Moira Grass plain has been lost to Red Gum regeneration and a further 1200 ha to Giant Rush (Juncus ingens) encroachment.

Impacts on Forest Access

Unseasonal flooding of the Barmah-Millewa forest during summer and autumn adversely affects commercial operations and recreational use of the forest. Restricted access for logging and stockpiling has significant economic impacts on the timber industry. Access problems also affect local tourism activities during the Christmas and Easter peak visitation periods, and bee-keeping and grazing activities. Fire suppression management in summer is impeded when floods block off access tracks.

4. Research Methodology

4.1 Overview

This section presents an outline of the research methodology which enabled :

- an evaluation of how the frequency of unseasonal surplus flows is related to system flexibility; and
- an analysis of the costs and benefits involved with increasing system flexibility to reduce this frequency.

The development of this research methodology and associated data requirements, which included analysis and evaluation of different research avenues, was documented in the Preliminary Report. It is reproduced in full in Appendix A.

A detailed description of analytical methodology is presented in each of Chapters 5 to 8.

Components of Research Methodology

1. Identification and definition of problem (Chapters 1 to 3).
2. Analysis of historical data to investigate changes in River Murray flows (caused by regulation), and to investigate changes in patterns of flooding in the Barmah-Millewa Forest (Chapter 5).
3. Definition of different methods for identifying individual unseasonal surplus flow events (for the period in which the current level of river regulation and irrigation demands is thought to apply). Application of these methods to calculate such characteristics as total excess volume and peak excess flow rate. Comparison between results of different methods, and selection of most "appropriate" method to be used in further research (Chapter 6).
4. Analysing the effects of increased system flexibility (increasing airspace at Yarrawonga, and limiting maximum River Murray flow at Tocumwal) of unseasonal surplus flow volumes, frequencies and event characteristics (Chapter 7).
5. Identify and evaluate selective economic benefits and costs of increasing system flexibility to reduce the frequency of unseasonal surplus flows (Chapter 8).

4.2 Initial Research Phase (Chapters 1 to 3)

The emphasis of the initial research phase was to document, investigate and understand the physical, regulatory, institutional and economic environment of the problem.

The information gained in the initial research phase was used to identify and evaluate possible avenues of research, and to determine data requirements and availability.

The research steps conducted in this phase included:

- identification of problem;
- identification of stakeholders and management agencies responsible for the use of the Barmah-Millewa Forest and the River Murray;
- literature review of information available in refereed journals and other publications, including an overview of the evolution of management principles and practices for the region;
- documentation of background information relevant to the project.

These steps enabled an understanding of the complex physical system and the identification of agencies and institutions from which further information would be available.

4.3 Historical Analysis (Chapter 5)

This analysis involved the use of historical data (daily flows at Tocumwal) to compare pre-regulation (1908 - 1929) conditions with present (1981 - 2001) conditions.

This analysis determined:

- whether regulation has caused changes in the pattern of summer-autumn River Murray flows;
- whether regulation has caused changes in the pattern of summer-autumn Barmah Forest floods;
- which months in the summer-autumn period have experienced a significant increase in forest flooding.

This comparative analysis was facilitated by the construction of bar and line graphs.

The analysis of changes in the frequency of forest flooding involved consideration of different threshold Tocumwal flows at which forest flooding commences.

The analysis of the changes in the areal extent of forest flooding involved the use of the relationship derived by Bren *et. al.,* (1987).

4.4 Identification of Unseasonal Surface Flow Events (Chapter 6)

Different methods for identifying unseasonal surplus flow events were identified in the literature. Three of these methods were used to identify various characteristics related to unseasonal surplus flow events and frequency of forest flooding.

The results of these three methods were compared, and their degree of overlap evaluated.

The advantages and disadvantages of each method were outlined, and one method selected for use in further analysis.

4.5 Analysis of Increased System Flexibilty (Chaper 7)

This analysis quantified (through graphical representation) the (individual) effects of:

- increasing airspace at Yarrawonga; and
- limiting maximum River Murray flow at Tocumwal during December-April;

on:

- flooding frequency (proportion of days in season during which flooding occurs in the forest);
- number of events per season;
- event duration; and
- total surplus flow volume per season.

4.6 Economic Analysis (Chapter 8)

This analysis identified both market- and non-market costs and benefits. Given resource and data constraints, only selected costs and benefits were quantified. These were selected to provide:

- an “upper limit” indication of economic costs, or
- a “lower limit” indication of economic benefits

associated with:

- increasing air space at Lake Mulwala; and
- reducing the flowrate of the Murray between Yarrawonga and the Choke.

5. Historical Analysis

5.1 Overview

This section presents the data requirements, methodology, results and analysis of historical changes in the patterns of summer-autumn River Murray flows (at Tocumwal) and forest flooding. The purpose of the historical analysis is to define which months comprise the "summer-autumn period" during which regulation has increased flooding of the Barmah (and Millewa) Forest.

The historical analysis comprises two main parts. First, River Murray flow at Tocumwal is analysed on a month-by-month basis to compare present flows (1981 - 2001) to flows which occurred before regulation (1908 - 1929). Second, frequency and areal extent of forest flooding is analysed on a month-by-month basis to compare present patterns of forest flooding (1981 - 2001) to the pattern of forest flooding before regulation (1908 - 1929).

Refer to Appendix B for supporting documentation of the data analysis.

5.2 Data

The mean daily flows of the River Murray at Tocumwal from 2 January 1908 to 15 March 2001 were divided into flows occurring in the months of November, December, January, February, March, April and May respectively.

River Murray flow at Tocumwal was selected because it was identified by Bren *et. al.* (1987) as the most significant factor relating to the percentage flooded of the Barmah Forest. Various management plans and strategies also cite the flow at Tocumwal as indicative of the restrictive capacity of the Choke. A record of significant length (1908 - present) for mean daily flows is readily available for Tocumwal from RMW.

The months November - May were selected because this represents the widest range of months suggested in publications as the season in which rain rejections occur (DLWC 1996).

Key periods were identified to represent the intervals between successive, major changes to regulation of the Murray upstream of the forest. The following time periods were used in the analysis:

• 1908 - 1929	Before the construction of the Hume Dam;
• 1936 - 1960	After the construction of the Hume Dam, and before its enlargement;
• 1961 - 2001	After the enlargement of the Hume Dam;
• 1981 - 2001	"Present" level of regulation (representing current irrigation demand conditions).

The descriptive statistics for these periods for the months November - May are illustrated in Figure 5.1. Characteristic to all months is the reduction in standard deviation from 1908 - 1929 to 1981 - 2001, i.e. regulation has reduced the variability of flows.

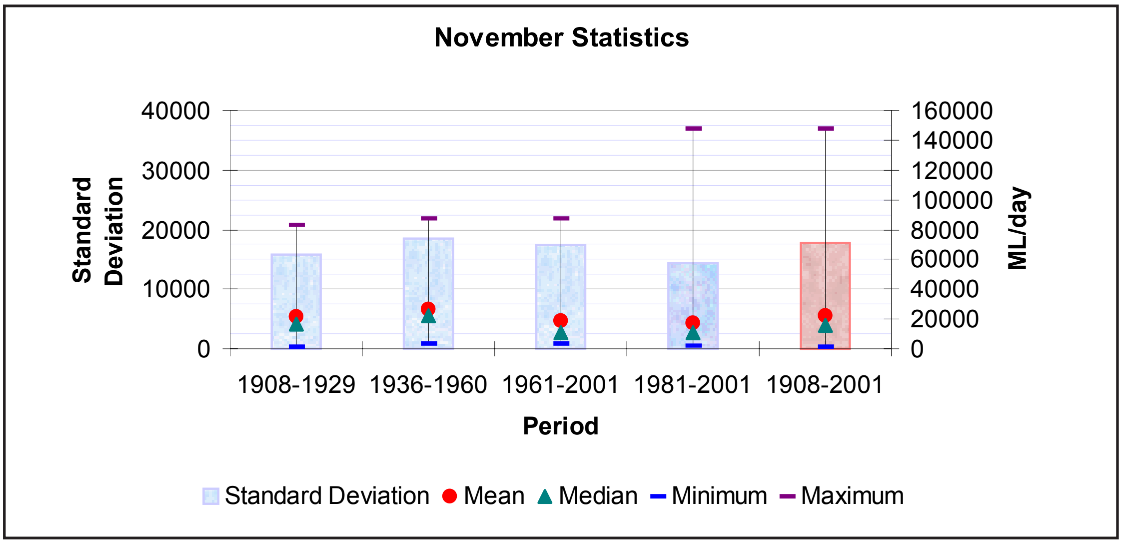


Figure 5.1 Descriptive Statistics

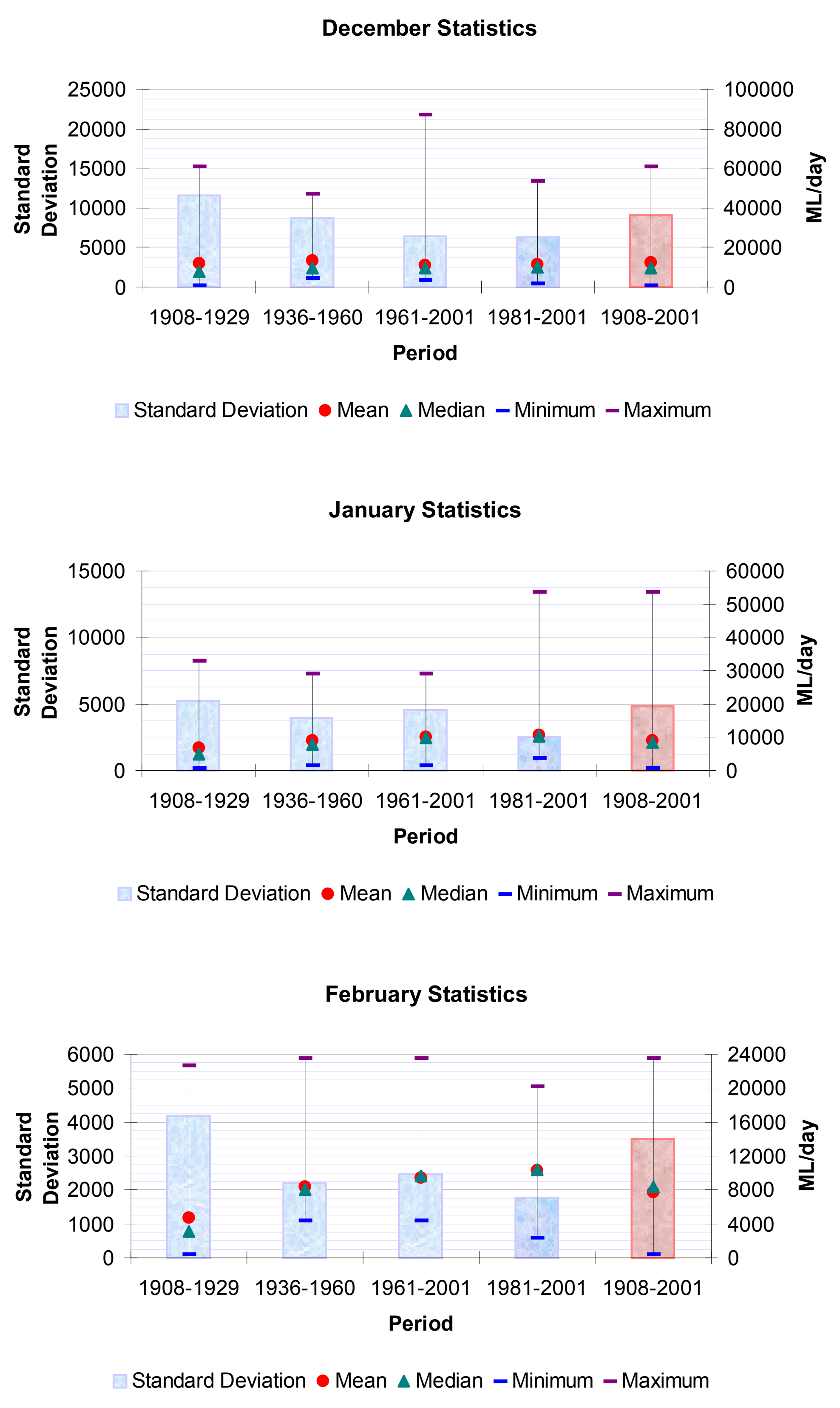


Figure 5.1 Descriptive Statistics (continued)

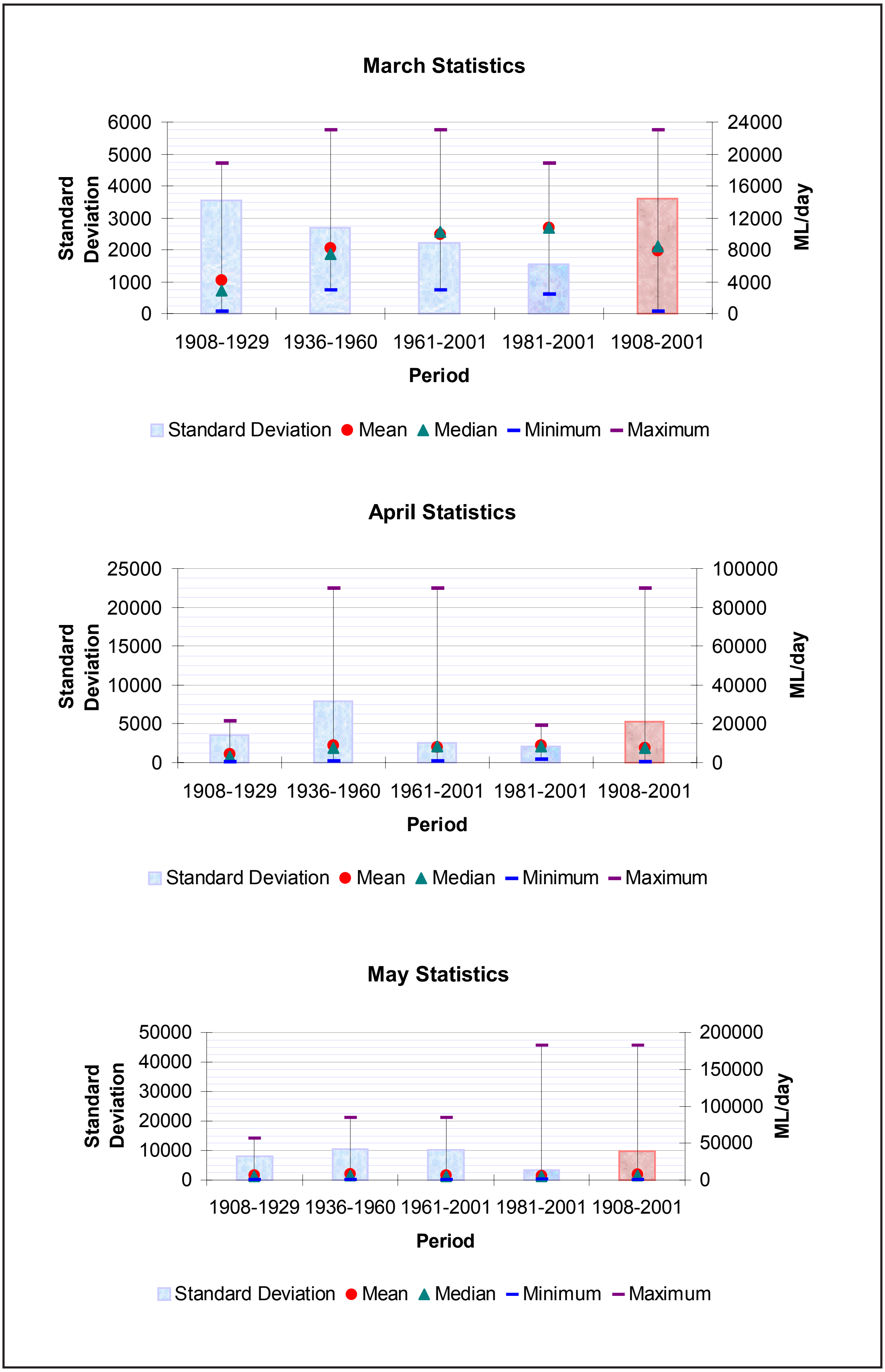


Figure 5.1 Descriptive Statistics (continued)

5.3 River Murray Flow at Tocumwal

5.3.1 Methodology

For each month between November - May, three graphs were constructed to present how the pattern of flows has changed with regulation. Each of these graphs divided the data into the time periods outlined in Section 5.2.

1. Flow Duration Curve

The flow duration curves present plots of daily flow (ML/day) against percentage of time exceeded. They illustrate the cumulative distribution of flows, and provide indication of how the pattern of flows has changed with regulation.

2. Frequency Column Graph

The frequency column graphs provide alternative representations of how the pattern of flows has changed with regulation. For each of the flows 0 - 5000, 5000 - 10,000, 10,000 - 15,000 (etc.) ML/day, a frequency column graph illustrates the frequency of daily flows which fall into each category, as a clustered column graph.

3. Stacked Column Graph

Stacked column graphs compare how the pattern of flows below 20,000 ML/day has changed with regulation. For each of the time periods, a stacked column graph illustrates the proportion of days in which flow was between 2000 - 4000, 4000 - 6000, 6000 - 8000, 8000 - 10,000, 10,000 - 12,000, 12,000 - 14,000, 14,000 - 16,000, 16,000 - 18,000 and 18,000 - 20,000 ML/day.

5.3.2 November

Results are summarised in Figures 5.2 to 5.4.

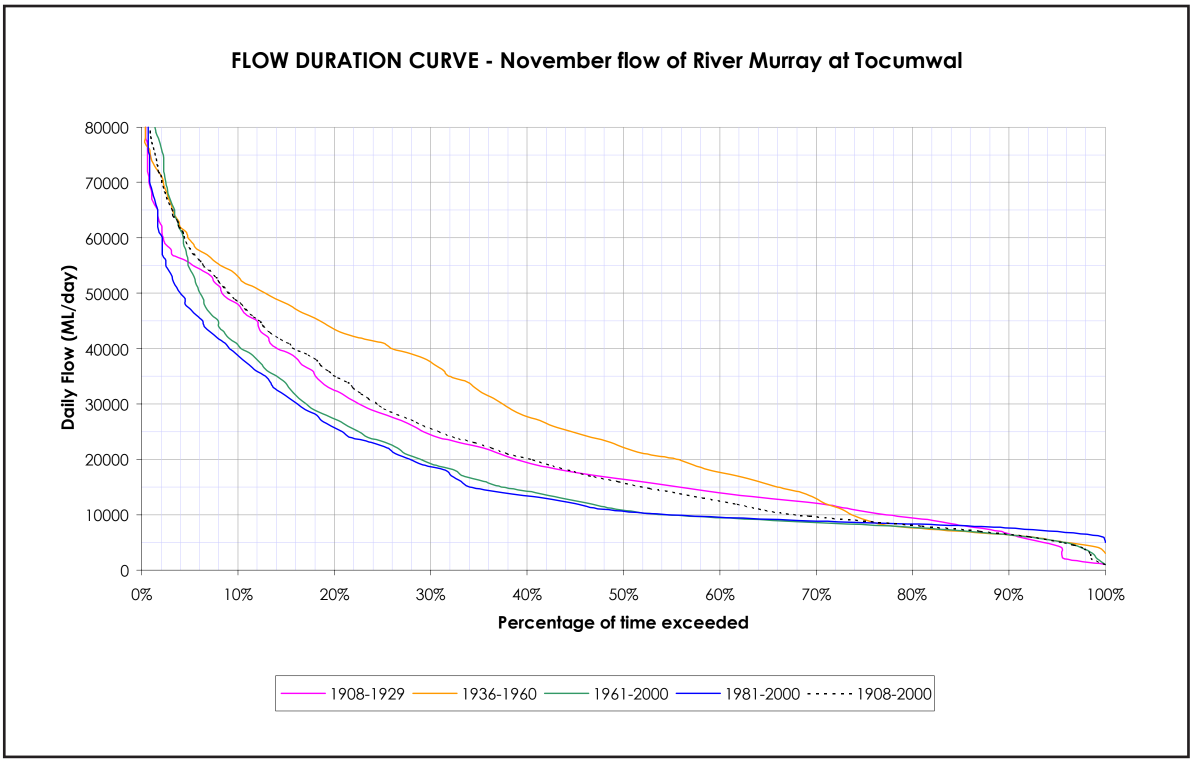


Figure 5.2 Historical Flow Analysis: November: Flow Duration Curve

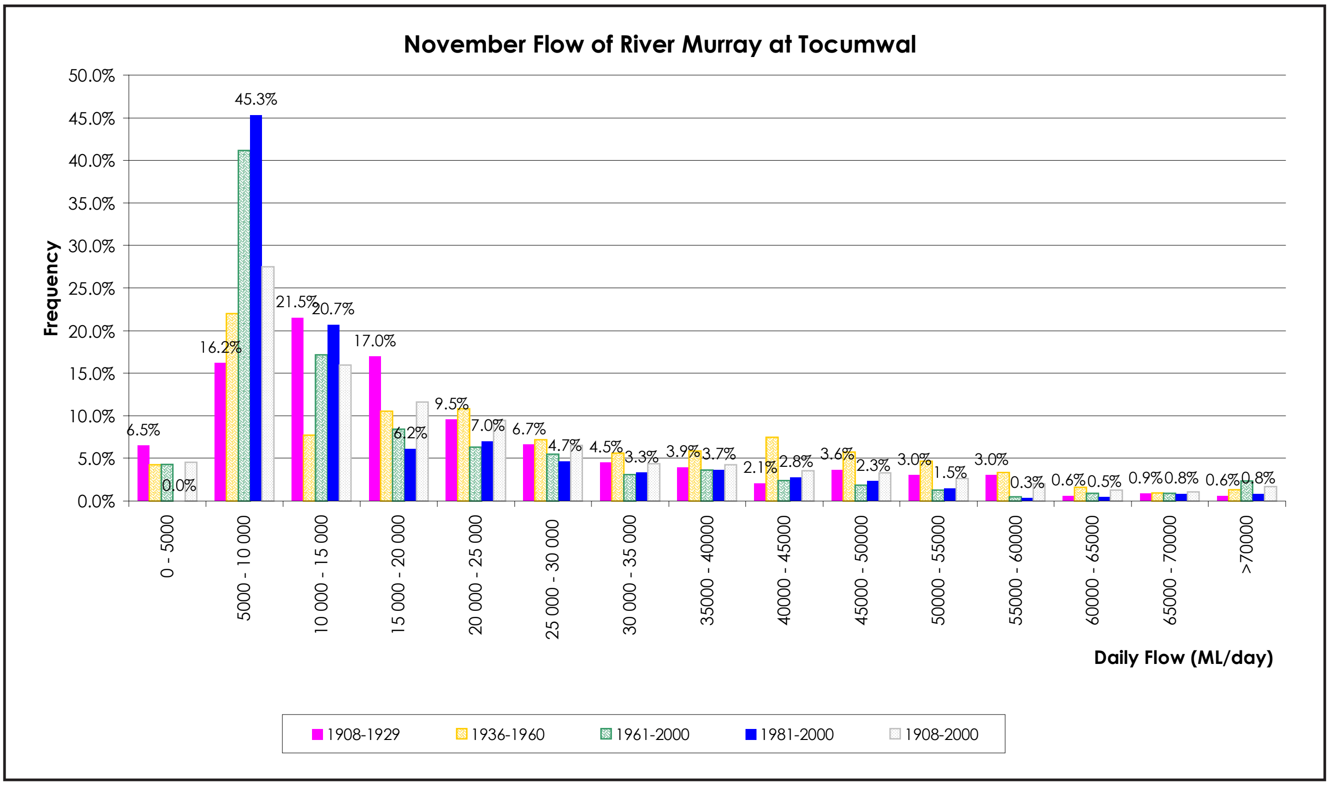


Figure 5.3 Historical Flow Analysis: November: Frequency Column Graph

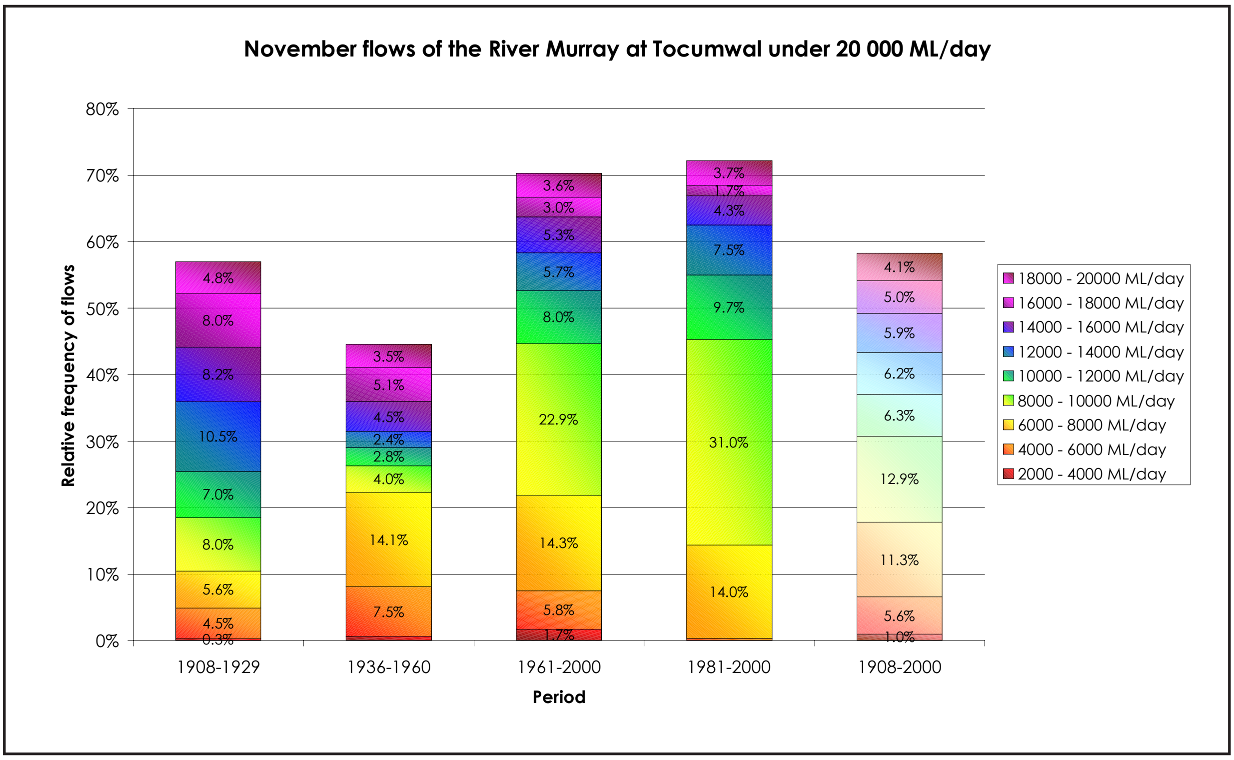


Figure 5.4 Historical Flow Analysis: November: Stacked Column Graph

Analysis

November flows are characterised by an overall DECREASE in the proportion of flows OVER 10,000 ML/day. The following describes changes from the periods 1908 - 1929 to 1981 - 2000.

The flow duration curves illustrate the following changes due to regulation:

- An increase in the proportion of daily flows that exceed 5000 ML/day (from 93.5% to 100%);
- A decrease in the proportion of daily flows that exceed 10,000 ML/day (from 77.3% to 54.7%);
- A decrease in the proportion of daily flows that exceed 20,000 ML/day (from 38.8% to 27.8%).

The frequency column graph illustrates the following changes due to regulation:

- A decrease in the proportion of flows under 5000 ML/day (from 6.5% to 0.0%);
- An increase in the proportion of flows between 5000 and 15 000 ML/day (from 16.2% to 45.3%);
- A decrease in the proportion of flows over 15,000 ML/day (from 77.3% to 54.7%).

The stacked column graphs illustrate the following changes due to regulation:

- A decrease in the proportion of flows under 6000 ML/day (from 9.1% to 0.3%) ;
- An increase in the proportion of flows between 6000 and 12,000 ML/day (from 20.6% to 54.7%);
- A decrease in the proportion of flows over 12,000 ML/day (from 70.3% to 45.0%).

In summary, regulation has reduced the variability of daily flows in November. In particular, it has decreased the frequency of flows under 6000 ML/day and over 12,000 ML/day, with flows more likely to lie between 6000 and 12,000 ML/day. Present flows are less likely to be over 8000 or 10,000 ML/day than those before regulation.

5.3.3 December

Results are summarised in Figures 5.5 to 5.7.

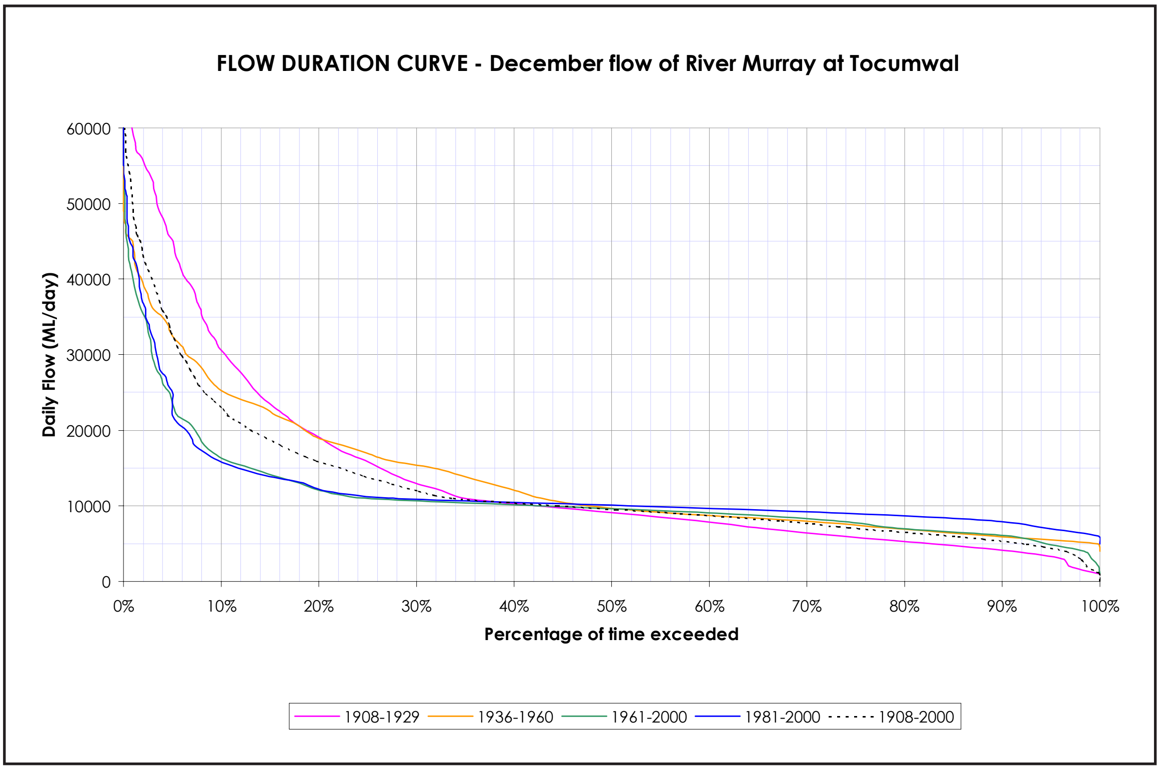


Figure 5.5 Historical flow analysis: December: Flow Duration Curve

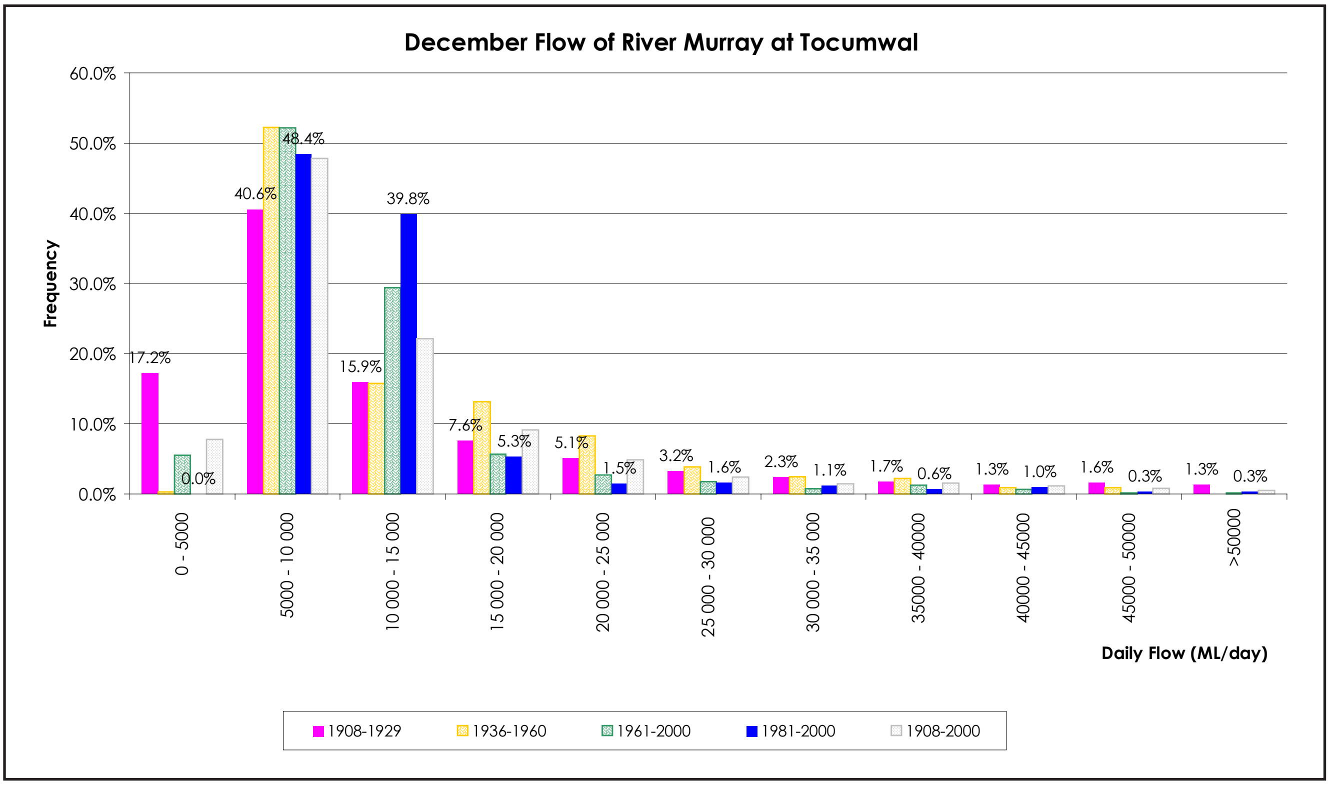


Figure 5.6 Historical Flow Analysis: December: Frequency Column Graph

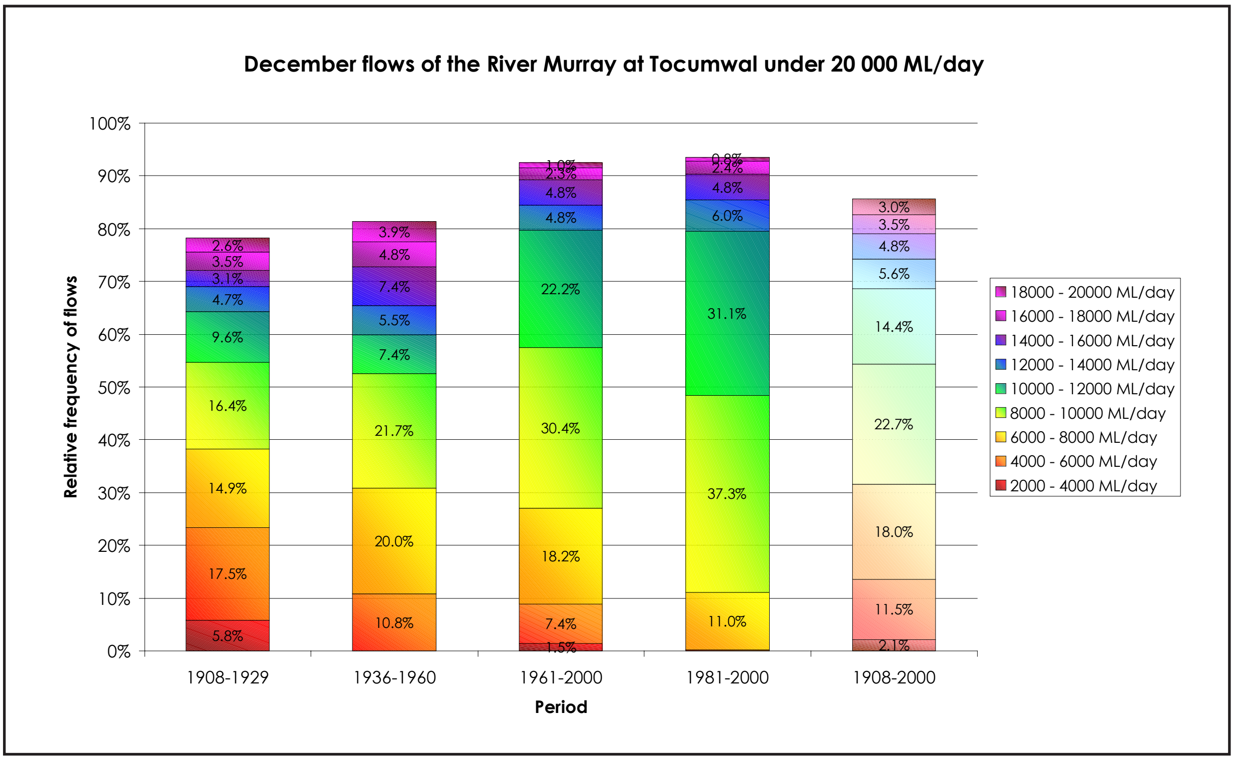


Figure 5.7 Historical Flow Analysis: December: Stacked Column Graph

Analysis

December flows are characterised by an overall INCREASE in the proportion of flows OVER 10,000 ML/day. The following describes changes from the periods 1908 - 1929 to 1981 - 2000.

The flow duration curves illustrate the following changes due to regulation:

- An increase in the proportion of daily flows that exceed 5000 ML/day (from 82.8% to 100%);
- An increase in the proportion of flows that exceed 10,000 ML/day (from 42.2% to 51.5%);
- A decrease in the proportion of flows that exceed 20,000 ML/day (from 18.7% to 6.5%);

The frequency column graph illustrates the following changes due to regulation:

- A decrease in the proportion of flows under 5000 ML/day (from 17.2% to 0.0%);
- An increase in the proportion of flows between 5000 and 15,000 ML/day (from 56.5% to 88.2%);
- A decrease in the proportion of flows over 15,000 ML/day (from 26.3% to 11.8%);

The stacked column graphs illustrate the following changes due to regulation:

- A decrease in the proportion of flows under 8000 ML/day (from 41.3% to 11.1%);
- An increase in the proportion of flows between 8000 and 16,000 ML/day (33.9% to 79.2%);
- A decrease in the proportion of flows over 16,000 ML/day (from 24.8% to 9.7%)

In summary, regulation has reduced the variability of daily flows in December. In particular, it has decreased the frequency of flows under 8000 ML/day and over 16,000 ML/day, with flows more likely to lie between 8000 and 16,000 ML/day. Present flows are more likely to be over 10,000 ML/day than those before regulation, but less likely to be over 12,000 ML/day.

5.3.4 January

Results are summarised in Figures 5.8 to 5.10.

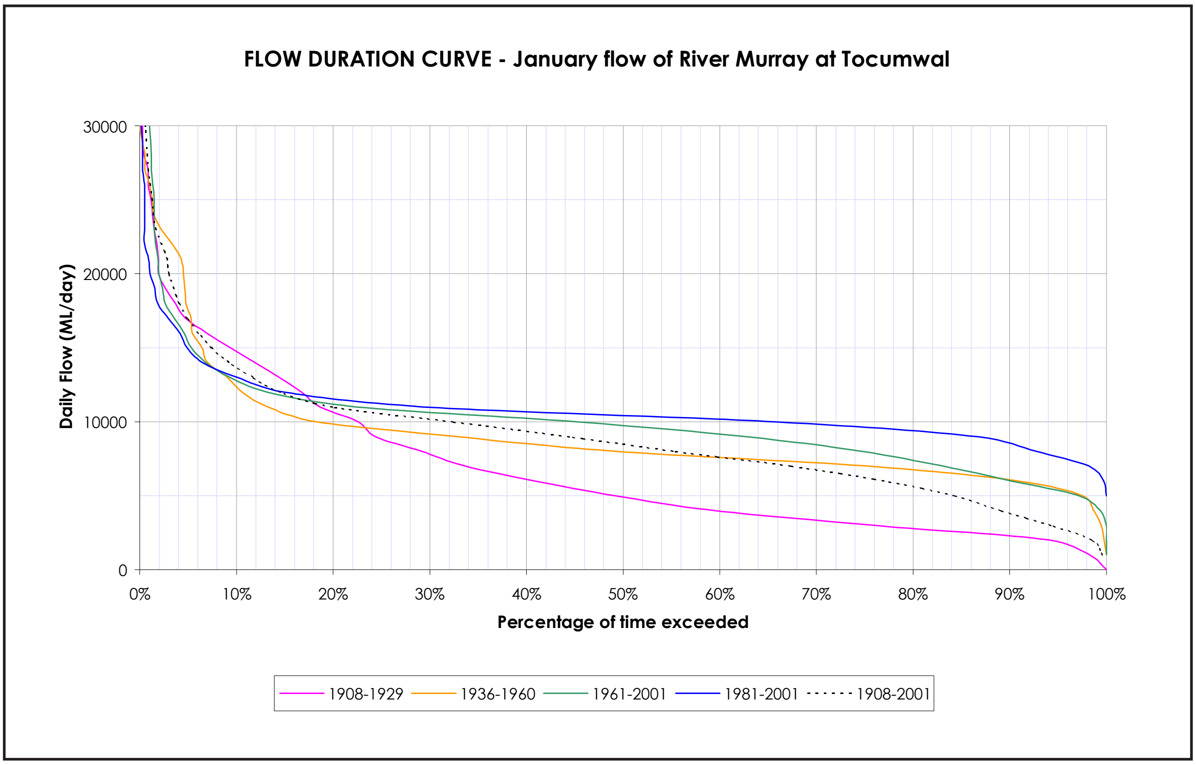


Figure 5.8 Historical Flow Analysis: January: Flow Duration Curve

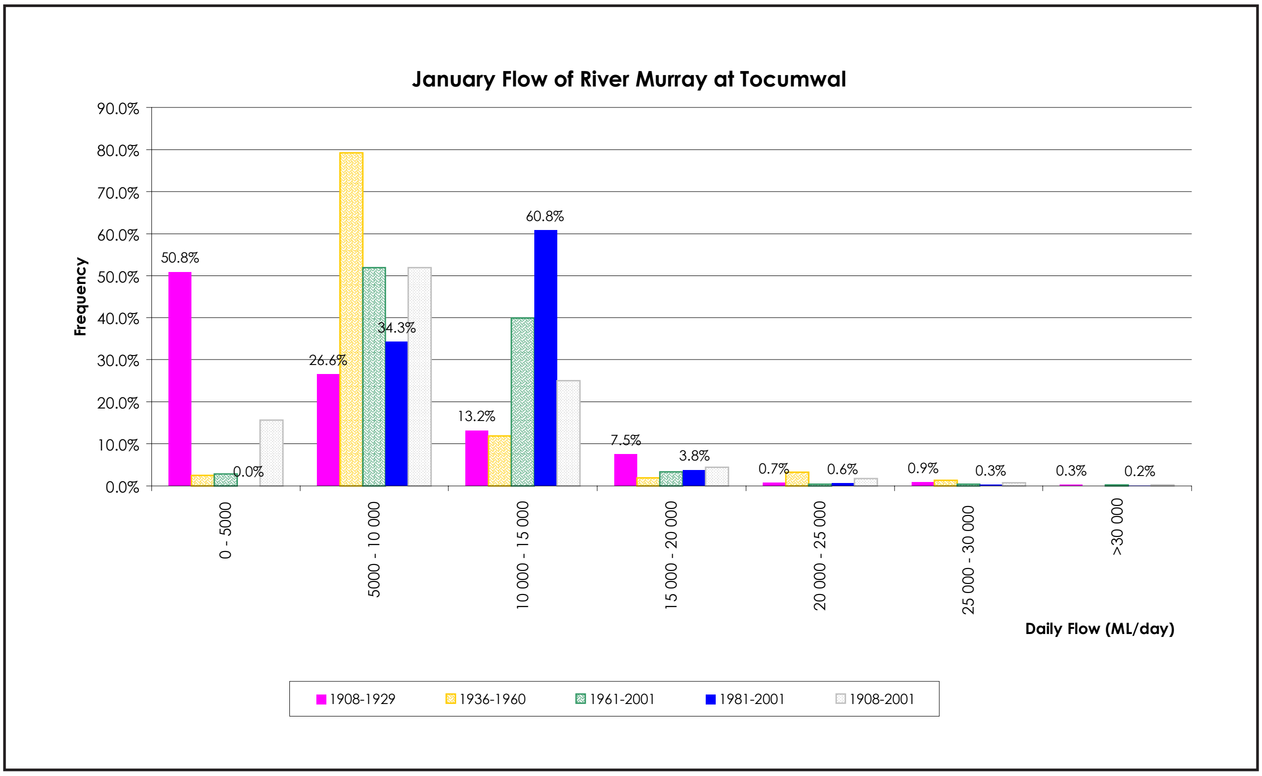


Figure 5.9 Historical Flow Analysis: January: Frequency Column Graph

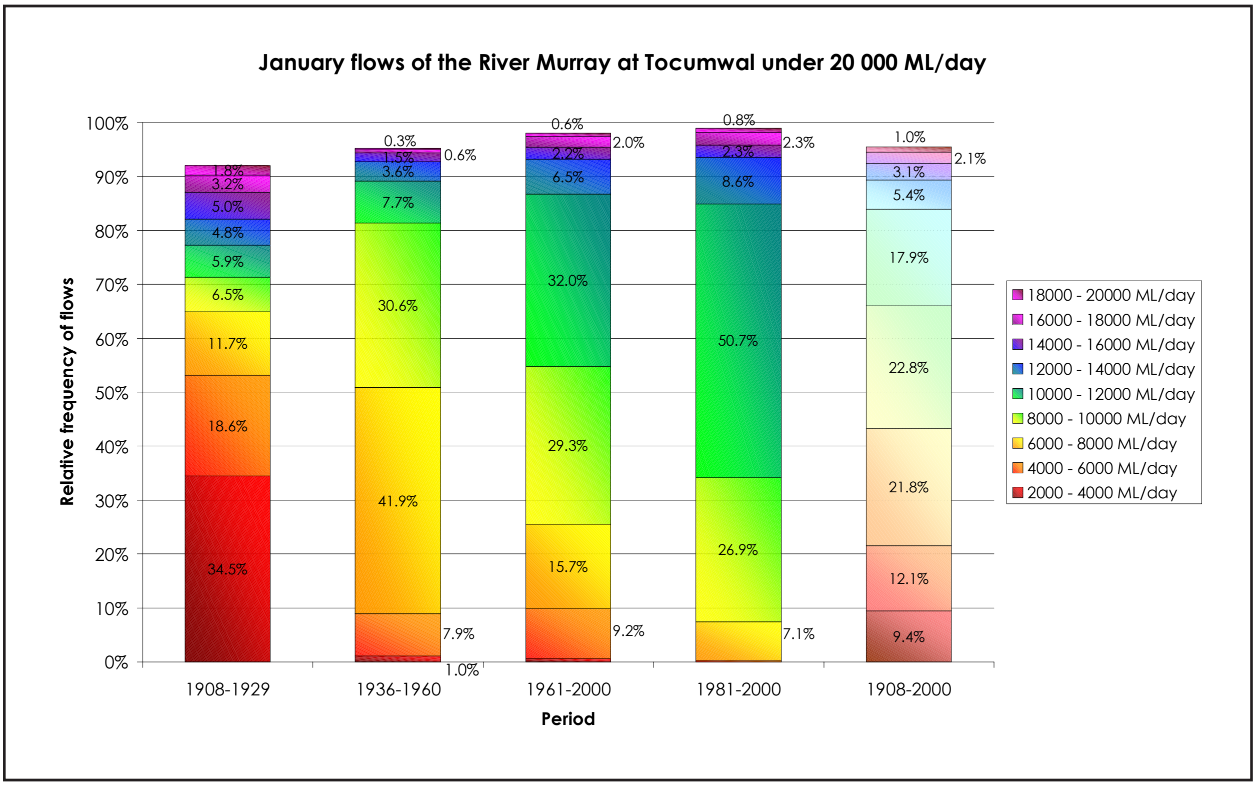


Figure 5.10 Historical Flow Analysis: January: Stacked Column Graph

Analysis

January flows are characterised by an overall INCREASE in the proportion of flows OVER 10,000 ML/day. The following describes changes from the periods 1908 - 1929 to 1981 - 2000.

The flow duration curves illustrate the following changes due to regulation:

- An increase in the proportion of daily flows that exceed 5000 ML/day (from 49.2% to 100%);
- An increase in the proportion of flows that exceed 10,000 ML/day (from 22.6% to 65.7%);
- A decrease in the proportion of flows that exceed 20,000 ML/day (from 1.9% to 1.1%);

The frequency column graph illustrates the following changes due to regulation:

- A decrease in the proportion of flows under 5000 ML/day (from 50.8% to 0.0%);
- An increase in the proportion of flows between 5000 and 15,000 ML/day (from 39.5% to 95.1%);
- A decrease in the proportion of flows over 15,000 ML/day (from 9.7% to 4.9%);

The stacked column graphs illustrate the following changes due to regulation:

- A decrease in the proportion of flows under 8000 ML/day (from 70.9% to 7.4%);
- An increase in the proportion of flows between 8000 and 14,000 ML/day (17.2% to 86.1%);
- A decrease in the proportion of flows over 14,000 ML/day (from 11.9% to 6.5%).

In summary, regulation has reduced the variability of daily flows in January. In particular, it has decreased the frequency of flows under 8000 ML/day and over 14,000 ML/day, with flows more likely to lie between 8000 and 14,000 ML/day. Present flows are more likely to be over 10,000 ML/day than those before regulation, but less likely to be over 12,000 ML/day.

5.3.5 February

Results are summarised in Figures 5.11 to 5.13.

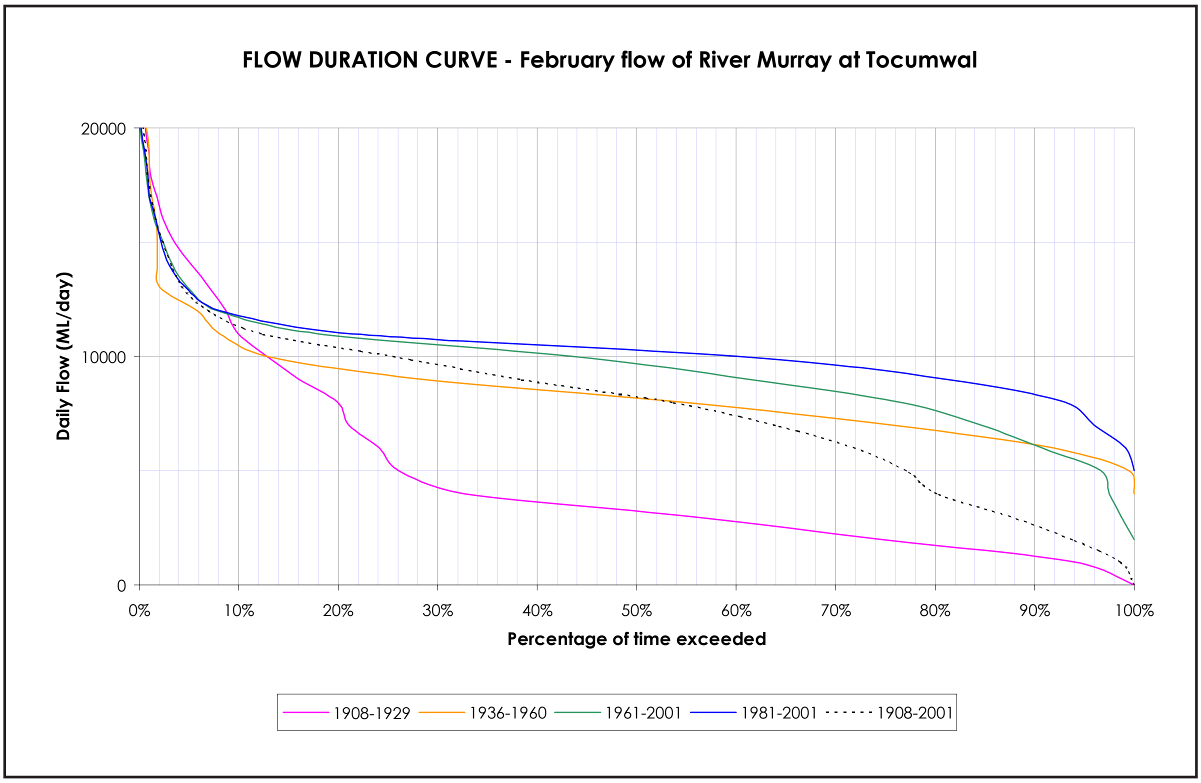


Figure 5.11 Historical Flow Analysis: February: Flow Duration Curve

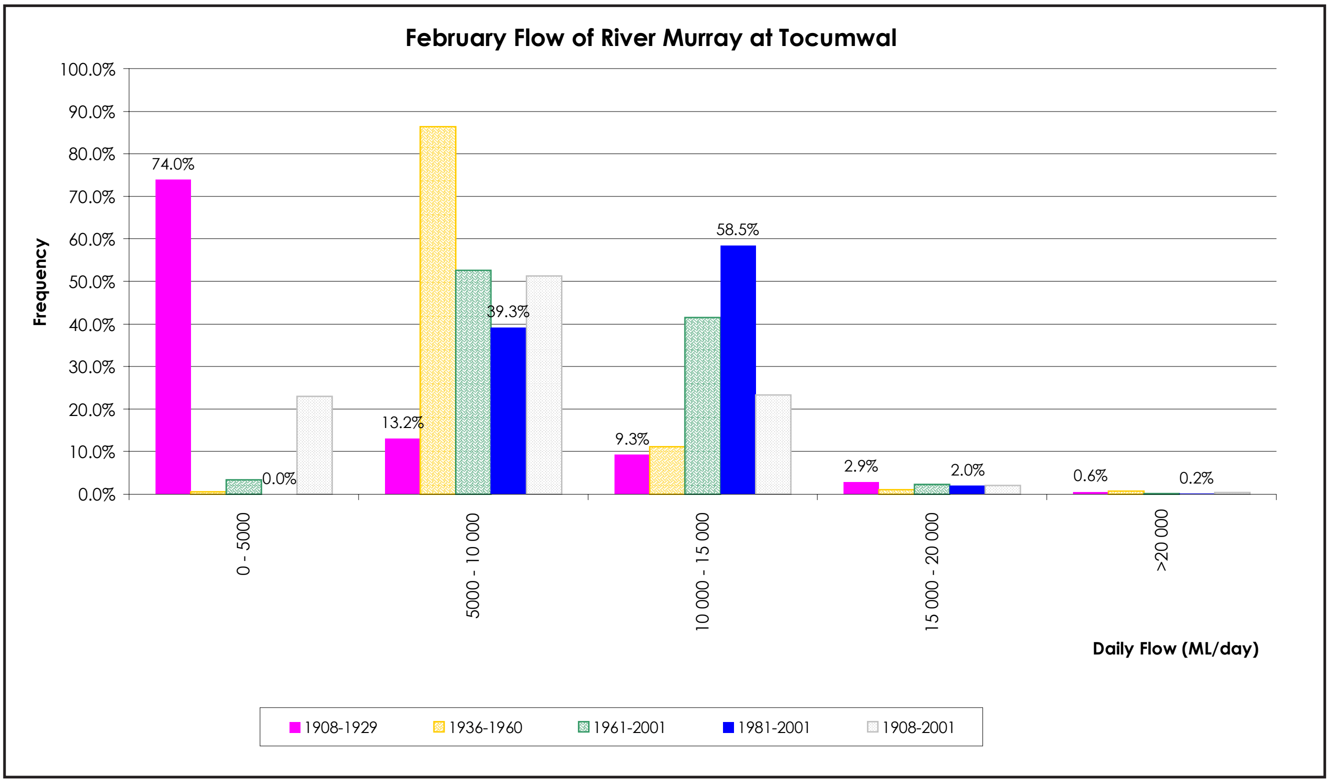


Figure 5.12 Historical Flow Analysis: February: Frequency Column Graph

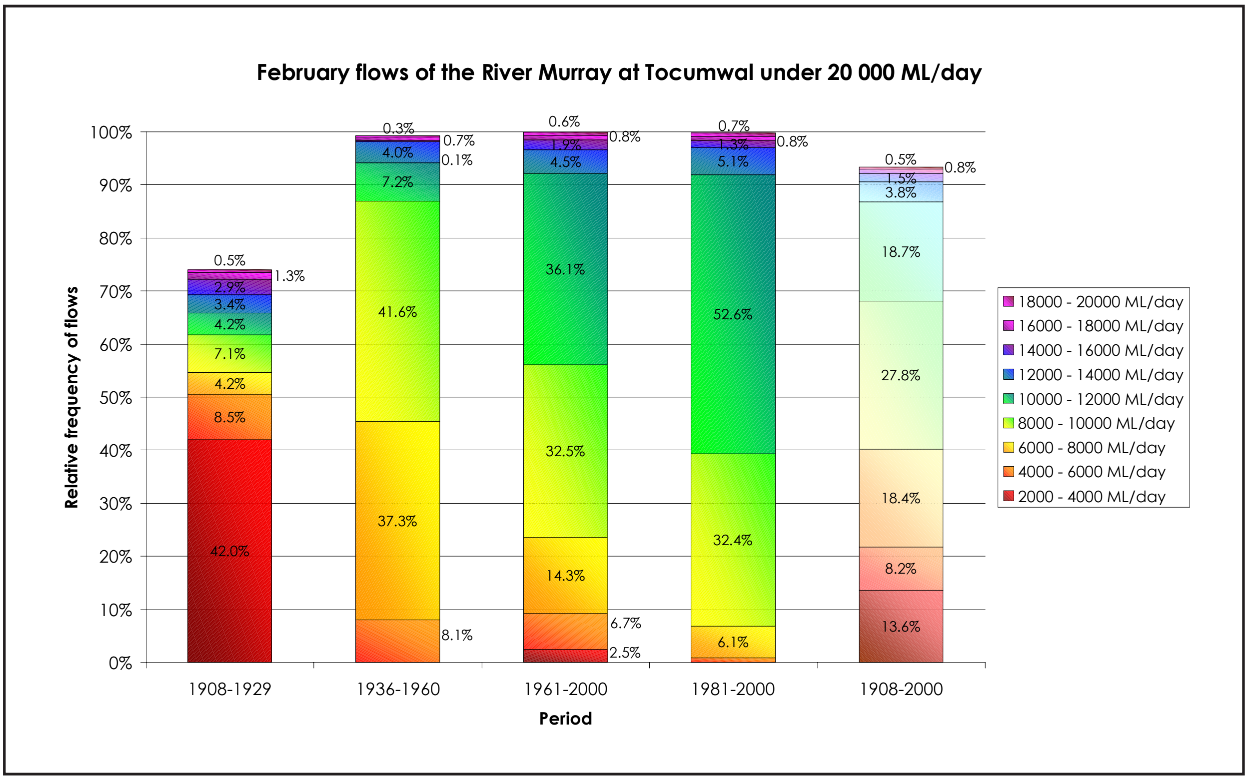


Figure 5.13 Historical Flow Analysis: February: Stacked Column Graph

Analysis

February flows are characterised by an overall INCREASE in the proportion of flows OVER 10,000 ML/day. The following describes changes from the periods 1908 - 1929 to 1981 - 2000.

The flow duration curves illustrate the following changes due to regulation:

- An increase in the proportion of daily flows that exceed 5000 ML/day (from 26.0% to 100%);
- An increase in the proportion of flows that exceed 10,000 ML/day (from 12.9% to 60.7%);
- A decrease in the proportion of flows that exceed 20,000 ML/day (from 0.6% to 0.2%);

The frequency column graph illustrates the following changes due to regulation:

- A decrease in the proportion of flows under 5000 ML/day (from 74.0% to 0.0%);
- An increase in the proportion of flows between 5000 and 15,000 ML/day (from 22.5% to 97.8%);
- A decrease in the proportion of flows over 15,000 ML/day (from 3.5% to 2.2%);

The stacked column graphs illustrate the following changes due to regulation:

- A decrease in the proportion of flows under 6000 ML/day (from 75.9% to 0.8%);
- An increase in the proportion of flows between 8000 and 12,000 ML/day (15.4% to 91.1%);
- A decrease in the proportion of flows over 12,000 ML/day (from 8.7% to 8.1%).

In summary, regulation has reduced the variability of daily flows in February. In particular, it has decreased the frequency of flows under 6000 ML/day and over 12,000 ML/day, with flows more likely to lie between 6000 and 12,000 ML/day. Present flows are more likely to be over 8000 or 10,000 ML/day than those before regulation.

5.3.6 March

Results are summarised in Figures 5.14 to 5.16.

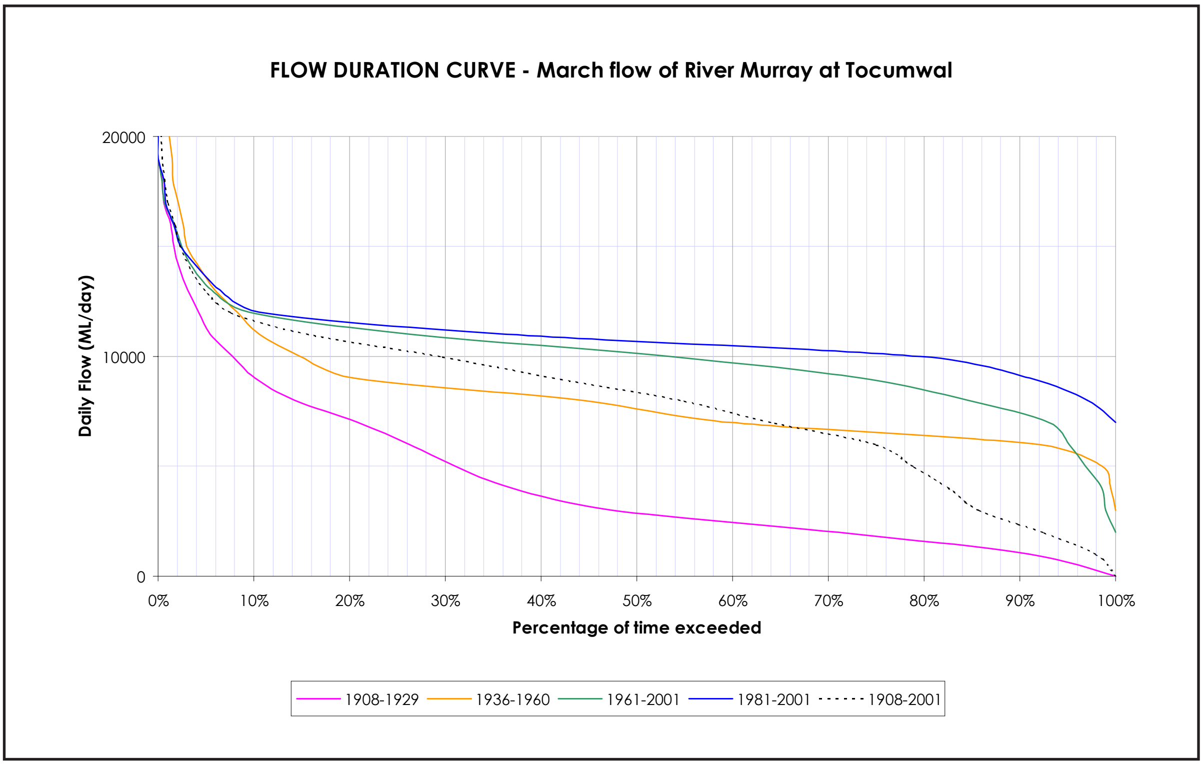


Figure 5.14 Historical Flow Analysis: March: Flow Duration Curve

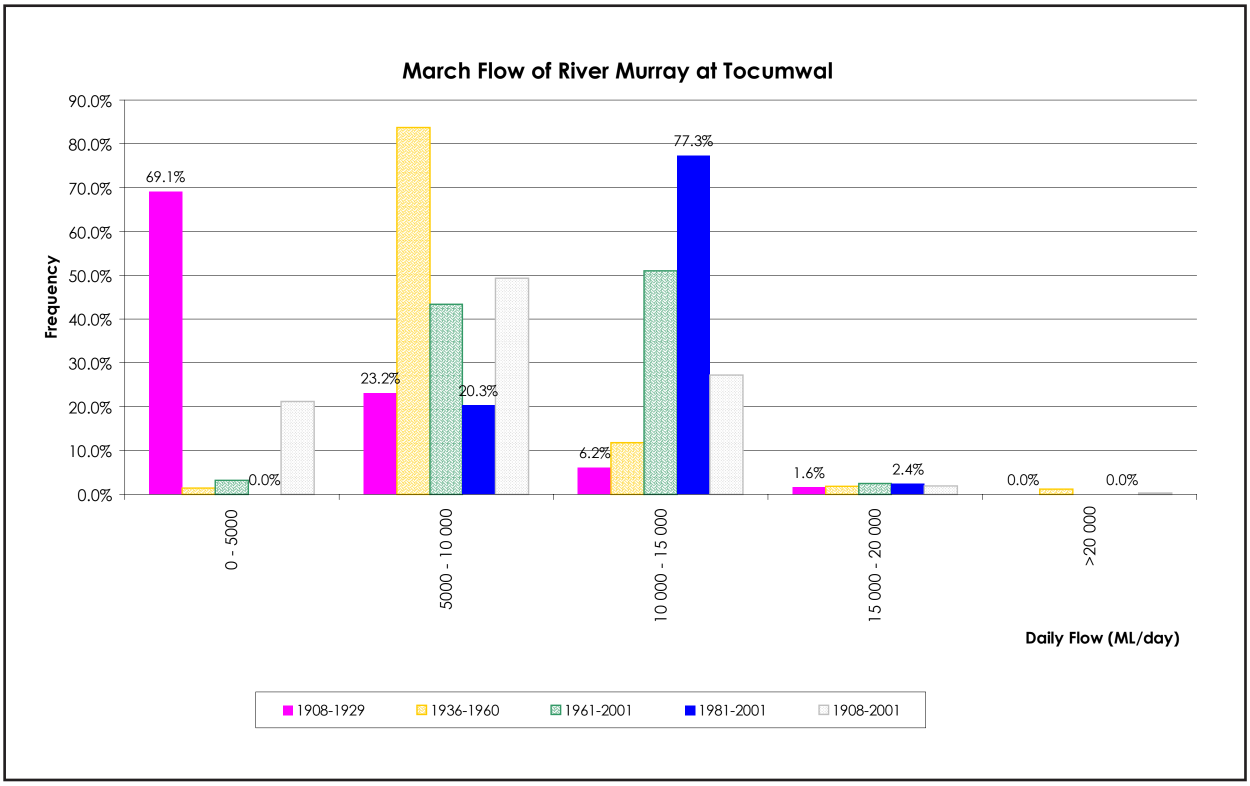


Figure 5.15 Historical Flow Analysis: March: Frequency Column Graph

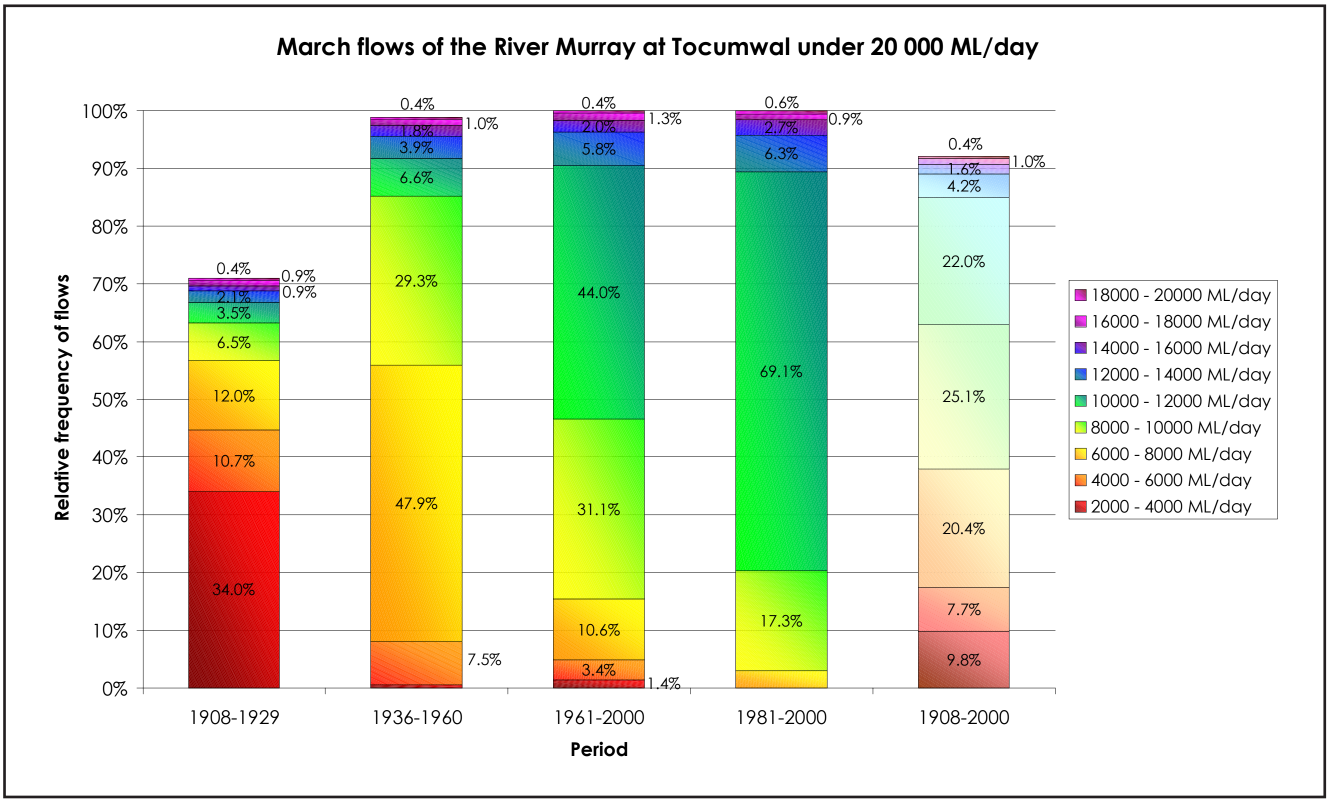


Figure 5.16 Historical Flow Analysis: March: Stacked Column Graph

Analysis

March flows are characterised by an overall INCREASE in the proportion of flows OVER 10,000 ML/day. The following describes changes from the periods 1908 - 1929 to 1981 - 2000.

The flow duration curves illustrate the following changes due to regulation:

- An increase in the proportion of daily flows that exceed 7000 ML/day (from 20.8% to 100%);
- An increase in the proportion of flows that exceed 10,000 ML/day (from 7.8% to 79.7%);
- No change in the proportion of flows that exceed 20,000 ML/day (from 0.0% to 0.0%);

The frequency column graph illustrates the following changes due to regulation:

- A decrease in the proportion of flows under 10,000 ML/day (from 92.3% to 20.3%);
- An increase in the proportion of flows over 10,000 ML/day (from 7.7% to 79.7%).

The stacked column graphs illustrate the following changes due to regulation:

- A decrease in the proportion of flows under 8000 ML/day (from 85.8% to 3.8%);
- An increase in the proportion of flows over 8000 ML/day, especially from 10,000 - 12,000 ML/day (3.5% to 69.1%).

In summary, regulation has reduced the variability of daily flows in March. In particular, it has decreased the frequency of flows under 8000 ML/day and increased those over 8000 ML/day, with a large increase in the likelihood of flows falling between 10,000 and 12,000 ML/day. Present flows are more likely to be over 10,000 ML/day than those before regulation, but less likely to be over 12,000 ML/day.

5.3.7 April

Results are summarised in Figures 5.17 to 5.19.

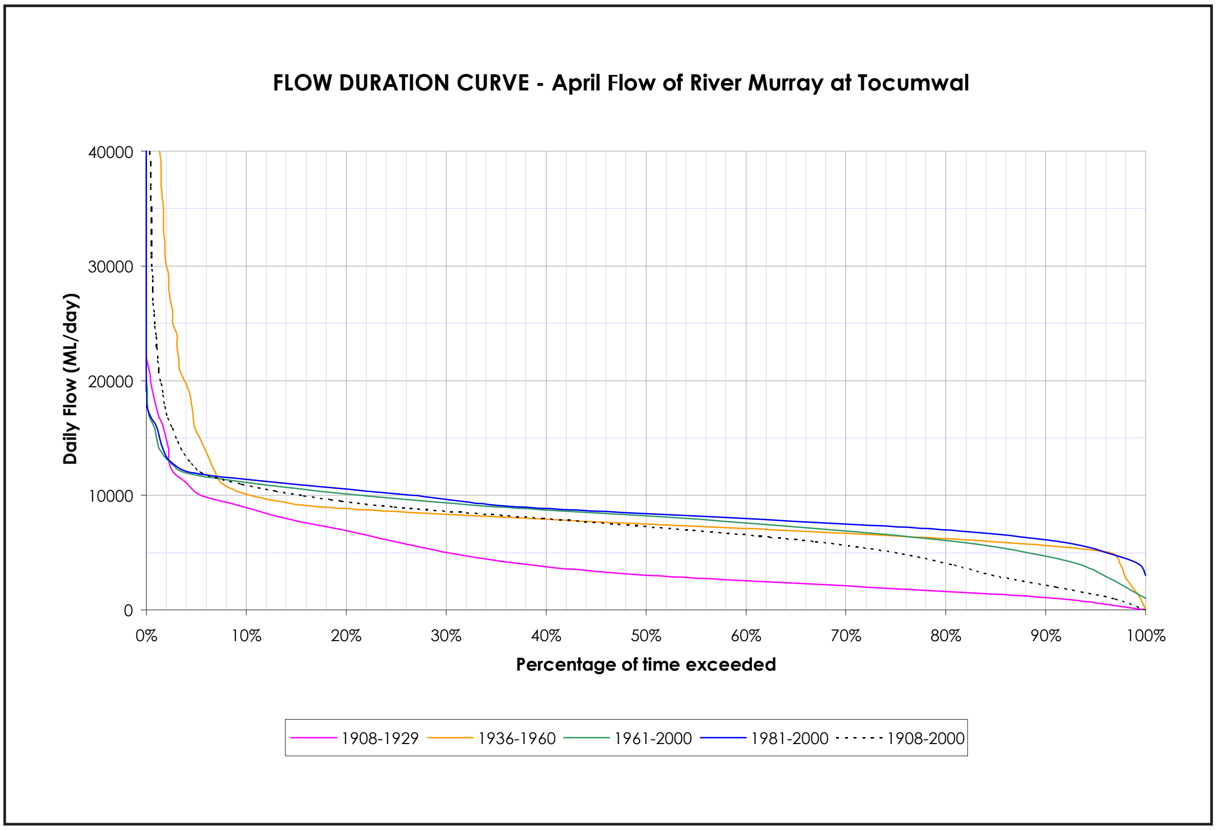


Figure 5.17 Historical Flow Analysis: April: Flow Duration Curve

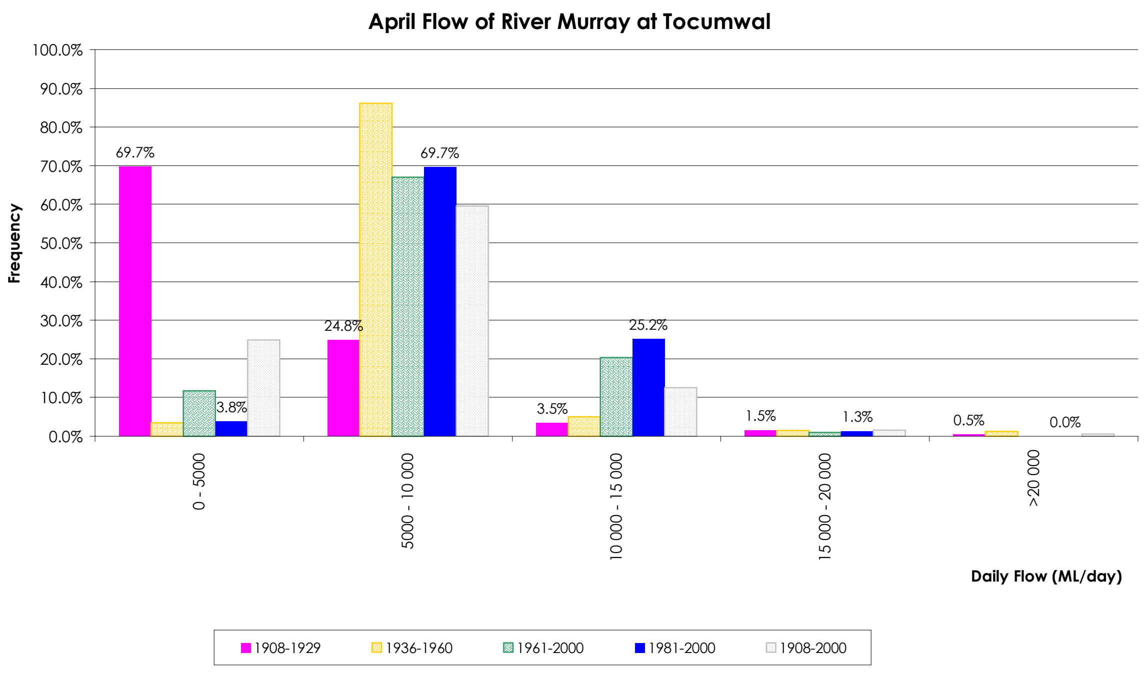


Figure 5.18 Historical Flow Analysis: April: Frequency Column Graph

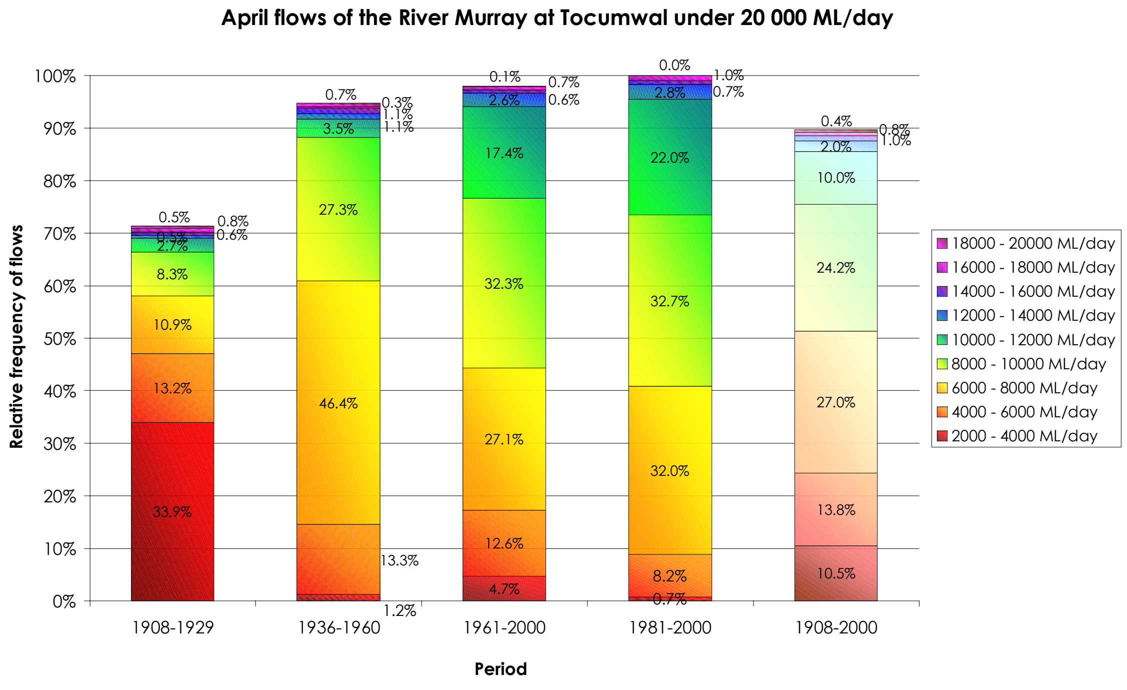


Figure 5.19 Historical Flow Analysis: April: Stacked Column Graph

Analysis

April flows are characterised by an overall INCREASE in the proportion of flows OVER 10,000 ML/day. The following describes changes from the periods 1908 - 1929 to 1981 - 2000.

The flow duration curves illustrate the following changes due to regulation:

- An increase in the proportion of daily flows that exceed 3000 ML/day (from 50.0% to 100%);
- An increase in the proportion of flows that exceed 10,000 ML/day (from 5.5% to 26.5%);
- No change in the proportion of flows that exceed 20,000 ML/day (from 0.0% to 0.0%);

The frequency column graph illustrates the following changes due to regulation:

- A decrease in the proportion of flows under 5000 ML/day (from 69.7% to 3.8%);
- An increase in the proportion of flows over 5000 ML/day.

The stacked column graphs illustrate the following changes due to regulation:

- A decrease in the proportion of flows under 6000 ML/day (from 75.3% to 8.8%);
- An increase in the proportion of flows over 6000 ML/day.

In summary, regulation has reduced the variability of daily flows in April. In particular, it has decreased the frequency of flows under 6000 ML/day. Present flows are more likely to be over 10,000 ML/day than those before regulation.

5.3.8 May

Results are summarised in Figures 5.20 to 5.22.

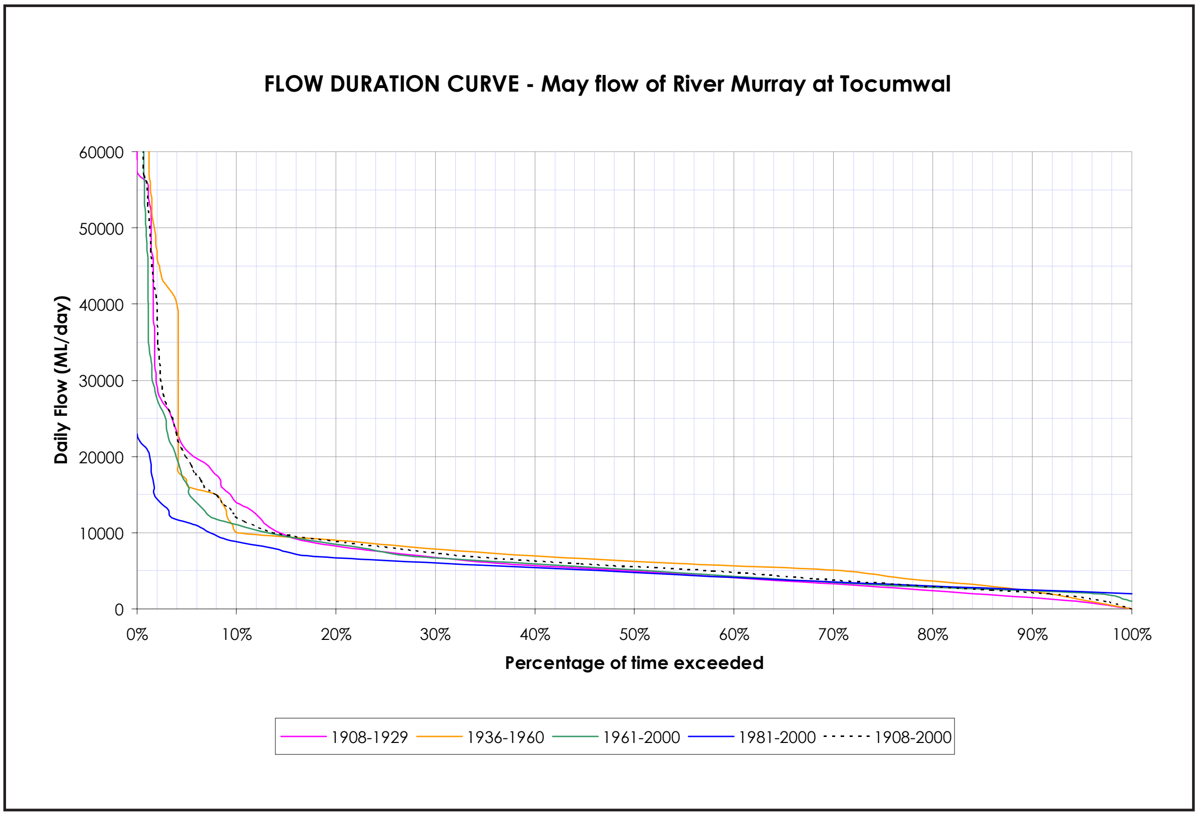


Figure 5.20 Historical Flow Analysis: May: Flow Duration Curve

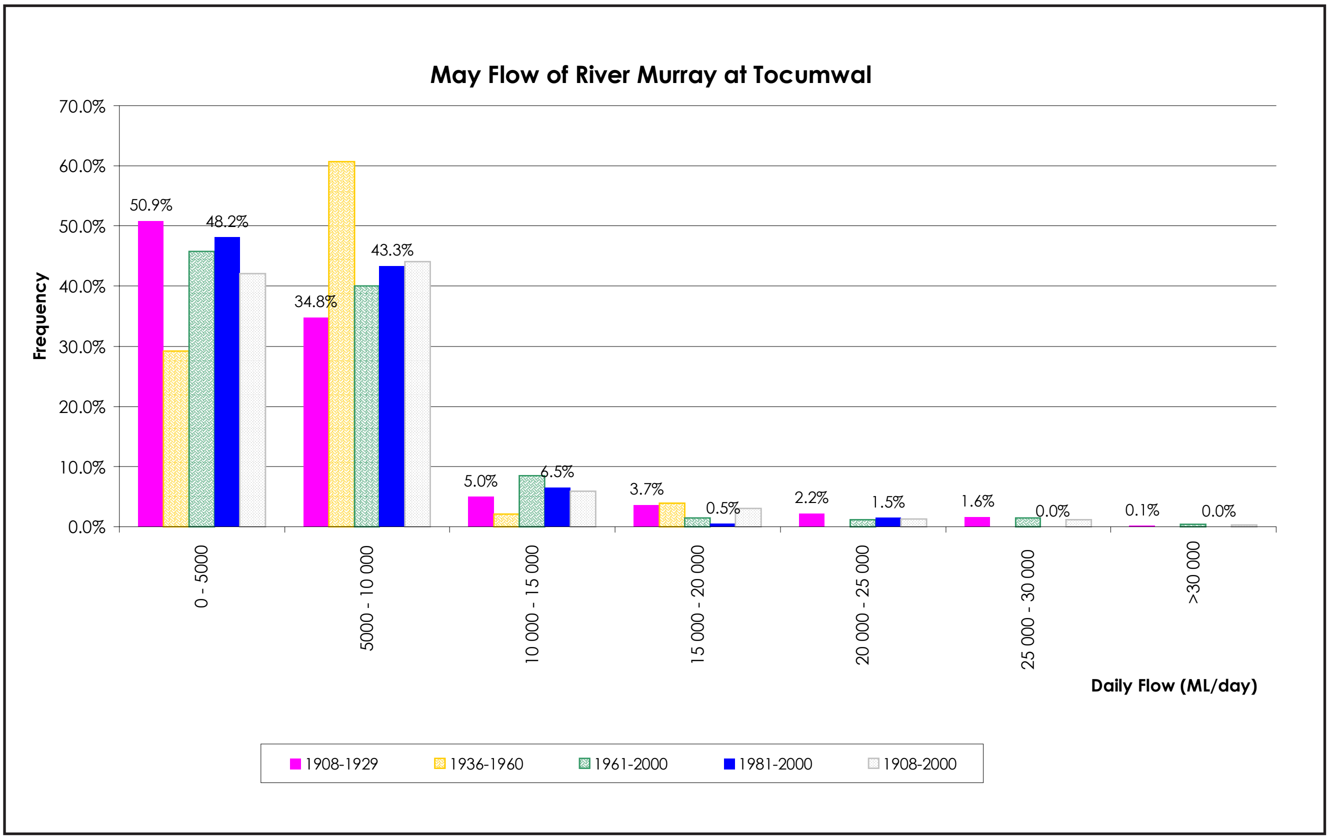


Figure 5.21 Historical Flow Analysis: May: Frequency Column Graph

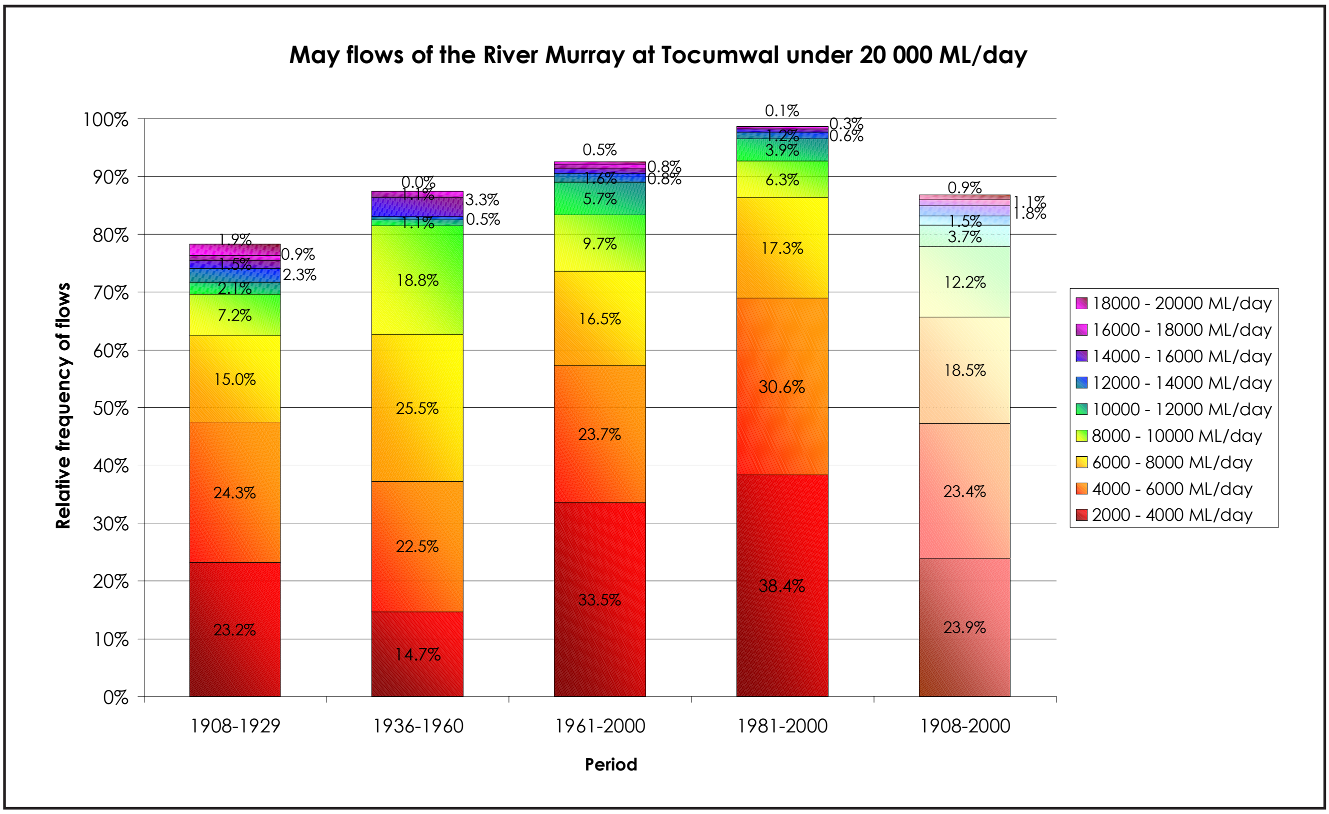


Figure 5.22 Historical Flow Analysis: May: Stacked Column Graph

Analysis

May flows are characterised by an overall DECREASE in the proportion of flows OVER 10,000 ML/day. The following describes changes from the periods 1908 - 1929 to 1981 - 2000.

The flow duration curves illustrate the following changes due to regulation:

- An increase in the proportion of daily flows that exceed 2000 ML/day (from 84% to 100%);
- An decrease in the proportion of flows that exceed 10,000 ML/day (from 14.4% to 7.4%);
- A decrease in the proportion of flows that exceed 20,000 ML/day (from 5.7% to 1.3%);

The frequency column graph illustrates the following changes due to regulation:

- A decrease in the proportion of flows under 5000 ML/day (from 50.9% to 48.2%);
- An increase in the proportion of flows over 5000 ML/day.

The stacked column graphs illustrate the following changes due to regulation:

- An increase in the proportion of flows under 8000 ML/day (from 78.4% to 86.3%);
- A decrease in the proportion of flows over 8000 ML/day.

In summary, regulation has reduced the variability of daily flows in May. In particular, it has increase the frequency of flows under 8000 ML/day and decreased the likelihood of flows over 8000 ML/day.. Present flows are less likely to be over 10,000 ML/day than those before regulation.

5.3.9 Summary

The main findings of the flow analysis are (see Table 5.1):

- Flows in all months have lower variability now than before regulation;
- November and May flows are characterised by a DECREASE in the occurrence of flows over 10,000 ML/day, whereas December - April flows are characterised by an INCREASE in the occurrence of flows over 10,000 ML/day, due to regulation;
- November, December, January and February flows are characterised by a decrease in the occurrence of low flows, an increase in the occurrence of medium flows, and a decrease in the occurrence of high flows, due to regulation;

Table 5.1 Summary of Flow Changes for Months November to May 1908 - 1929 and 1981 - 2000

Month	**Mean**		**Variability (std. dev.)**		**Flow range of increased likelihood (ML/day)**	**Proportion of flows in range**		**Proportion of flows > 10,000 ML/day**		**Proportion of flows 10,000 - 12,000 ML/day**	
	<1929	**>1980**	**<1929**	**>1980**		**<1929**	**>1980**	**>1929**	**>1980**	**<1929**	**>1980**
NOV	21522	17537	15802	14327	6000 - 12 000	20.6%	54.7%	77.3%	54.7%	7.0%	9.7%
DEC	11933	12286	11553	6347	8000 - 16 000	33.9%	79.2%	42.2%	51.5%	9.6%	31.1%
JAN	6775	8948	5240	2493	8000 - 14 000	17.2%	86.1%	22.6%	65.7%	5.9%	50.7%
FEB	4719	7765	4189	1775	8000 - 12 000	15.4%	91.1%	12.9%	60.7%	4.2%	52.6%
MAR	4208	7901	3547	1534	> 8000	14.2%	96.2%	7.8%	79.7%	3.5%	69.1%
APR	4221	7358	3457	2137	> 6000	24.7%	91.2%	5.5%	26.5%	2.7%	22.0%
MAY	6963	7529	8185	3300	< 8000	78.4%	86.3%	14.4%	7.4%	2.1%	3.9%

- March and April flows are characterised by a decrease in the occurrence of low flows and an increase in the occurrence of higher flows;
- May flows are characterised by an increase in the occurrence of low flows and a decrease in the occurrence of higher flows.

Therefore, the months December - April most closely match the description of "unseasonal surplus flows" caused by regulation. In particular, the flow records for these months exhibit a trend towards maintenance of high (>10,000 ML/day) River Murray flows (to maintain irrigation flexibility).

The months of November and May do not closely match the description of unseasonal surplus flows. Rather, analysis of the flow records indicate that regulation has actually lowered river flows during these months.

Further analysis of the impact of these flow changes on the frequency and extent of flooding of the Barmah-Millewa Forest is presented in Section 5.4.

5.4 Forest Flooding

For each month between November - May, two graphs were constructed to present how the frequency and areal extent of forest floods has changed with regulation. Both of these graphs divided the data into the time periods outlined in Section 5.2.

5.4.1 Frequency

Methodology

The analysis of forest flooding requires investigation of the "threshold Tocumwal flow" at which forest flooding commences. This threshold has changed over time, due to activities such as desnagging of the Choke in the 1950's and increases in regulator capacity. Various publications cite values for threshold flows, including:

* 9386.8 ML/day derived for the period 1963 - 1984 (Bren *et. al.,* 1987);

* 11,000 ML/day (RMC 1980; Johnson *et. al.,* 1980); and

* 10,600 ML/day (Thoms *et. al.,* 2000).

The graphs of frequency of forest flooding compare the percentage of days during which the forest flooded, using these three thresholds. The purpose is to illustrate the sensitivity of calculated flooding frequency to the selection of the threshold.

Results are summarised in Figure 5.23.

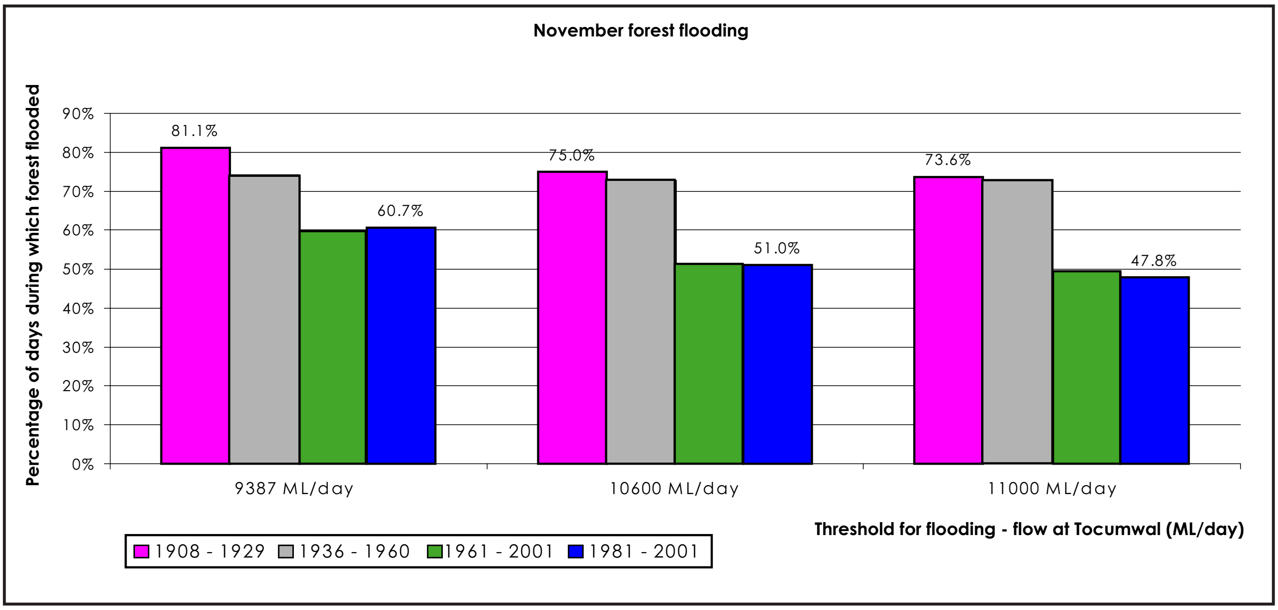


Figure 5.23 Frequency of Flooding

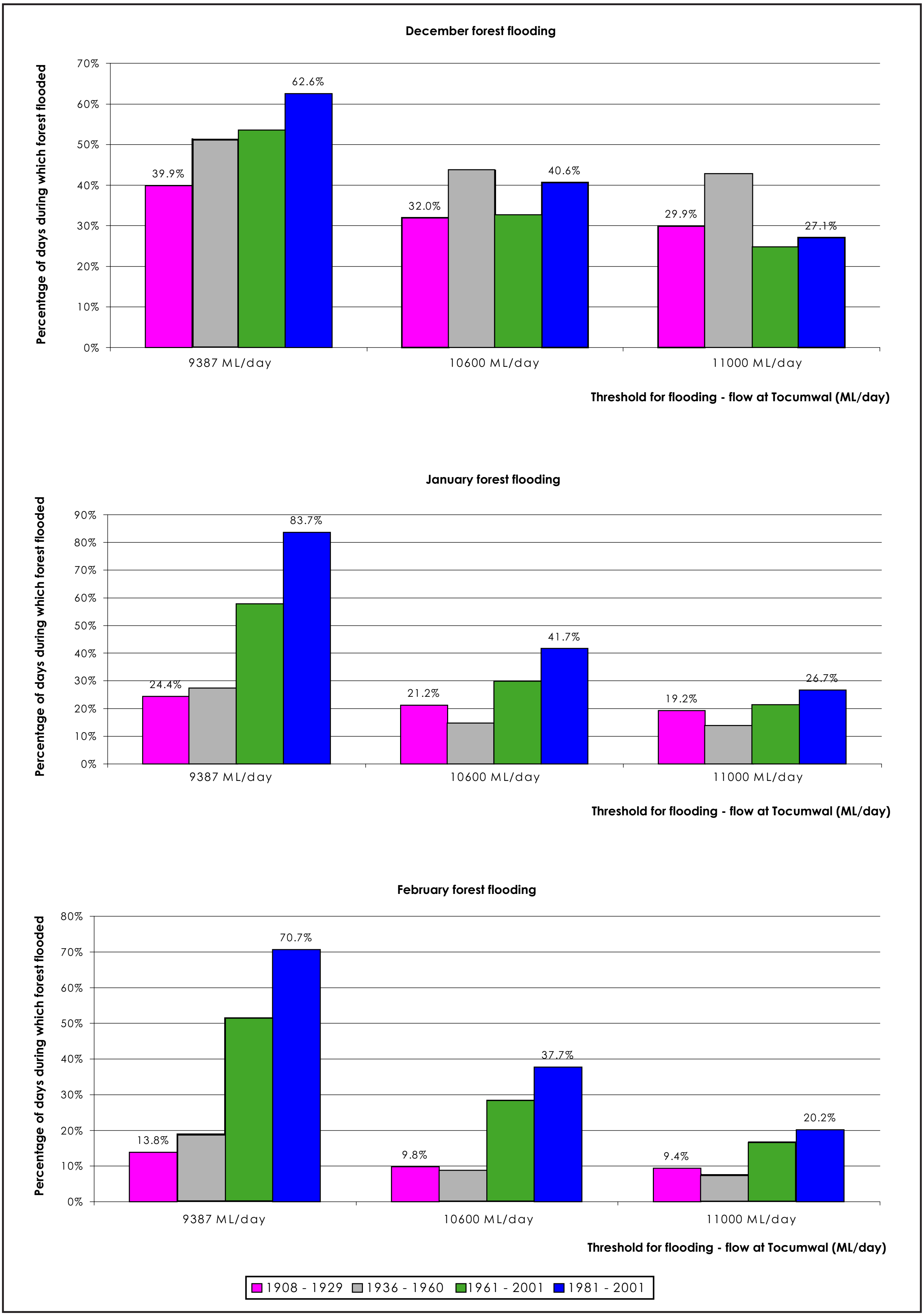


Figure 5.23 Frequency of Flooding (continued)

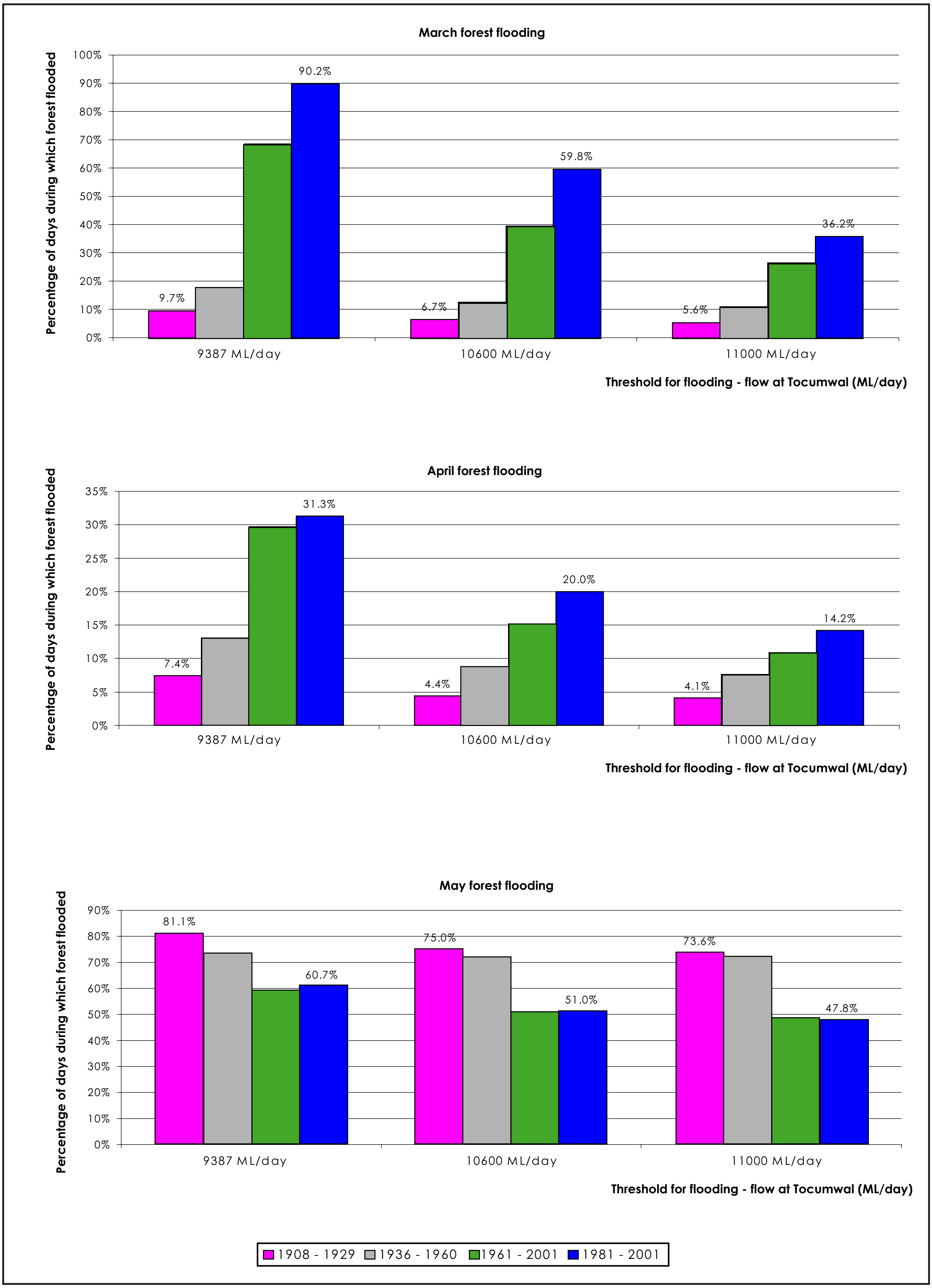


Figure 5.23 Frequency of Flooding (continued)

Analysis

The main characteristics of the forest flooding plots are:

- For all thresholds, November and May exhibited DECREASES in the proportion of days during which flooding occurred in the forest.
- For all thresholds, January, February, March and April exhibited INCREASES in the proportion of days during which flooding occurred in the forest.
- For thresholds of 9387 ML/day and 10,600 ML/day, December exhibited an INCREASE in the proportion of days during which flooding occurred. However, for threshold equal to 11,000 ML/day, December exhibited a DECREASE in the proportion of days during which flooding occurred.
- The greatest increase in the occurrence of forest flooding was for March (6.67% of days in 1908 - 1929, compared with 59.83% of days in 1981 - 2001, using 10,600 ML/day as the threshold).

To illustrate the extent to which regulation has increased forest flooding, “factor increases/decreases” were calculated, e.g. regulation has increased the occurrence of flooding in March by a factor of 59.83/6.67 = 8.97, using 10,600 ML/day as the threshold. These factor changes are illustrated in Figure 5.24.

The greatest relative increase in flooding frequency has occurred during March, followed by April, February, January and December (if a threshold of 10,600 or 11,000 ML/day is used). Except for April, an increase of the threshold flow results in a decrease in the factor increase.

The greatest relative decrease in flooding frequency occurred during May, followed by November.

Overall, the results suggest that regulation has not increased the flooding frequency during the months November or May. Regulation has increased the flooding frequency during December - April, with the greatest impact during March, and the smallest impact during December.

The choice of threshold value affects the calculated changes in flooding frequency. In general, a higher threshold results in the calculation of a smaller impact of regulation on flooding frequency. However, December is the only month in which the sign of the change in flooding frequency (ie. increase or decrease) is sensitive to the selection of the threshold, within the range 9387 - 11,000 ML/day.

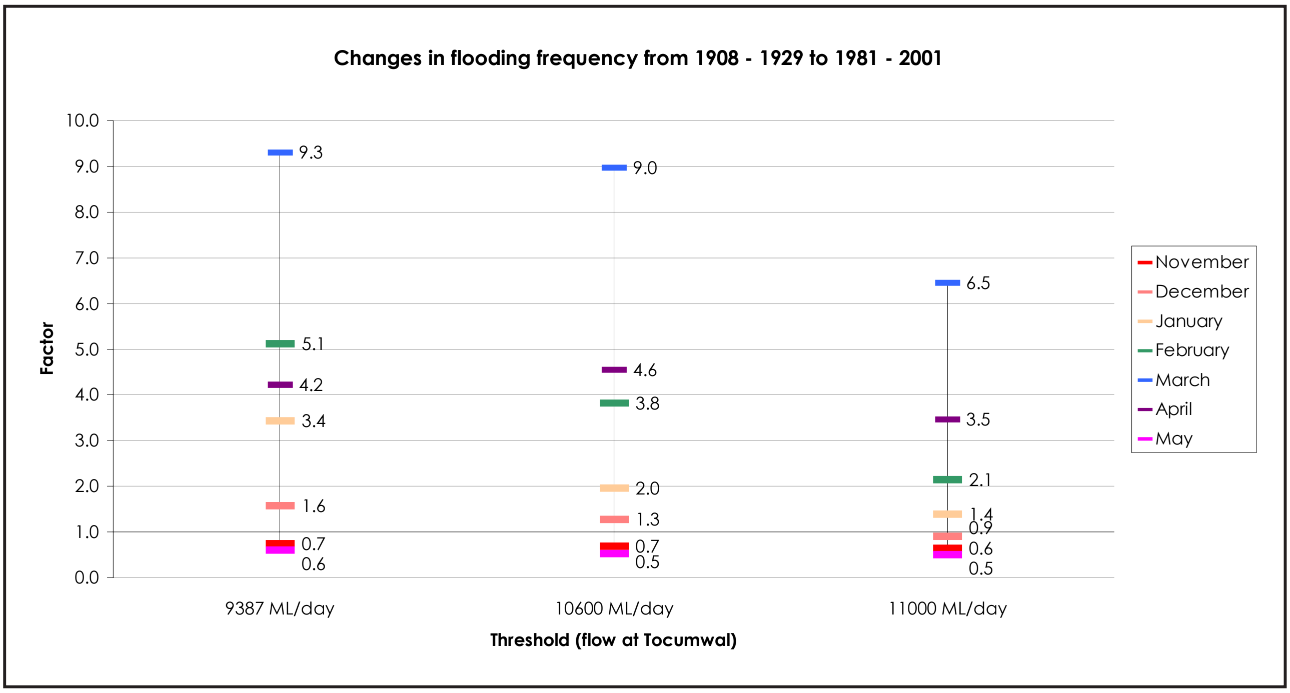


Figure 5.24 Factor Increases in Frequency of Flooding

5.4.2 Areal Extent

Methodology

The analysis of forest flooding requires investigation of how the area extent of forest flooding has changed over time, due to regulation. Repeated inundation has the greatest ecological impact with regards to tree deaths and changes in patterns of vegetation. Therefore, a large increase in the frequency of the flooding of a small forest area is likely to be more damaging than small increases in the frequency of flooding of a greater area.

This flooding extent analysis uses the relationship derived by Bren *et. al.* (1987), which relates proportion of Barmah Forest flooded (P percent) to the daily flow at Tocumwal for the period 1963 - 1984:

$P = -435.40 + 47.6 \ln (Q)$ $\quad$ $Q < 68{,}500$ ML/day

$P = 93.5$ $\quad$ $Q > 68{,}500$ ML/day

This relationship was used to construct column graphs which show the proportion of days in which 0%, 0 - 10%, 10 - 20%, 20 - 30%, 30 - 40%, 40 - 50%, 50 - 60%, 60 - 70%, 70 - 80%, 80 - 93,5% and 93.5% (maximum) of the forest was flooded (refer to Appendix B).

Two assumptions were used in this analysis:

- The value “Q” in Bren’s relationship is equivalent to the mean daily flow at Tocumwal, rather than the peak value;
- The relation (although derived from the period 1963 - 1984) is applicable for the period 1908 - 2001.

The consequences of these assumptions are:

- Areal extent of flooding excludes Millewa Forest;
- The graphs provide general illustrations of the trends in area of forest flooded, rather than exact values.

Results

The results are summarised in Table 5.2.

Table 5.2 Areal Extent of Flooding

Month	**Percentage of forest flooded**											
	0		**0 - 10**		**10 - 20**		**20 - 30**		**30 - 40**		**> 40**	
	<1929	>1981	<1929	>1981	<1929	>1981	<1929	>1981	<1929	>1981	<1929	>1981
NOV	18.9%	39.3%	9.25	14.3%	12.4%	9.8%	14.1%	5.0%	9.9%	5.7%	35.5%	25.9%
DEC	60.1%	37.1%	12.65	39.0%	5.3%	10.2%	2.6%	6.1%	6.0%	2.4%	13.4%	5.2%
JAN	76.4%	18.0%	5.7%	60.8%	6.8%	15.0%	6.8%	3.7%	2.6%	1.8%	1.7%	0.7%
FEB	85.4%	25.1%	5.3%	60.9%	4.7%	11.0%	3.1%	2.2%	1.1%	0.8%	0.4%	0.0%
MAR	90.6%	12.1%	4.7%	73.7%	2.8%	10.2%	1.5%	3.3%	0.4%	0.6%	0.0%	0.0%
APR	92.6%	68.5%	4.1%	25.8%	1.4%	4.0%	0.9%	1.7%	1.1%	0.0%	0.0%	0.0%
MAY	84.6%	91.8%	2.6%	4.5%	2.9%	1.7%	1.6%	0.6%	3.7%	0.7%	4.6%	0.7%

greater than 75% decrease in the proportion of days

50 -75% decrease in the proportion of days

less than 50% decrease in the proportion of days

greater than 75% increase in the proportion of days

50 - 75% increase in the proportion of days

less than 50% increase in the proportion of days

Blue shading represents an increase in the proportion of days. Darker blue indicates a greater relative increase in the proportion of days.

Red shading represents a decrease in the proportion of days. Darker red indicates a greater relative decrease in the proportion of days.

This indicates that for the months December to April, regulation has caused an increase in the frequency of floods of small areal extent (<20%). However, regulation has caused a decrease in larger floods (i.e. those in which over 30% of the forest is flooded).

Analysis

The main characteristics of forest flooding patterns are:

- During May and November, regulation increased the proportion of days during which the forest was dry, and the proportion of days during which 0 - 10% of the forest was flooded. It decreased the proportion of days during which over 10% of the forest was flooded.
- During December - April, regulation decreased the proportion of days during which the forest was dry.
  - During December and April, regulation increased the proportion of days during which between 0 - 30% of the forest was flooded;
  - during March, regulation increased the proportion of days during which 0 - 40% of the forest was flooded;
  - during January and February, regulation increased the proportion of days during which 0 - 20% of the forest was flooded.
- The most severe increases in the proportion of days that between 0 - 10% of the forest was flooded occurred in March (4.7% of March days in 1908 - 1929 compared to 73.7% of March days in 1981 - 2001).

The main consequences of unseasonal surplus flooding are tree deaths (red gum) and encroachment of moira grass plains. These are caused by an increase in the frequency of summer-autumn flooding in particular sensitive areas of the forest.

All months revealed an increase in the proportion of days in which flooding of less than 10% of the forest occurred. Thus it could be assumed that from November - May, a proportion of the forest is adversely affected by increases in flooding frequency. However, the following reasons provide justification of why to exclude November and May from the “unseasonal season”:

- overall frequency of flooding has decreased in November and May;
- frequency of flooding of more than 10% of Barmah Forest has decreased in November and May;
- relative increases in flooding of less than 10% of Barmah Forest are not as severe for November and May as for the other months.

5.5 Summary: December - April

The analyses of River Murray flows and forest flooding indicate that November and May should not be included in the definition of the summer-autumn period (during which unseasonal surplus flows will be identified).

Analysis which employed a high threshold for forest flooding (11,000 ML/day) suggested that flooding frequency in December has actually decreased. However, analysis indicates that the proportion of days in December during which 0 - 30% of the forest is flooded has increased. Furthermore, flow analysis reveals an increase in the overall proportion of flows between 10,000 and 12,000 ML/day, and an increase in the proportion of flows greater than 10,000 ML/day. Therefore, December is included in the definition of the summer-autumn period.

This section presents the graphical results of combining flow data from the months of December - April to determine changes in patterns of River Murray flow and forest flooding.

5.5.1 River Murray flow at Tocumwal

Results are summarised in Figures 5.25 to 5.27.

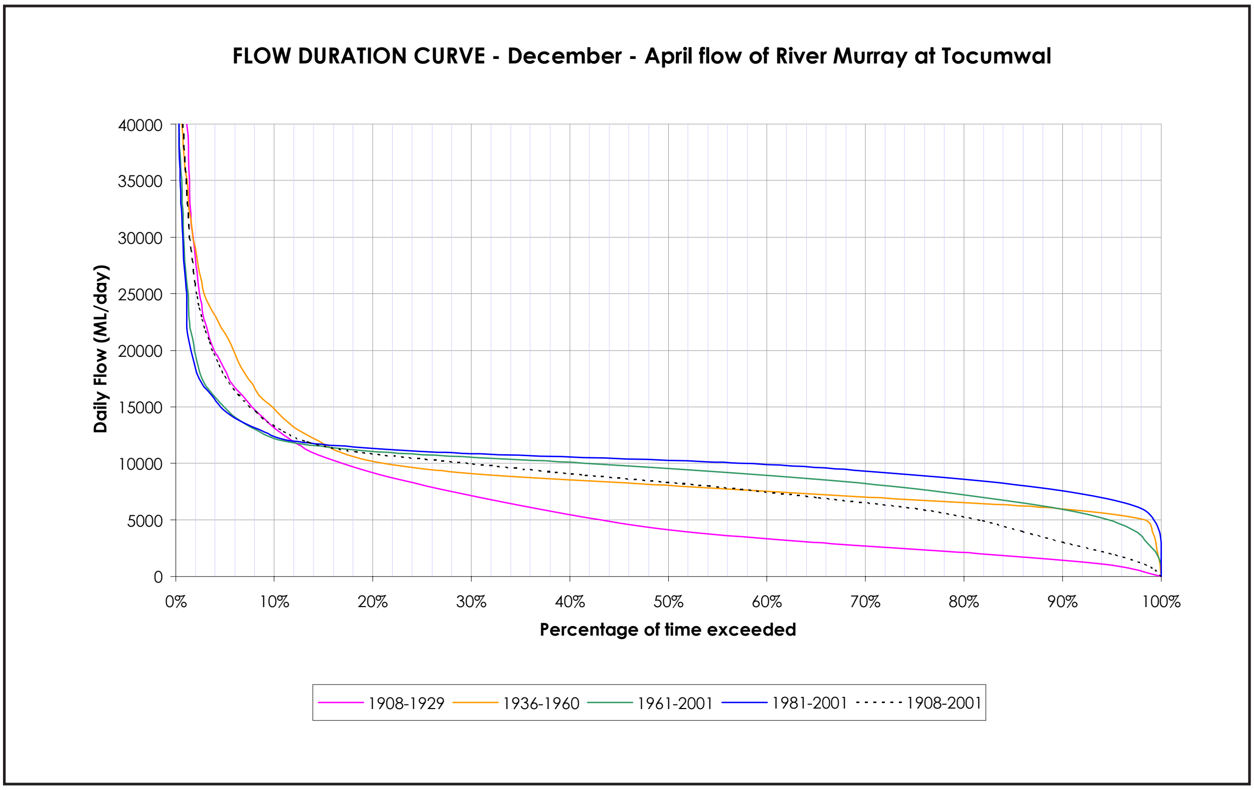


Figure 5.25 Historical Flow Analysis: December-April: Flow Duration Curve

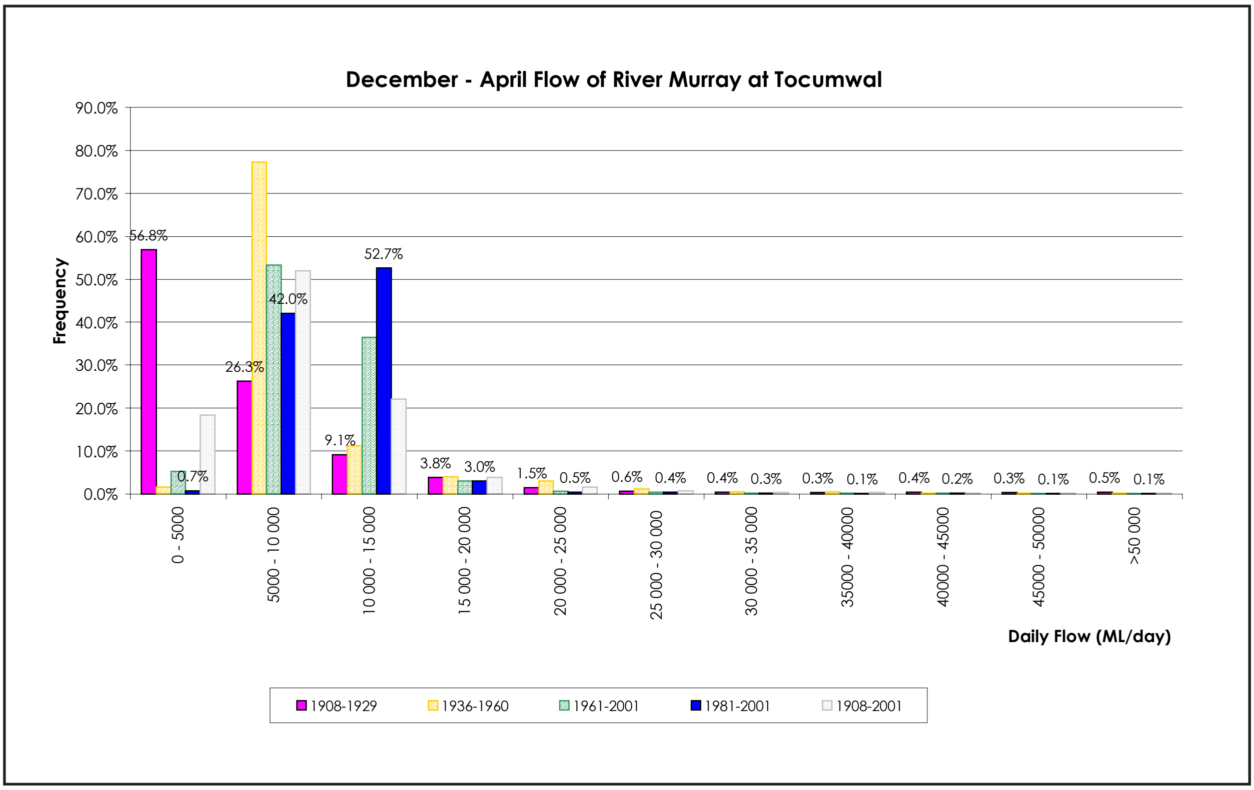


Figure 5.26 Historical Flow Analysis: December-April: Frequency Column Graph

Analysis

The following describes changes from the period 1908 - 1929 to 1981 - 2001.

The flow duration curves illustrate the following changes due to regulation:

- An decrease in the proportion of daily flows that exceed 3000 ML/day (from 64.7% to 100%);
- An increase in the proportion of flows that exceed 10,000 ML/day (from 16.9% to 57.2%);
- A decrease in the proportion of flows that exceed 20,000 ML/day (from 4.0% to 1.6%);

The frequency column graph illustrates the following changes due to regulation:

- A decrease in the proportion of flows under 5000 ML/day (from 56.8% to 0.7%);
- An increase in the proportion of flows between 5000 and 15,000 ML/day (from 35.4% to 94.7%;
- A decrease in the proportion of flows greater than 15,000 ML/day (from 7.8% to 4.6%)

The stacked column graphs illustrate the following changes due to regulation:

- A decrease in the proportion of flows under 6000 ML/day (from 63.4% to 2.0%);
- An increase in the proportion of flows between 6000 and 16,000 ML/day (from 29.8% to 94.3%);
- A decrease in the proportion of flows over 16,000 ML/day (from 6.8% to 3.7%

In summary, regulation has reduced the variability of daily flows in December-April. In particular, it has decreased the frequency of flows under 6000 ML/day and over 16,000 ML/day, with flows more likely to lie between 6000 and 16,000 ML/day. Present flows are more likely to be over 10 000 ML/day than those before regulation, but less likely to be over 12,000 ML/day. (See Table 5.3)

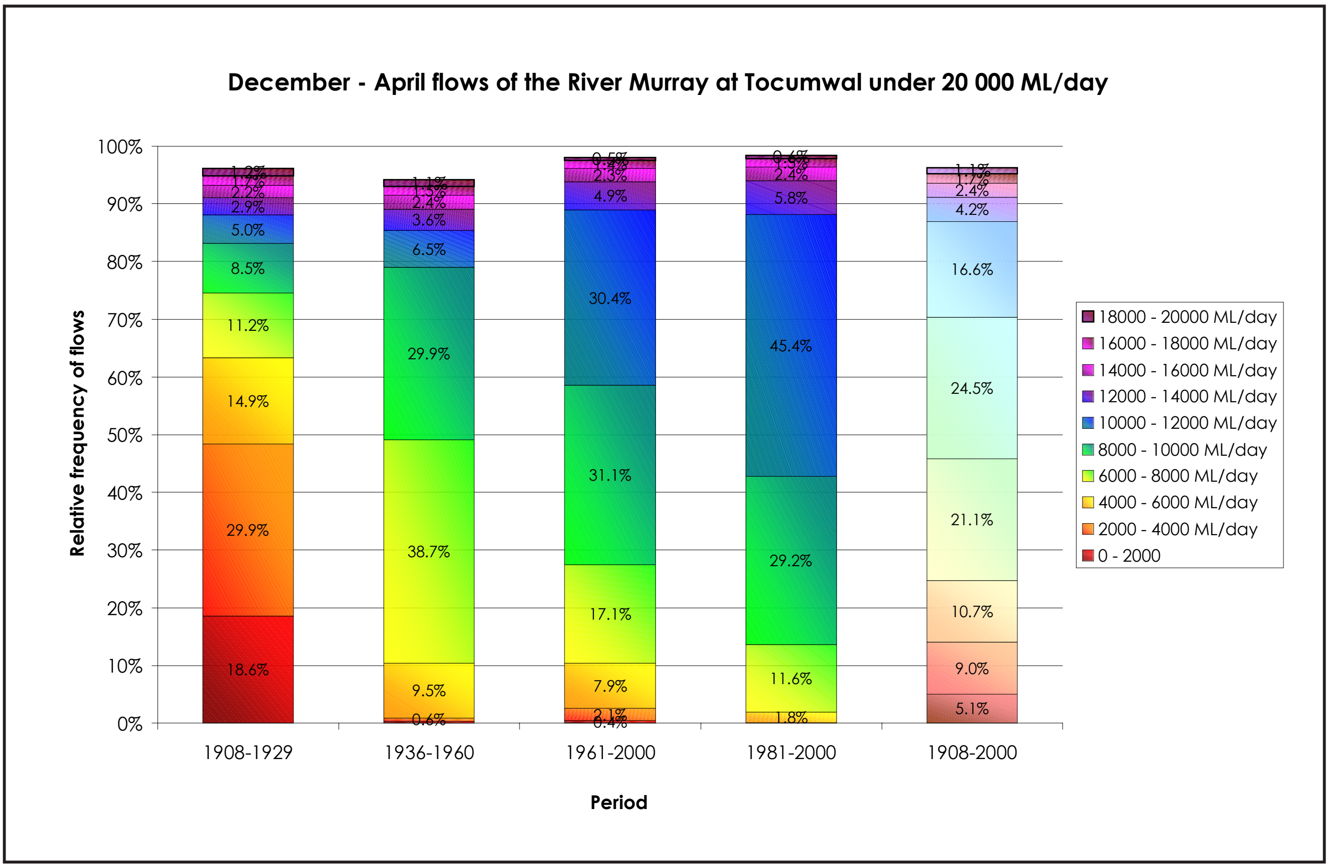


Figure 5.27 Historical Flow Analysis: December-April: Stacked Column Graph

Table 5.3 Summary of Flow Changes at Tocumwal for Period December to April 1908 - 1929 and 1981 - 2000

December - April Flow at Tocumwal	1908 - 1929	1981 - 2000
Mean daily flow (ML/day)	6415.4	10444.6
Variability (std. dev.)	7065.9	3508.2
Proportion of flows in range 6000 - 16,000 ML/day	29.8%	94.3%
Proportion of flows > 10,000 ML/day	16.9%	57.2%
Proportion of flows > 12,000 ML/day	11.9%	11.8%

5.5.2 Forest Flooding

The extent of forest flooding between December and April for the various periods is shown in Figure 5.28.

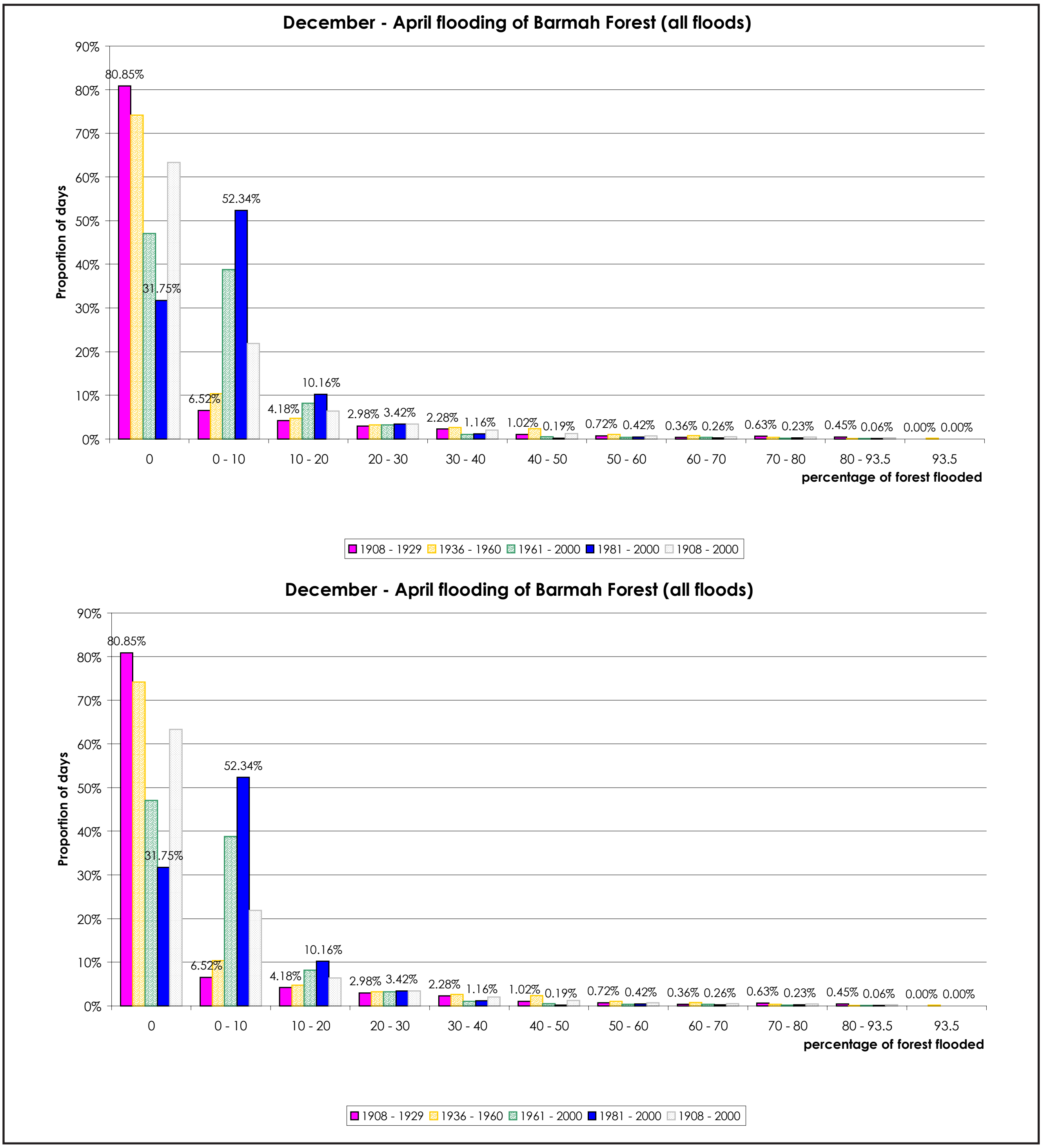


Figure 5.28 Areal Extent of Forest Flooding: December-April

Analysis

The main characteristics of the forest flooding frequency plots are:

- The proportion of days during which flooding occurred in the forest increased with regulation, whether the threshold was set at 9387 ML/day, 10,600 ML/day, or 11,000 ML/day.
- An increase in the threshold value decreases the relative increase of the proportion of flood days, i.e.
    - If the threshold is set at 9387 ML/day, the forest is calculated to flood 2.3 times more frequently during 1981 - 2001 (65.7% of the time) than in 1908 - 1929 (19.8% of the time);
    - If the threshold is set at 10 600 ML/day, the forest is calculated to flood 1.5 times more frequently during 1981 - 2001 (36.5% of the time) than in 1908 - 1929 (15.5% of the time);
    - If the threshold is set at 11,000 ML/day, the forest is calculated to flood 0.7 times more frequently during 1981 - 2001 (23.8% of the time) than in 1908 - 1929 (14.3% of the time).

The main characteristics of the areal extent of forest flooding during December - April are:

- Regulation has decreased the proportion of days during which the forest is dry from 80.9% in 1908 - 1929 to 31.8% in 1981 - 2001;
- Regulation has increased the proportion of days during which 0 - 30% of the forest is flooded (from 10.7% of the time to 65.91% of the time;
    - in particular, forest floods which cover less than 10% of the Barmah Forest have increased in frequency from 6.5% to 52.3%;
- Regulation has decreased the proportion of days during which over 30% of the forest is flooded (from 8.4% of the time to 2.3% of the time).

Table 5.4 Summary of Changes in the Extent of Forest Flooding between 1908 - 1929 and 1981 - 2000

Percentage of Forest Flooded											
0		0 - 10		10 - 20		20 - 30		30 - 40		> 40	
<1929	>1981	<1929	>1981	<1929	>1981	<1929	>1981	<1929	>1981	<1929	>1981
80.9	31.8	3.5	52.3	4.2	10.2	3.0	3.4	2.3	1.2	6.1	1.4

greater than 75% decrease in the proportion of days	greater than 75% increase in the proportion of days
50 -75% decrease in the proportion of days	50 - 75% increase in the proportion of days
less than 50% decrease in the proportion of days	less than 50% increase in the proportion of days

6. Identification of Unseasonal Surplus Flow Events

6.1 Overview

This section presents the data requirements, methodology, results and analysis of unseasonal surplus flow events identified using three different methods. The purpose of this section is to compare the characteristics of unseasonal surplus flow events identified using different methods, to evaluate the appropriateness of these methods, and to determine which method should be used in further analysis.

The unseasonal surplus flow events were defined during the season December - April (as identified in section 5) for the years 1980 - 2001. This period represents the "current" level of regulation and irrigation demands.

Refer to Appendix C for supporting documentation of the data analysis.

6.2 Data

The mean daily flows were obtained from RMW for:

- River Murray at Tocumwal (available from pre-regulation to 15 March 2001)
- River Murray downstream of Yarrawonga (available from pre-regulation to 15 March 2001)
- River Murray at Picnic Point (available from 16 March 1983 to 15 March 2001).

For comparative purposes, data for all series was used from 16 March 1983 to 15 March 2001.

6.3 Methodology

6.3.1 General

Five methods for identifying unseasonal surplus flow events have been identified in the literature:

- Peak daily flow at Tocumwal greater than 9387 ML/day (Bren *et. al.* 1987);
- Mean daily flow downstream of Yarrawonga greater than 11,400 ML/day (DLWC 1996);
- Mean daily flow at Tocumwal greater than 10,600 ML/day (Thoms *et. al.* 2001);
- Mean daily flow at Tocumwal greater than 11,000 ML/day (RMC 1980; Johnson *et. al.* 1980); and
- Gauge height at Picnic Point greater than 2.53m (MDBC operational rules 2001).

Methods 1 and 5 are not included in this analysis. Method 1 was derived for the period 1963 - 1984, and is thus unlikely to be accurate for the period 1981 - 2001. Similarly, method 5 was suggested in 1980 and is unlikely to be accurate for the period 1981 - 2001. Therefore, this section uses the three methods derived from the most recent literature.

As detailed in section 5, the months December - April were analysed for the occurrence of unseasonal surplus flows. Surplus flows which began before 1 December were included if the event ran for a greater number of days after 1 December than before 1 December. This excluded many large flood events which commenced in July, August or September and still had high flows in December, including the flood which occurred during summer 2000 - 2001 (which was not due to rain rejections).

Surplus flows which began before the end of April and ran into May were included if the even ran for a greater number of days before 30 April than after 30 April.

The following characteristics of each unseasonal surplus flow event were determined:

- start date
- end date
- duration
- peak date
- peak excess flow
- total excess volume

For each method, the following statistics were derived:

- total surplus flow days
- mean length of event
- median length of event
- variability of event length (standard deviation and percentile rankings)
- proportion of days in which surplus flow occurred
- average number of events per year

6.3.2 Tocumwal Analysis

This method for identifying unseasonal surplus flow events is derived from Recommendation Z3.1 by MDBC's River Murray Scientific Panel on Environmental Flows (Thoms *et. al.* 2001, p. 102):

During the period, December 1 to the end of the irrigation season, Barmah Choke should be run below channel capacity (i.e. 10,600 ML/day at Tocumwal) in order to prevent summer flooding.

Unseasonal surplus flow events were defined as follows:

- **start date:** first day that mean daily flow at Tocumwal exceeds 10,600 ML/day
- **end date:** last day that mean daily flow at Tocumwal exceeds 10,600 ML/day
- **total excess volume:** total volume of flow above 10,600 ML/day

6.3.3 Yarrawonga Analysis

This method for identifying unseasonal surplus flow events is derived from analysis conducted by the Department of Land & Water Conservation's Technical Services Directorate in 1996 (DLWC 1996, p. 8):

Unseasonal surplus flows were broadly identified as flows occurring in the period November to May which exceeded the regulated flow limit (11,400 ML/day) downstream of Yarrawonga Weir.

Unseasonal surplus flow events were defined as follows:

- **start date:** first day that mean daily flow downstream of Yarrawonga exceeds 11,400 ML/day
- **end date:** last day that mean daily flow downstream of Yarrawonga exceeds 11,400 ML/day
- **total excess volume:** total volume of flow above 11,400 ML/day

6.3.4 Picnic Point Analysis

This method for identifying unseasonal surplus flow events was derived from an authorisation of the Water Policy Committee and Water Audit Working Group of MDBC (effective date 23/2/96):

- *Purpose*

  To allow drying of the forest during the summer period. This allows for: forestry access, access for fire control, tourism access, simulation of drying/wetting cycle which would occur under unregulated conditions.
- *Rule Summary*

  During the summer months, do not exceed 2.53m on Picnic Point gauge.

The stage-discharge relation plotted for Picnic Point was not static. The relation took a different position during the period 1 July 1989 to 30 May 1994, but shifted back to its original (pre- July 1989) position after 31 May 1994 (see Appendix C). However, as the rule was derived in 1996, the stage-discharge relation derived for the period 31 May 1994 - present was used to determine the flow value corresponding to gauge height of 2.53m.

Furthermore, the data record for Picnic Point was incomplete. Where flow data was missing, infilling occurred by taking the mean of the flow value before and the flow value after the missing data point(s).

Unseasonal surplus flow events were defined as follows:

- **start date:** first day that mean daily flow at Picnic Point exceeds 8156 ML/day;
- **end date:** last day that mean daily flow at Picnic Point exceeds 8156 ML/day;
- **total excess volume:** total volume of flow above 8156 ML/day.

6.4 Results

Results from the three different methods are compared in Figure 6.1.

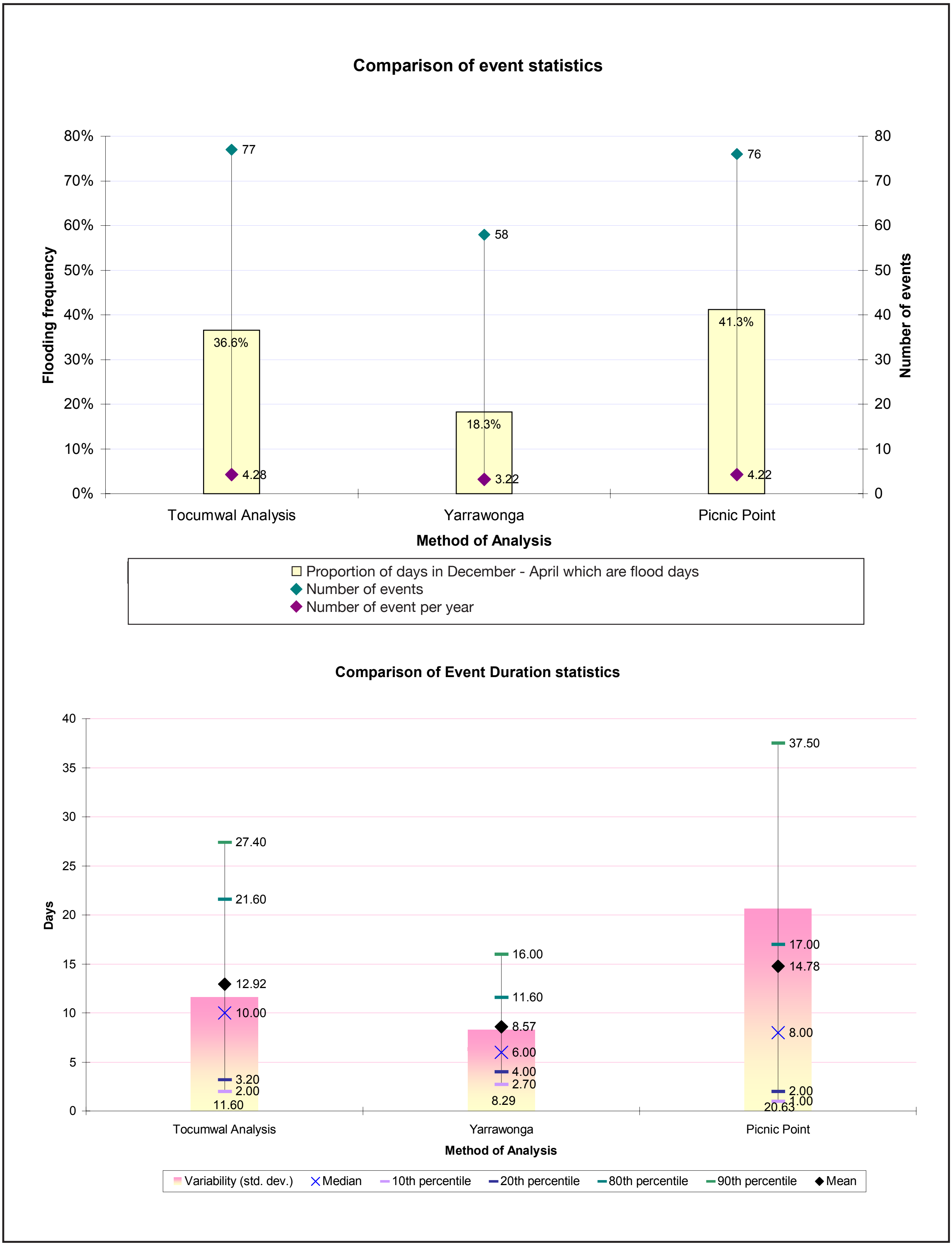
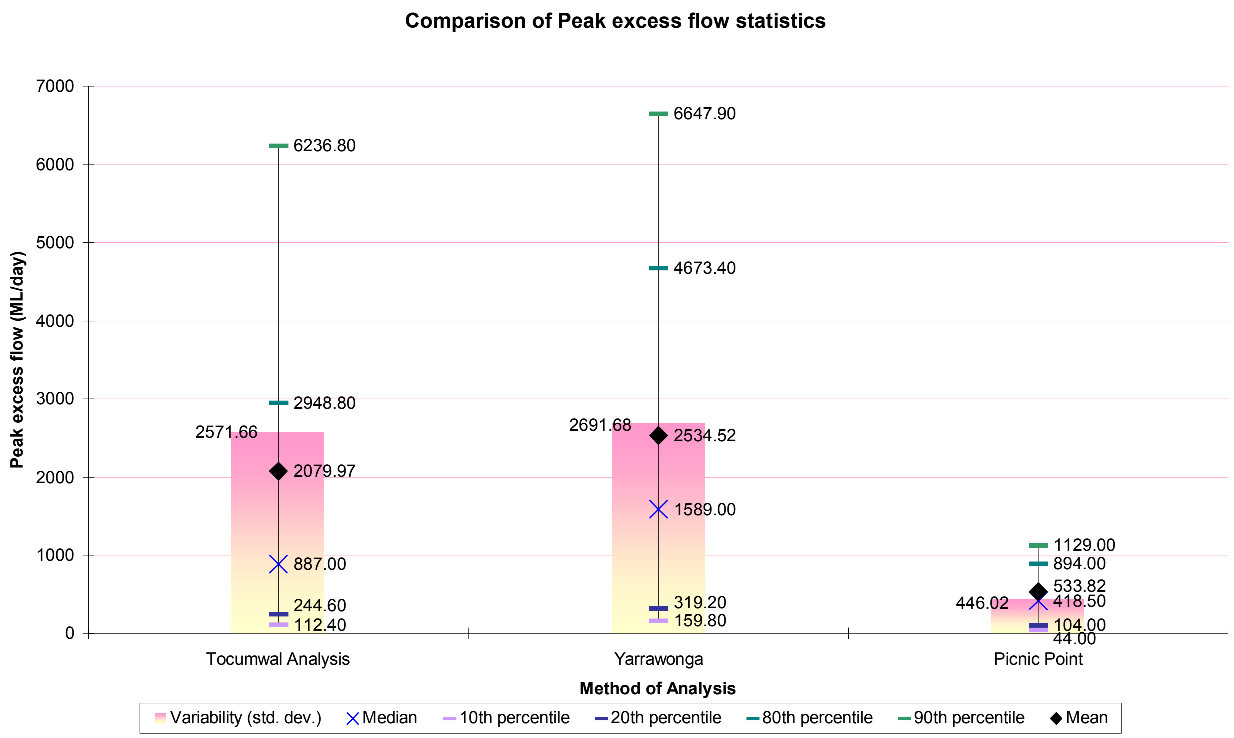


Figure 6.1 Event Statistics: Comparison Between Methods



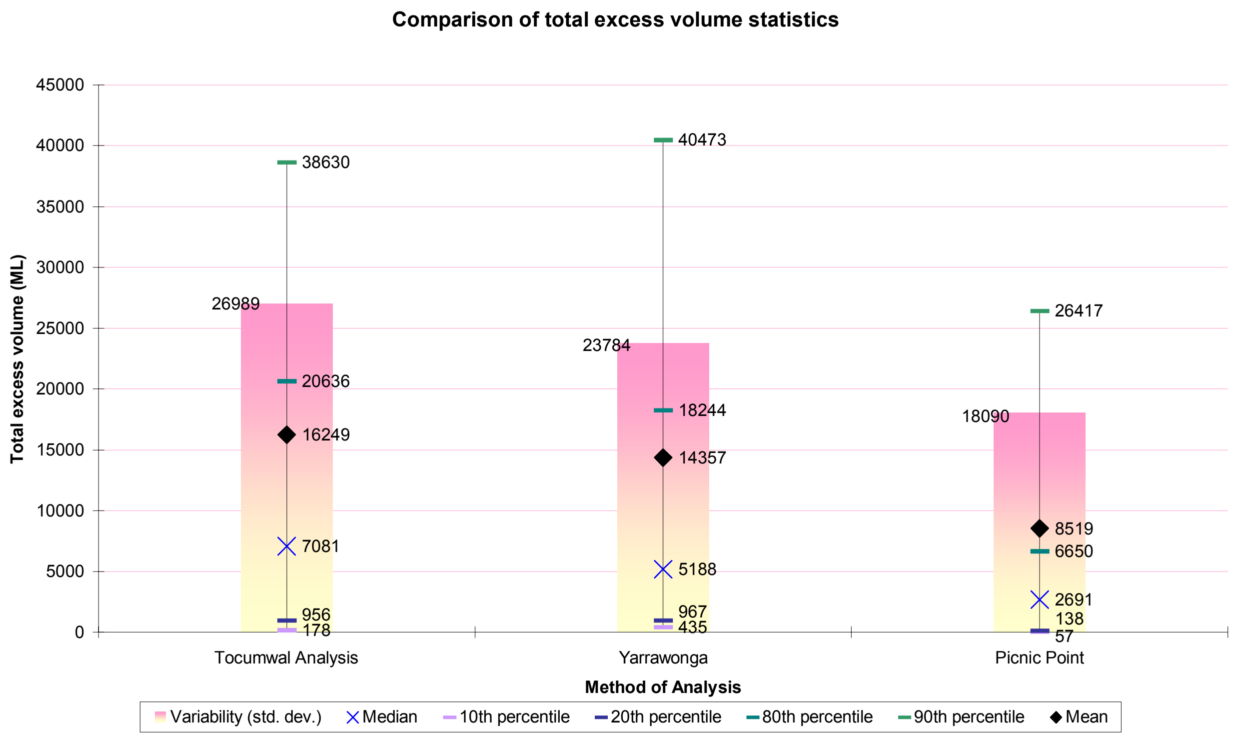


Figure 6.1 Event Statistics: Comparison Between Methods (continued)

6.5 Comparative Analysis

6.5.1 Degree of Coincidence

Descriptive Statistics
Examination of Figure 6.1 reveals that the choice of identification methodology has a significant influence on the calculated event statistics.

Analysis of Tocumwal and Picnic Point data yields similar results in terms of number of events per year (4.28 and 4.22), and the corresponding frequency of flooding during the summer - autumn period (36.6% and 41.3% of days). However, analysis of Yarrawonga data yields a significantly lower number of events per year (3.22) and corresponding frequency of flooding (18.3% of days).

For all three methods, the calculated mean event duration is greater than the median event duration, which indicates that there are more events of length shorter than the mean (i.e. the distribution of event length is skewed to the right). The different methods also yield different event duration statistics. However, the mean and median values for event length differ considerably between methods (Tocumwal: 12.92 days and 10.00 days; Yarrawonga: 8.57 days and 6.00 days; Picnic Point: 14.8 days and 8.00 days). The variability (standard deviation) of event duration also varies (Picnic Point 20.63, Tocumwal 11.60, Yarrawonga 8.29).

Although events identified using Picnic Point data are of longer duration, these events have lower mean peak excess flow and total excess volume values than Tocumwal or Yarrawonga-identified events. (533.8 ML/day compared with 2080 ML/day and 2534 ML/day for mean peak excess flow; 8519 ML compared with 16,249ML and 14,357 ML for mean total excess volume). Picnic Point events exhibit the lowest variability in terms of peak excess flow and total excess volume. Yarrawonga events have the highest variability of peak excess flow, and Tocumwal events have the highest variability of total excess volume.

Degree of Overlap
Figure 6.2 presents the degree of overlap between the methods.

- The overlap between Yarrawonga and Tocumwal analyses is given a score of "1" for each unseasonal surplus flow day at Yarrawonga (date = t) which corresponds to an unseasonal surplus flow day at Tocumwal the following day (date = t + 1);
- The overlap between Tocumwal and Picnic Point analyses is given a score of "1" for each unseasonal surplus flow day at Tocumwal (date = t) which corresponds to an unseasonal surplus flow day at Picnic Point the following day (date = t + 1);
- The overlap between Yarrawonga and Picnic Point analyses is given a score of "1" for each unseasonal surplus flow day at Yarrawonga (date = t) which corresponds to an unseasonal surplus flow day at Picnic Point, two days later (date = t + 2); and
- The overlap between all three methods is given a score of "1" if an unseasonal surplus flow day at Yarrawonga (at day t) corresponds to an unseasonal surplus flow day at Tocumwal (at day t+1) and an unseasonal surplus flow day at Picnic Point (at day t + 2).

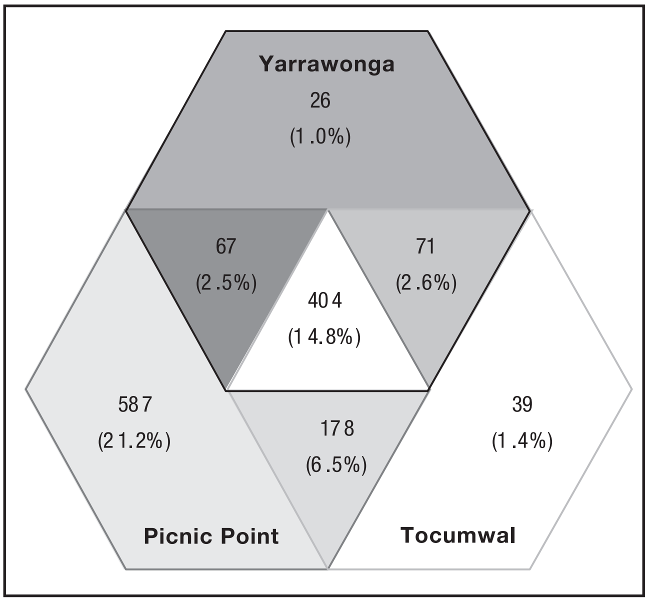


Figure 6.2 Comparing Degree of Overlap Between Methods

This method accounts for approximate travel time down the Murray from Yarrawonga to Tocumwal to Picnic Point.

There are numerous unseasonal surplus flow event days (587 days; 21.2% of total days in season) identified under the Picnic Point method that are not identified under the Yarrawonga or Tocumwal analyses. Relatively few of the identified unseasonal surplus flow days are exclusive to the Yarrawonga or Tocumwal analyses. There is a greater degree of overlap between Tocumwal and Picnic Point analyses than Yarrawonga and Picnic Point analyses.

6.5.2 Advantages and Disadvantages

The three methods of identifying unseasonal surplus flow events produce different results with regards to frequency, timing, duration and severity of events. The following objectives were identified to assist selection of the most appropriate method: (See Table 6.1)

1. Computable data set - this relates to the availability, quality and length of data required for the method; and
2. Accurate methodology for current conditions.

Computable Data Set

Daily flows downstream of Yarrawonga and at Tocumwal are available as a complete data set, and extend prior to 1980. However, the data set for Picnic Point is not considered as robust, due to missing data (which required infilling) and the shift in the stage-discharge relation in 1989.

Accurate Method for Current Conditions

The Picnic Point method of analysis uses a currently applicable MDBC operating rule. Similarly, the Tocumwal analysis uses a threshold recommended by the MDBC. Use of either of these two methods attempts to represent the objectives of the MDBC with regards to maintenance of unseasonal surplus flooding. However, the Yarrawonga method is not related to MDBC operating rules or recommendations. The threshold for flooding was “broadly defined” by DLWC, and its source was not referenced.

Table 6.1 Summary of Advantages and Disadvantages of the Three Methods for Identifying Unseasonal Surplus Flow Events

Method	Advantages	Disadvantages
Picnic Point	• Relates to current MDBC operational rule (1996)	• Incomplete data set • Unstable stage-height relation • Identifies several unseasonal surplus flow days not identified by other methods
Yarrawonga	• Previous study conducted recently (1996), facilitating comparison	• Does not relate to MDBC rules or recommendations • Bren *et. al.* (1987) identified that flow at Tocumwal is a better indicator of forest flooding than flow at Yarrawonga.
Tocumwal	• Relates to current MDBC recommendation (2001) • Flow at Tocumwal identified by Bren *et. al.* (1987) as the best indicator of forest flooding	

On the basis of these advantages and disadvantages, the Tocumwal method will be used to identify unseasonal surplus flow events for further analysis.

6.6 Summary: Tocumwal Method

This section summarises the unseasonal surplus flow event characteristics as identified by the Tocumwal method. (See Table 6.2)

The period December 1980 - December 1999 was selected to provide a 20-year data set which excluded the major floods which occurred over the summer of 2000 / 2001, as these were due to unusual operating circumstances rather than rain rejections or river flushes.

Table 6.2 Unseasonal Surplus Flow Events (Tocumwal method)

Start record	1-Dec-80	Surplus flow days	1160.0	**Events per year**	**4.1**
End record	1-Dec-00	**Surplus flow events**	**82**	**Flooding frequency**	**38.3%**
Years	**20**				

Event Characteristics	Duration	Peak Date	Peak Excess Flow (ML/day)	Total Excess Flow (ML)
AVERAGE	**14.1**	0.57	**2211**	**17833**
MEDIAN	**10.0**	0.57	**1133**	**7960**
MAX	84.0	1.00	10807	162545
MIN	1.0	0.00	8	12
SD	14.0	0.25	2572	28868
10th percentile	2.0	0.20	116	195
20th percentile	4.0	0.42	259	982
30th percentile	6.3	0.50	422	2667
40th percentile	8.0	0.50	615	4882
50th percentile	10.0	0.57	1133	7960
60th percentile	11.6	0.66	1914	11352
70th percentile	16.0	0.68	2697	15772
80th percentile	22.0	0.80	4105	22442
90th percentile	29.8	0.89	6345	43140

7. Analysis of Increased System Flexibility

7.1 Overview

This section presents the methodology, results and analysis of the effects of increased system flexibility on unseasonal surplus flow volumes, frequencies, and event characteristics. The purpose of this analysis is to quantify (through graphical representation) the (individual) effect of:

- increasing airspace at Yarrawonga and reduced unseasonal flows; and
- limiting maximum River Murray flow at Tocumwal during December-April.

on:

- flooding frequency (proportion of days in season during which flooding occurs in the forest);
- number of events per season;
- event duration; and
- total surplus flow volume per season.

The results will be used in Section 8 to analyse the costs of increasing system flexibility to reduce the flooding frequency.

Throughout this section, the analysis is assisted by the assumption that events are independent of one another. Refer to Section 9 for a discussion of how the analysis could be refined by relaxing this assumption.

The events analysed in this section were identified in Section 6.4. They occurred between December 1980 to April 2000 inclusive (20 seasons).

Refer to Appendix D for supporting documentation of the data analysis.

7.2 Increasing Airspace at Yarrawonga Weir

7.2.1 Methodology

To determine the impact of increasing the airspace at Yarrawonga Weir (by 500, 1000, 1500... 20,000 ML), each unseasonal surplus flow event was analysed on a day-by-day basis.

To illustrate, an imaginary event is described in Table 7.1.

Table 7.1 Surplus Flow Each Day for an Event that Exceeds the Flooding Threshold of 10,600ML/d

Day	Flow at Tocumwal (ML/day)	Surplus flow[1] (ML/day)
0	10,500	-
1	10,900	300
2	11,100	500
3	11,300	700
4	11,000	400
5	10,700	100
Total		2000

[1] Surplus flow = Flow at Tocumwal - 10,600, the threshold at which flooding starts

If airspace at Yarrawonga was increased by 1000ML, there is the potential to contain the first 1000ML of an unseasonal surplus flow event whilst maintaining flow at Tocumwal at 10,600 ML/day (see Table 7.2).

Without increasing airspace, this event is five days long, with a total surplus flow of 2000 ML. If 1000ML

Table 7.2 Reduction in Surplus Flow when Airspace at Yarrawonga Weir is Increased to 1000ML

Day	Flow at Tocumwal (ML/day)	Surplus flow (ML/day)	Airspace	Adjusted flow at Tocumwal (ML/day)	Adjusted surplus flow (ML/day)
0	10,500	-	1000	10,500	-
1	10,900	300	700	10,600	-
2	11,100	500	200	10,600	-
3	11,300	700	0	11,000	500
4	11,000	400	0	10,000	400
5	10,700	100	0	10,700	100

free storage was available at Yarrawonga, this event would be three days long with a total surplus flow of 1000ML.

Thus increasing airspace at Yarrawonga by “A” ML would effectively capture all events with total surplus flow < A, i.e. increasing airspace at Yarrawonga reduces the number of surplus flow events.

Graphs were plotted to illustrate how the increased airspace affected event duration, excess flow per season, excess flow per event, days per season, events per season and flooding frequency.

7.2.2 Results

Results are summarised in Figures 7.1 and 7.2.

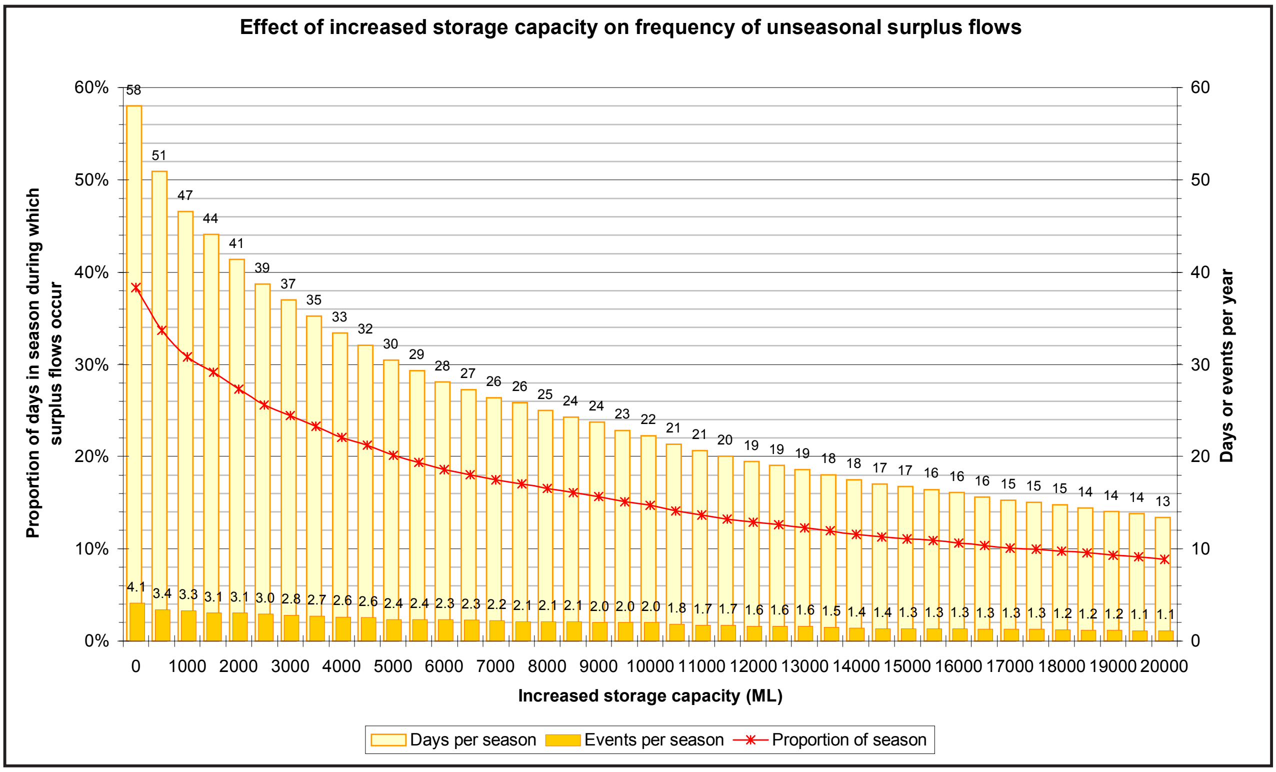


Figure 7.1 Increasing Airspace at Yarrawonga Weir: Impact on Flooding Frequency

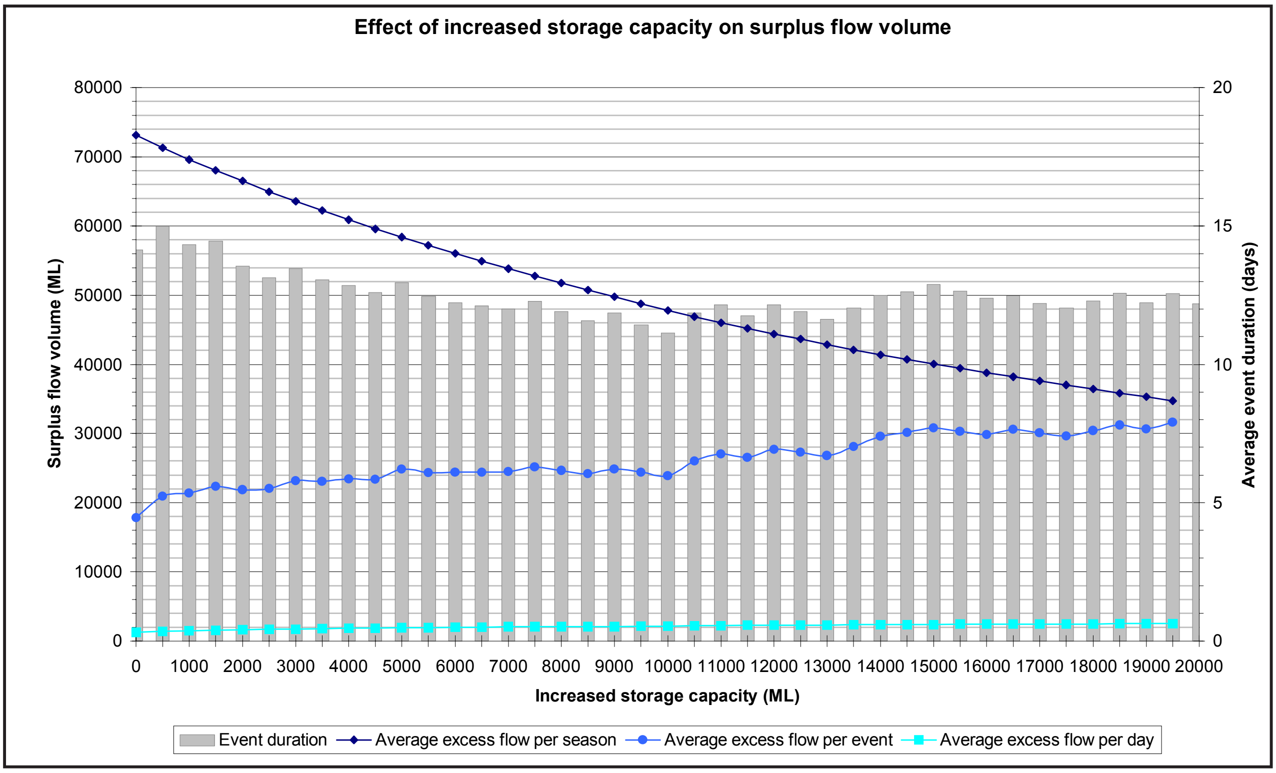


Figure 7.2 Increasing Airspace at Yarrawonga Weir: Impact on Surplus Flow Volume

7.2.3 Analysis

Flooding Frequency

Increasing airspace decreases the flooding frequency (proportion of days in which forest flooding occurred). The relationship is logarithmic in form, i.e. the marginal benefit of increasing airspace diminishes as airspace increases. Put simply, considerable benefit accrues from increasing airspace by 5000ML [reduces flooding frequency from 38% (58 days per year) to 20% (30 days per year)], but increasing airspace by a further 5000ML (to 10,000 ML) has lower benefits [only reduces flooding frequency from 20% to 14% (22 days per year)].

Event Frequency and Duration

The relationship between increasing airspace and decreasing event frequency is also logarithmic, e.g. 5000ML extra airspace reduces event frequency from 4.1 to 2.4; another 5000ML extra airspace reduces event frequency from 2.4 to 2.0. There is no distinct trend between increased airspace and average event duration (grey bars in figure 2).

Surplus Flow

The surplus flow volume per season decreases from 73 000ML to 58,000ML (with 5000ML extra airspace) to 48,000 ML (with 10 000ML extra airspace) to 34,000ML (with 20 000 extra airspace).

The average excess flow volume per event increases with increase storage capacity. This reflects the distribution of events by total volume. The mean total surplus volume (17,833 ML) is much greater than the median (7960 ML), which suggests that the majority of events have total surplus volume less than the mean. Therefore whilst increasing storage capacity reduces the total surplus volume of all events, it has a greater effect in reducing the number of events.

7.3 Limiting Flow of the River Murray at Tocumwal

7.3.1 Methodology

To determine the impact of limiting the flow of the River Murray at Tocumwal (to a maximum of 10500, 10,400, 10,300...9000 ML/day), each unseasonal surplus flow event was analysed on a day-by-day basis. (See Table 7.3).

To illustrate, an imaginary event is described below:

Table 7.3 Surplus Flow Each Day for an Event that Exceeds the Flooding threshold of 10,600 ML/d

Day	Flow at Tocumwal (ML/day)	Surplus flow[1] (ML/day)
0	10,500	-
1	10,900	300
2	11,100	500
3	11,300	700
4	11,000	400
5	10,700	100
Total		2000

[1] Surplus flow = Flow at Tocumwal - 10,600, the threshold at which flooding starts

If the flow at Tocumwal was limited (in non-surplus flow times) to 10,100ML/day, then on day 0 of this illustrative event (the day before the surplus flows commenced) the flow would have been 10400 ML/day (instead of 10,500ML/day). [If an event is preceded by a flow of, say, 10,000 ML/day, then there will be no change to the event, because the constraint is the imposition of a maximum flow of 10,400ML/day.] (See Table 7.4)

Table 7.4 Reduction in Surplus Flow when Tocumwal Flow is Limited to 10,100 ML/d

Day	Flow at Tocumwal (ML/day)	Surplus flow (ML/day)	Adjusted flow at Tocumwal (ML/day)	Adjusted surplus flow (ML/day)
0	10,500	-	10,100 (limit)	-
1	10,900	300	10,500 (= 10,100 + (10,900 - 10,500))	-
2	11,100	500	10,700 (= 10,500 + (11,100 - 10,900))	100
3	11,300	700	10,900	300
4	11,000	400	10,600	400
5	10,700	100	10,300	100

Without limiting the maximum flow at Tocumwal, this event is five days long, with a total surplus flow of 2000 ML. If the flow at Tocumwal is limited to a maximum of 10,100 ML/day, this event would be two days long with a total surplus flow of 400ML.

Thus limiting the maximum flow at Tocumwal to "B" ML (where B<10,600 ML) would effectively capture all events with peak flow < (Flowday 0 - B), where Flowday0 is the flow at Tocumwal the day before an event starts. Put simply, limiting the maximum flow at Tocumwal to "B" ML reduces the number of surplus flow events.

Graphs were plotted to illustrate how the increased airspace affected event duration, excess flow per season, excess flow per event, days per season, events per season and flooding frequency.

7.3.2 Results

Results are summarised in Figures 7.3 and 7.4.

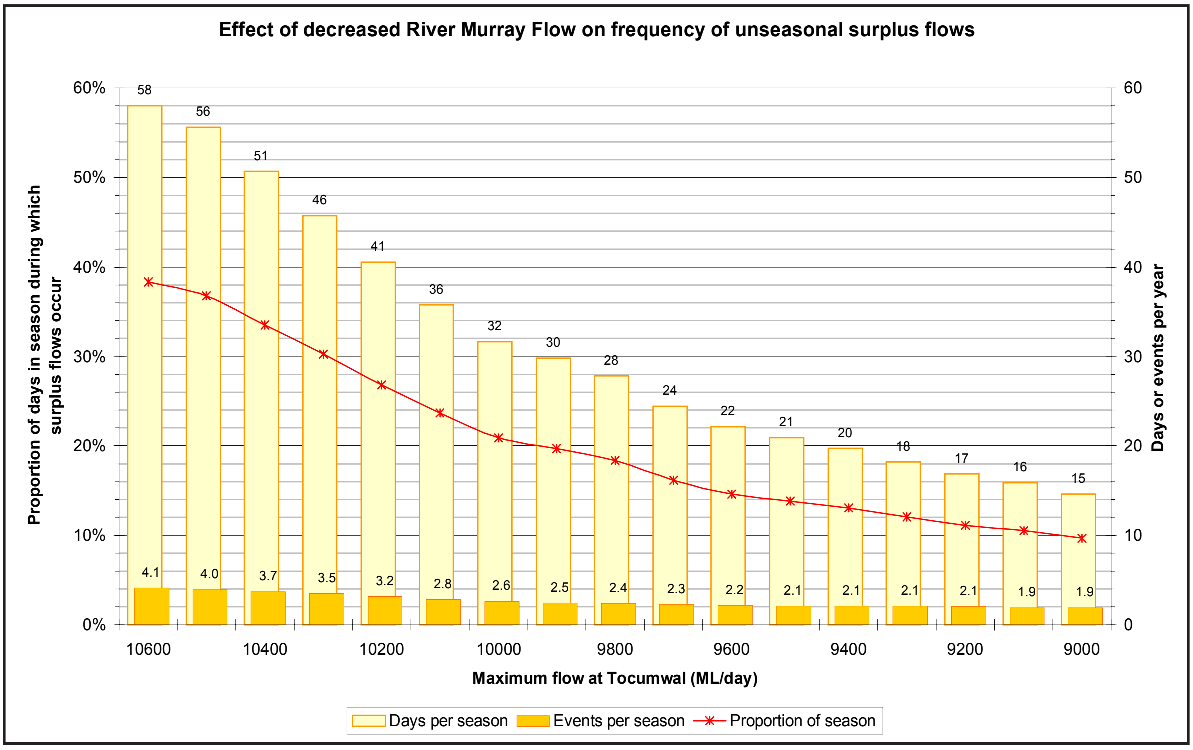


Figure 7.3 Limiting Maximum Flow at Tocumwal: Impact on Flooding Frequency

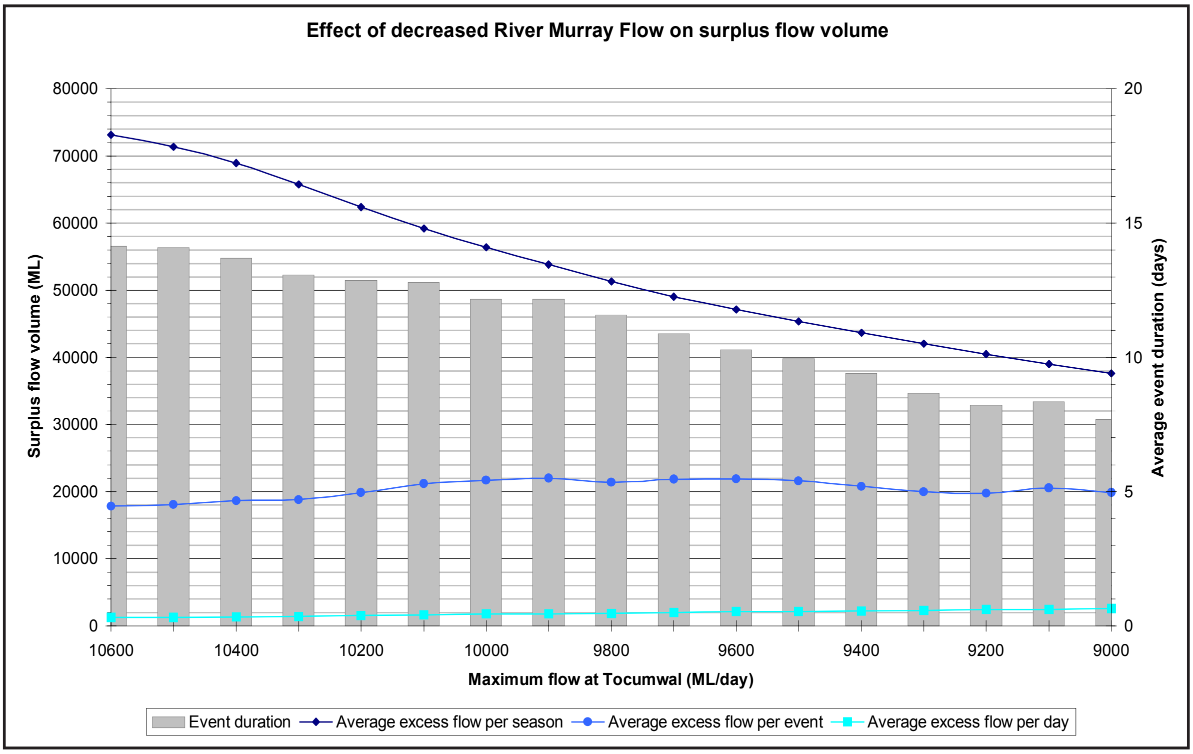


Figure 7.4 Limiting Maximum Flow at Tocumwal: Impact on Surplus Flow Volume

7.3.3 Analysis

Flooding Frequency

Limiting flow decreases the flooding frequency (proportion of days in which forest flooding occurred). The marginal benefit of increasing airspace diminishes as airspace increases. Put simply, considerable benefit accrues from limiting flow to 10,000 ML/day [reduces flooding frequency from 38% (58 days per year) to 21% (32 days per year)], but limiting flow to 9400 ML/day has lower benefits [reduces flooding frequency to 13% (20 days per year)].

Event Frequency and Duration

The relationship between increasing airspace and decreasing event frequency is also logarithmic, e.g. a 10,000 ML/day limit reduces event frequency from 4.1 to 2.6 times per year, but a 9400 ML/day limit results in event frequency of 2.1 times per year. Event duration decreases from 14.1 days to 12.2 days (10,000 ML/day limit) to 9.4 days (9400 ML/day limit).

Surplus Flow

The surplus flow volume per season decreases from 73,000 ML to 56,000 ML (10,000 ML/day limit) to 44,000 ML (9400 ML/day limit).

The average excess flow volume per event does not change considerably with decreasing the maximum flow limit.

Pre-regulation Conditions

Prior to regulation (1908 - 1929), flooding occurred in the forest 15.5 per cent of the time (see Section 5). To achieve this pre-regulation frequency:

- airspace must be increased by 9100 ML; or
- flow at Tocumwal must be limited to a maximum of 9600 ML/day.

Consequently, the volume of surplus water entering the forest would be significantly reduced, from 73,000 ML per year to 48,000 ML per year.

7.4 Summary

Based on an analysis of historical events, increasing system flexibility by increasing airspace at Yarrawonga or limiting the maximum flow at Tocumwal has the following effects:

- reducing flooding frequency (proportion of days during which forest flooding occurs);
- decreasing the number of events per season; and
- reducing the total surplus flow volume per season.

Minor increases in system flexibility can have a significant impact on reducing flooding frequency:

- increasing storage capacity by 5500 ML reduces the flooding frequency by a factor of 2;
- limiting maximum flow to 9900 ML/day reduces the flooding frequency by a factor of 2.

8. Economic Analysis

8.1 Overview

This section outlines the methodology and analysis of the economic costs and benefits of increasing system flexibility to decrease the frequency of unseasonal flooding in the Barmah-Millewa Forest (proportion of days in season during which flooding occurs) from 38.3% (current) to 15.5% (pre-regulation). The economics of two options are analysed:

- increasing airspace at Yarrawonga;
- limiting the maximum flow at Tocumwal.

The economic analysis of the alternative strategies is not straightforward. The approach taken here is identify both market- and non-market costs and benefits, but to selectively quantify only the following costs and benefits (collectively defined as "net conservative cost/benefit"):

- benefit of irrigation water "saved" due to reduced forest flooding (both options);
- cost of irrigation water foregone due to reduced diversions (both options);
- cost of the reduction of hydroelectric generation (increasing airspace only).

The quantification of other market benefits and non-market costs and benefits is outside the scope of this project. This is because an accurate valuation (eg. of increased forestry yields) is prohibited without further, detailed investigation of the complex patterns of forest hydrology (in which each vegetation association requires a distinct watering regime). Furthermore, although methods such as hedonic pricing, travel cost demand, contingent valuation and conjoint analysis are used to value non-market costs and benefits, these tools require significant amounts of information and data to prevent biased results (Kahn 1998).

The non-market costs of reduced amenity value are also likely to be negligible, given the small changes to Murray River and Lake Mulwala levels. The non-market benefits (environmental values) are likely to exceed the non-market costs.

As detailed in Section 8.2, the net operation costs involved with decreasing flooding frequency are likely to be negligible. Therefore, quantifying the abovementioned "net conservative cost/benefit" provides a lower limit of the actual net benefit of each option (or an upper limit of the actual net cost of each option).

The actual market benefit/cost would include value (benefit) from increased activities such as forestry and tourism during December-April. The actual economic (market- and non-market) benefit/cost would further include benefits such as amenity, option and intrinsic value.

Refer to Appendix E for supporting documentation of the data analysis.

8.2 Identification of Economic Costs and Benefits

8.2.1 Market Costs and Benefits

These are costs and benefits which have a direct quantifiable financial value within the market.

Market Costs

- Operation

  The annual cost of regulation to increase airspace at Yarrawonga OR limit the maximum flow at Tocumwal. Due to the automation of River Murray regulation, these costs are likely to be low, and offset by the reduced cost of forest regulator operation (see below).

- Water

  The value of net reductions in diversions from the River Murray system.

  - Increasing airspace at Yarrawonga has the potential to reduce irrigation supply flexibility to the Murray and Murray Valley Irrigation Areas. Lowered head may restrict the outflow into the Yarrawonga and Mulwala irrigation channels.
  - Limiting maximum flow at Tocumwal reduces the supply of water to areas in Victoria downstream of the forest (South Australia must still receive its entitlement).

- Hydroelectricity

  Annual expected cost of decreased power generation due to reduced head at Yarrawonga (relates to increasing airspace at Yarrawonga only).

- Water quality

  Annual expected costs (eg. reduced agricultural production) incurred by consumers of River Murray Water downstream of Yarrawonga diversions, due to reduced water quality (higher Ecw) (relates to reducing maximum flow at Tocumwal only).

Market Benefits

- Operation

  The annual reduction in cost of reduced need to operate regulators in the Barmah-Millewa Forest (due to reduced flooding frequency).

- Water

  The volume of water which is "saved" through reduced forest flooding may be used for irrigation (or other) purposes.

  - Although under the accounting rules of the Murray-Darling Cap, Victoria would not be able to sell this water, it could be stored for environmental flows (eg. flooding the Barmah-Millewa Forest in winter and spring) at an assumed equivalent marginal value.

- Timber production

  Annual expected value of increased yield due to reduced tree death in highly stressed areas.

- Recreation

  Annual expected value of increased recreational opportunities due to increased access.

8.2.2 Non-market Costs and Benefits

Non-market Costs

- Amenity value

  Associated with the loss of amenity value (anthropocentric) from lower levels at Lake Mulwala or the River Murray between Yarrawonga and Tocumwal.

Non-market Benefits

- Amenity value

  Associated with the increased amenity value (anthropocentric) from reduced tree death and maintenance of vegetation associations.

- Option and bequest value

  Associated with the preservation of non-market benefits for an individual's future use, or the use of the individual's descendents.

- Ecological services

  Associated with the value of services such as nutrient cycling, carbon cycling, clean air, clean water and biodiversity.

- Intrinsic value

  Unlike amenity value, intrinsic value refers to the preservation of ecosystems and habitat for their own sake, in addition to the value of that preserved for human benefit. Intrinsic value is not accrued anthropocentrically, except through the indirect value that (some) individuals may gain because they are sympathetic to the preservation and well-being of other species, independent of the use to humans.

8.3 Option 1: Costs and Benefits of Increasing Airspace at Yarrawonga

8.3.1 Cost: Reduced Irrigation Supply Flexibility

Methodology and Data Requirements

This section quantifies the costs of increasing airspace at Yarrawonga associated with reduced irrigation supply flexibility. From Figure 7.1, airspace at Yarrawonga would need to be increased by approximately 9100ML to lower unseasonal flooding frequency to 15.5% (pre-regulation frequency).

It has been suggested (Ladson 2001, *pers. comm*. 9 May) that authorities maintain Lake Mulwala at a high level in December-April because they believe that it is necessary to ensure that maximum flows can be released down Yarrawonga Main Channel and Mulwala Canal for irrigation. Reportedly, this is a more significant problem at the end of the irrigation season, when weed growth obstructs Yarrawonga Main Channel.

The FSL (full supply level) of Lake Mulwala is 124.9 mAHD (GMW 2001b), however the absolute limit is approximately 125.1m, when water begins to flood property in nearby low-lying areas.

Data provided by RMW reports daily height upstream of Yarrawonga Weir from 1 December 1967 and daily volumes of Lake Mulwala from 1 March 1993. A stage-volume curve was constructed to determine the relation between height (mAHD) and volume (ML) using available data from 1 March 1993 - 15 March 2001.

Scatter plots were constructed (using data from 1 December 1980) of:

- lake height (mAHD) vs. outflow at Yarrawonga Main Channel (ML/day)
- lake height (mAHD) vs. outflow at Mulwala Canal (ML/day)

Scatter plots were constructed using data from December-April, and compared to scatter plots constructed using data from the end of the irrigation season (March-April). (See Figures 8.2 and 8.3)

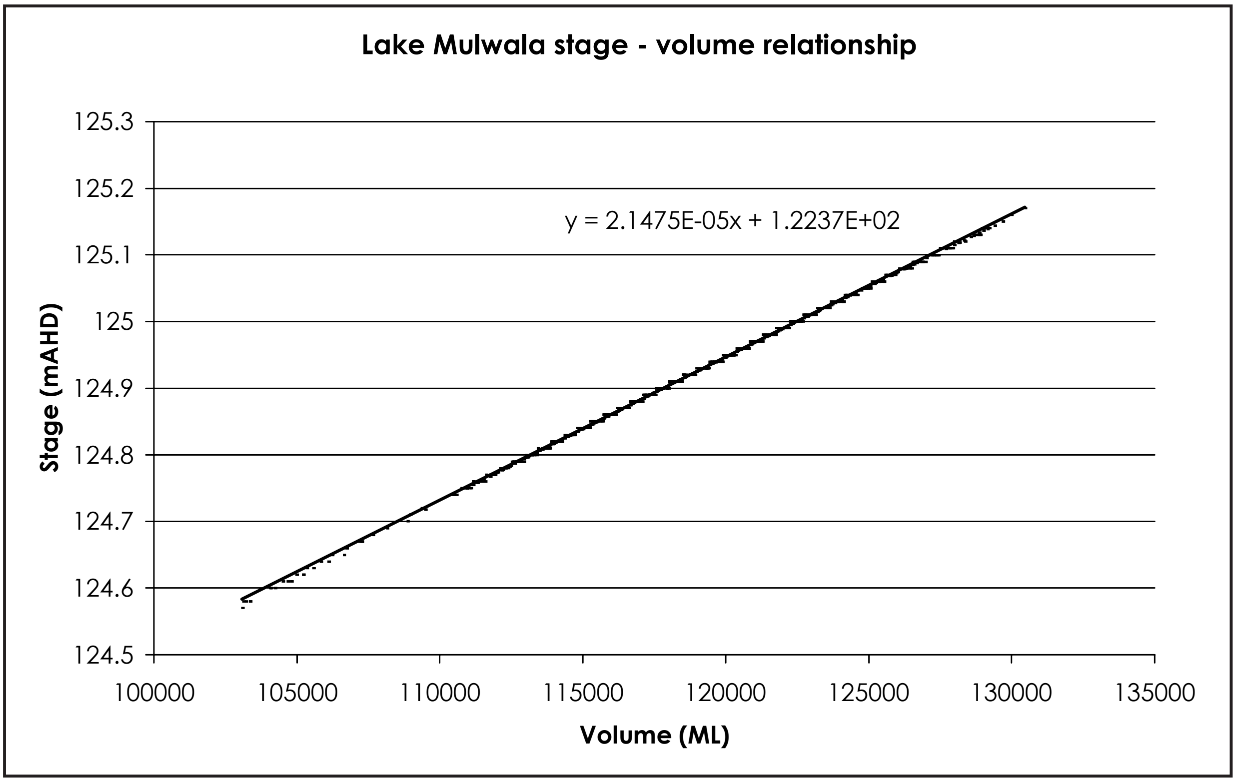


Figure 8.1 Lake Mulwala Stage - Volume Relationship

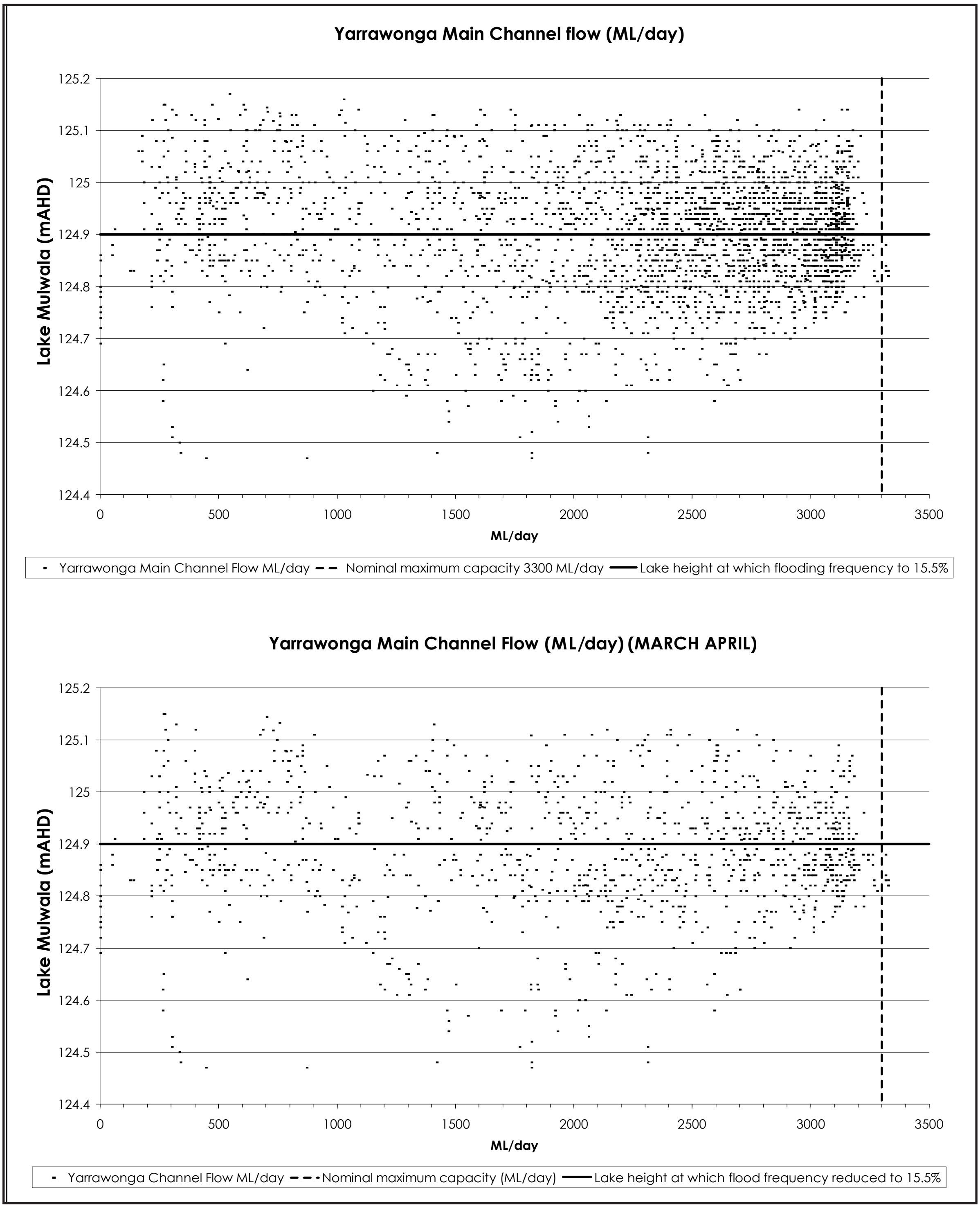


Figure 8.2 Lake Mulwala Scatter Plots Showing Outflows to Yarrawonga Main Channel

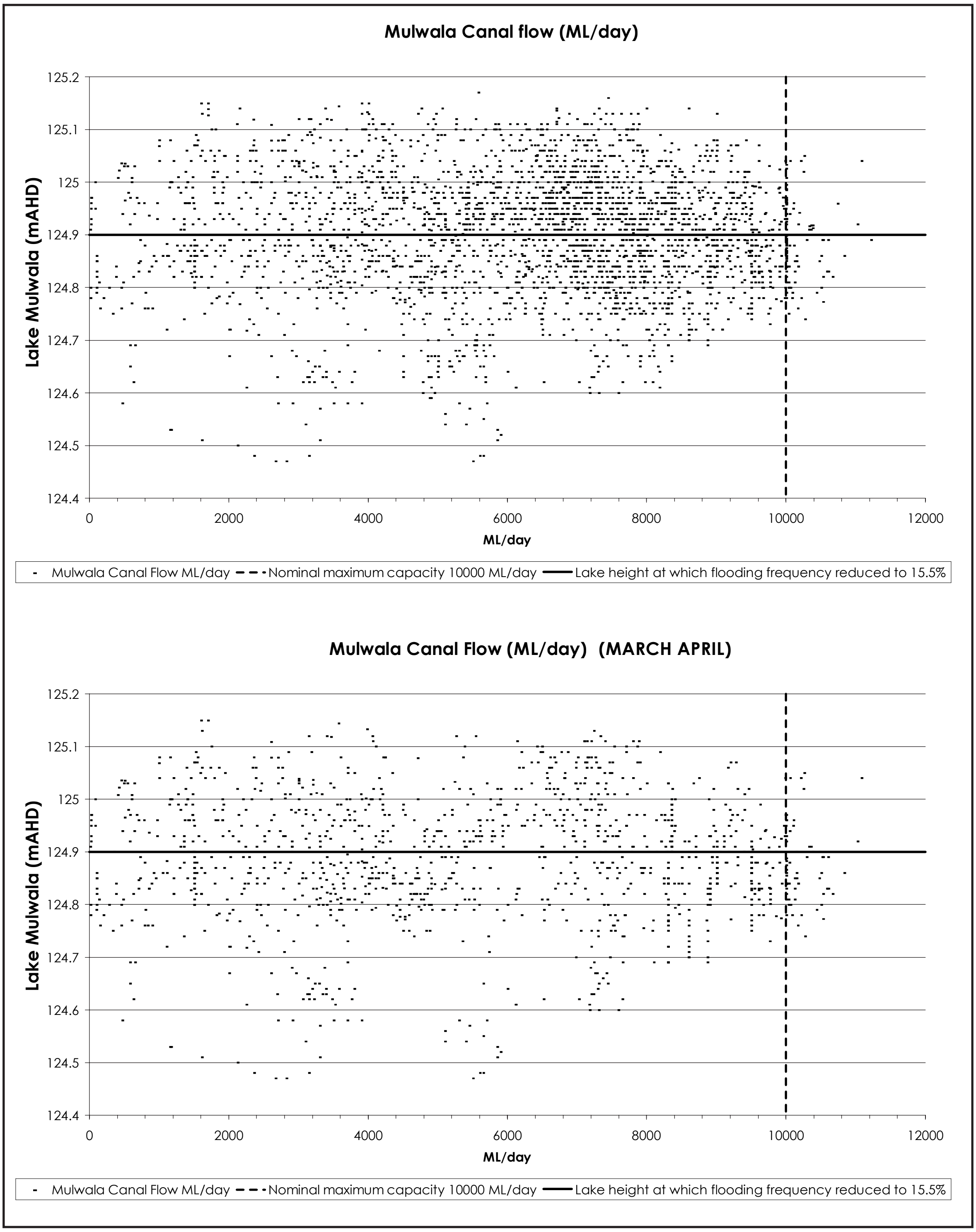


Figure 8.3 Lake Mulwala Scatter Plots Showing Outflows to Mulwala Canal

Analysis

Yarrawonga Main Channel

Both the scatter plots for Yarrawonga Main Channel indicate that the nominal maximum flow (3300 ML/ day) occurred when Lake Mulwala was between about 124.8m (11,3162 ML) and 125.1m (12,7131 ML). The maximum recorded flows (>3300 ML/day) corresponded to lake heights between 124.8 and 124.9 mAHD.

In order to reduce flooding frequency to 15.5% (pre-regulation frequency), approximately 9000 ML extra storage space is required at Lake Mulwala. This corresponds to a volume of 12,7131 - 9000 = 11,8132 ML, or 124.9 mAHD.

The scatter plots reveal that at least 3300 ML/day can flow in Yarrawonga Main Channel when the lake height is 124.9m, i.e. increasing the airspace at Lake Mulwala to reduce flooding frequency to 15.5% does NOT have any negative impact on irrigation supply flexibility (Yarrawonga Main Channel flows).

Mulwala Canal

Similarly, both the scatter plots for Mulwala Canal indicate that the nominal maximum flow (10000 ML/day) occurred when Lake Mulwala was between about 124.8m (11,3162 ML) and 125.1m (12,7131 ML). The maximum recorded flows (>3300 ML/day) corresponded to lake heights between 124.8 and 125.05 mAHD.

In order to reduce flooding frequency to 15.5% (pre-regulation frequency), approximately 9000 ML extra storage space is required at Lake Mulwala. This corresponds to a volume of 12,7131 - 9000 = 11,8132 ML, or 124.9 mAHD.

The scatter plots reveal that at least 10000 ML/day can flow in Mulwala Canal when the lake height is 124.9m, i.e. increasing the airspace at Lake Mulwala to reduce flooding frequency to 15.5% does NOT have any negative impact on irrigation supply flexibility (Mulwala Canal).

Conclusion

Increasing airspace at Lake Mulwala to reduce unseasonal flooding frequency to 15.5% (pre-regulation) does NOT result in any costs incurred due to reduced irrigation supply flexibility.

8.3.2 Cost: Reduced Hydroelectric Power Generation

Methodology

Increasing airspace at Lake Mulwala results in a cost due to the value of lost hydroelectric power generation.

The hydro-electric generation facility at Yarrawonga Weir was a venture undertaken between the Rural Water Corporation of Victoria and Power Facilities Pty Ltd. Electricity generated by the station is sold under contract to Power Australia Ltd. Construction commenced in December 1992 and power was first generated in June 1994 (GMW 2001b).

The station's maximum capacity is 9.4 MW, which corresponds to a maximum head differential of 9m. The average wholesale price of electricity in Victoria over the period 1 December 1999 to 30 April 2001 was $46.36/MWh (NEMMCO 2001).

A linear relationship exists between maximum capacity and maximum head differential (eg. increasing airspace by 0.1m reduces maximum capacity by 0.1/9.0 *9.2 = 0.1044 MW).

Thus a graph can be constructed illustrating cost (value of foregone electricity generation) vs. unseasonal flooding frequency. (See Figure 8.4).

The following assumptions underlie the analysis:

- If the maximum allowable level at Lake Mulwala is "X" mAHD, electricity generation is only affected on days where the historical records indicate a level "Y" mAHD where Y>X;
- On days where lake level is Y>X, it is assumed that the power facility was running at full capacity (maximum head of 9m), i.e. 9.4MW*24 hours = 225.6 MWh;
- Thus if the lake level was held at "X" rather than "Y" m, it would reduce the head by (Y - X)m to (9 - (Y - X))m , which corresponds to a power level of ((9 - (Y - X))m * 9.4MW / 9m) MW, and an energy level of ((9 - (Y - X))m * 9.4MW / 9m) * 24 MWh

This results in a significant overestimate of the costs due to foregone electricity because in practice, the system rarely (if ever) runs at full capacity (GMW 2001b).

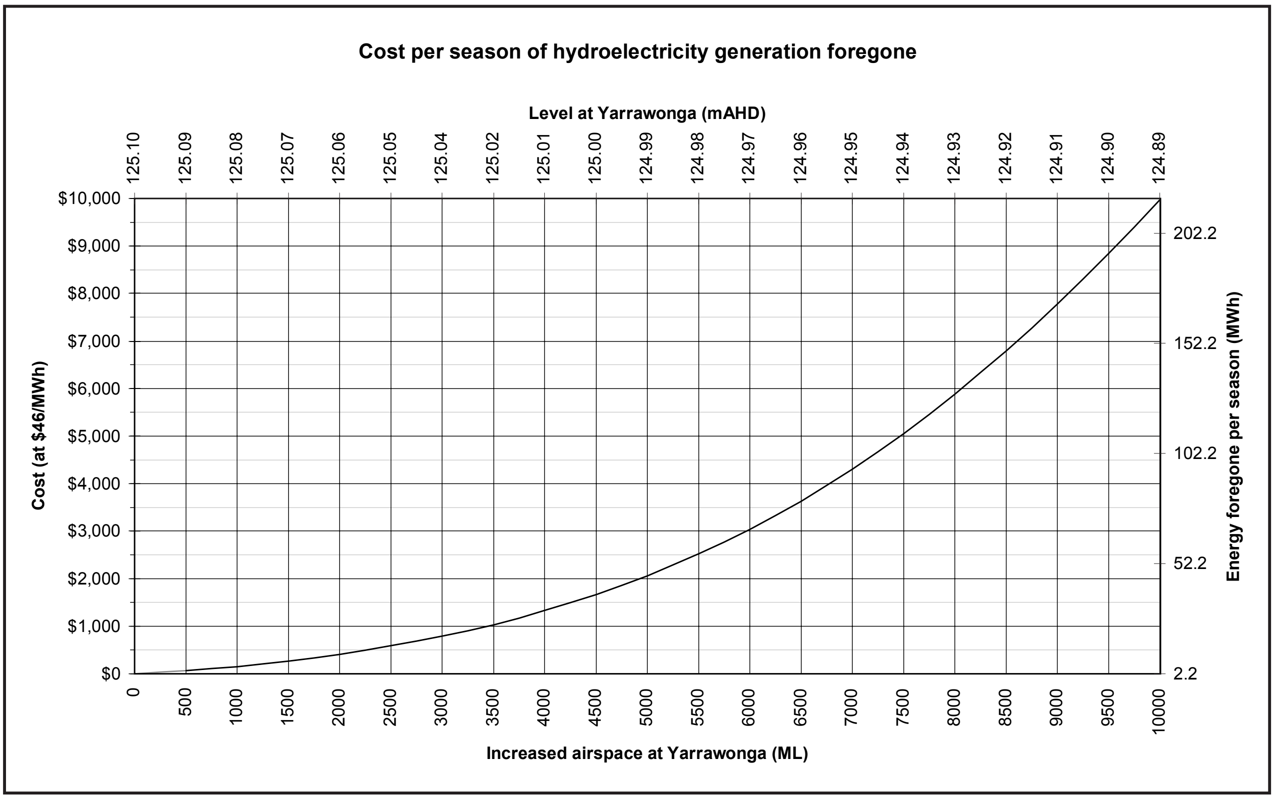
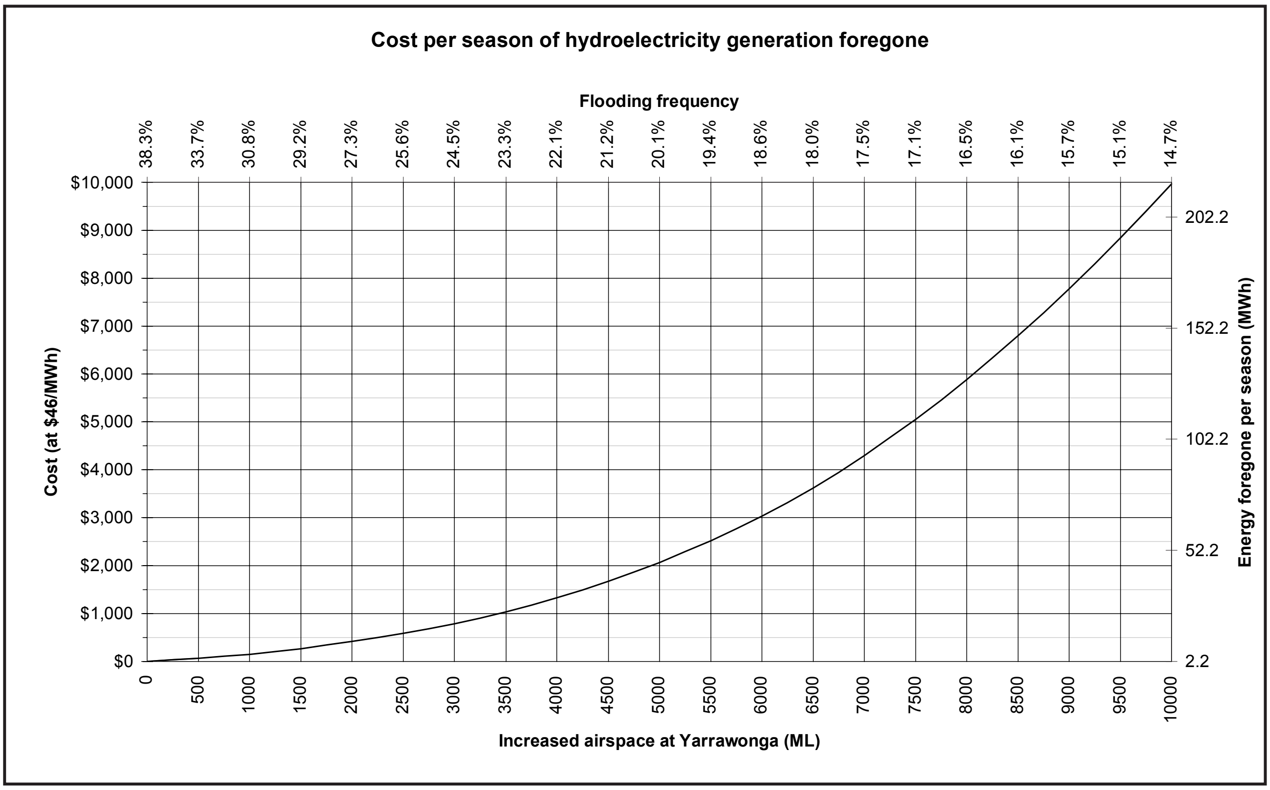


Figure 8.4 Cost of Hydroelectricity Generation Foregone



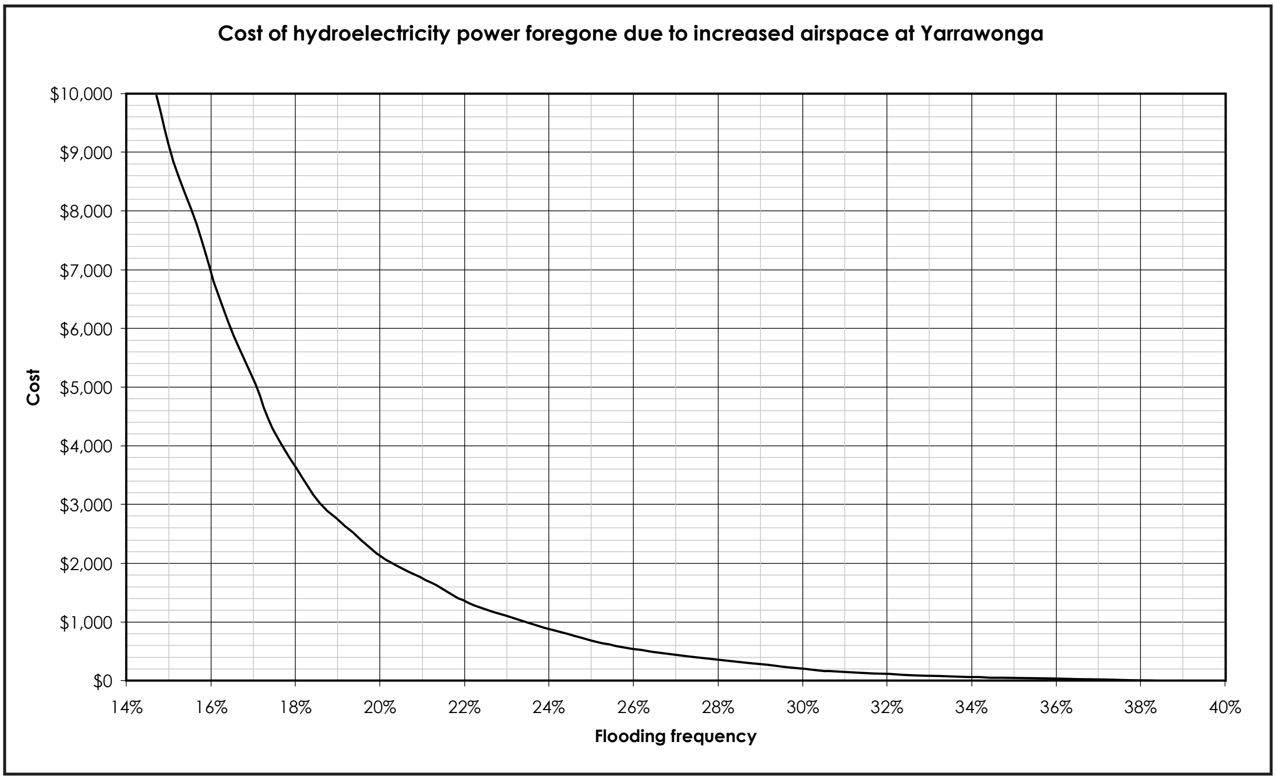


Figure 8.4 Cost of Hydroelectricity Generation Foregone (continued)

Analysis

To reduce flooding frequency to 15.5%, approximately 9100 ML extra airspace is required i.e. a reduction in maximum lake height from 125.1m to 124.9m. Reducing the maximum head differential by 0.2m reduces energy generation, at a cost of about $8,000 per season.

8.3.3 Benefit: Value of Water Saved from Reduced Flooding Frequency

Methodology and Data Requirements

The relationship between value of water saved and flooding frequency was derived and is illustrated in Figure 8.5.

The relationship between surplus flow volume per season, increased airspace and reduction in flooding frequency was illustrated graphically in Section 7 (i.e. increasing airspace by 5000 ML reduced surplus flow by 73,000 - 58,000 = 15,000 ML per season, which corresponds to a flooding frequency of 20%).

Under the current accounting rules of the Murray-Darling Cap, water that floods the forest is not included in the calculation of net diversions for Victoria. Therefore any water "saved" by reducing flooding cannot be sold for irrigation purposes. However, this saved water could be used for environmental flows and watering the forest during winter and spring. Ladson (2001, *pers comm.,* 20 May) suggests that the marginal value of water saved for environmental benefits is at least as great as if the water saved had been used for agriculture. Thus the gross margins for irrigated agriculture have been adopted as the marginal value of water saved from reduced flooding frequency.

Gross margins (activity income less associated variable costs) associated with irrigated agriculture vary considerably between region and for different landuses. Gordon *et. al*. (2000) estimated that the average farm gross margin foregone by irrigated agriculture is $60/ML. This is the figure adopted for the value of water saved from reducing the flooding frequency (Figure 8.6).

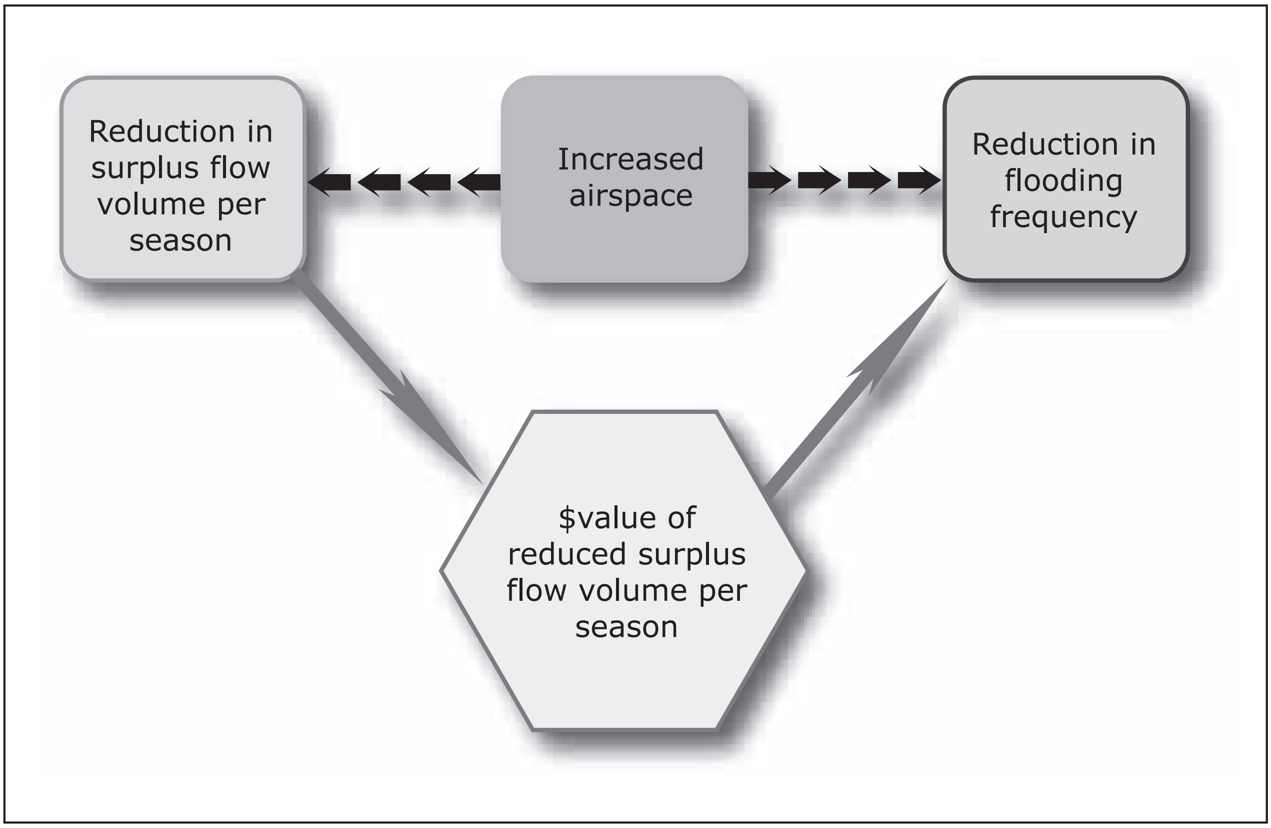
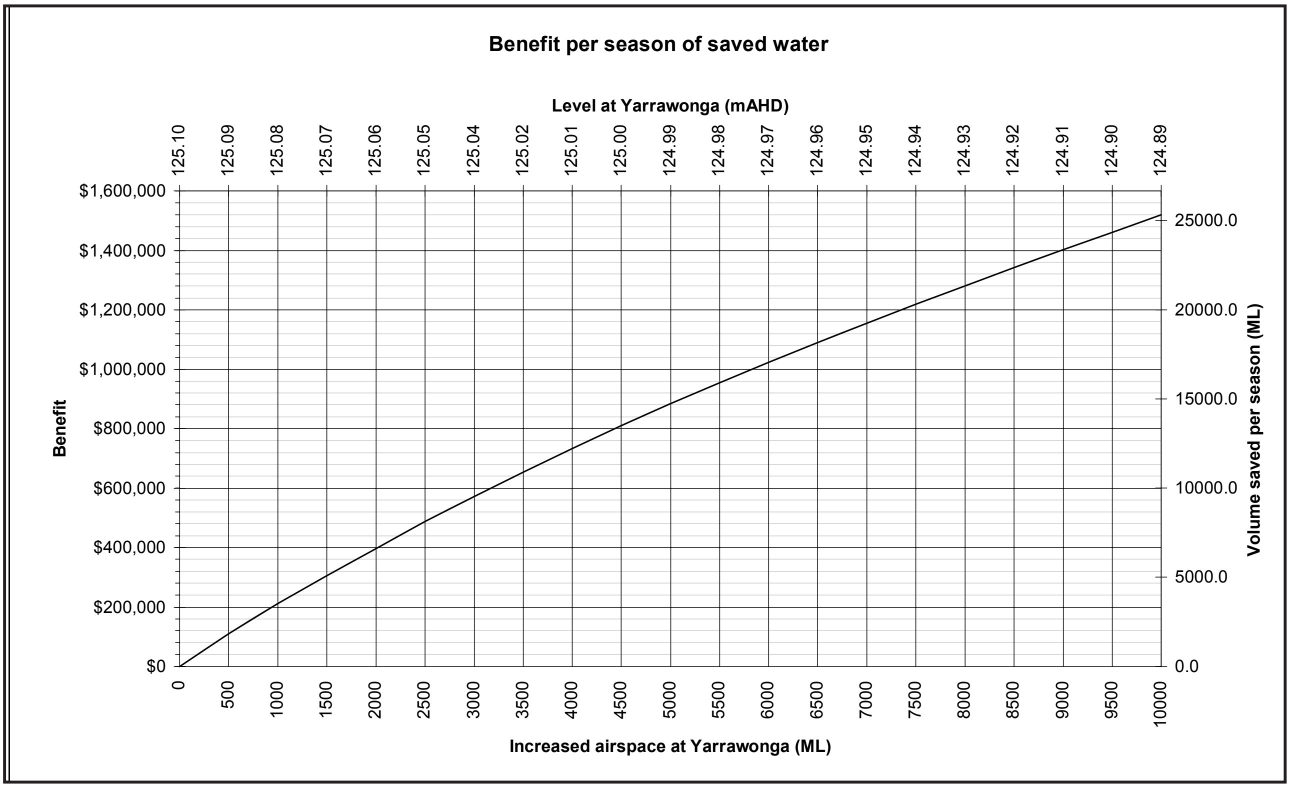


Figure 8.5 Valuing the Water Saved from Reduced Forest Flooding

Results



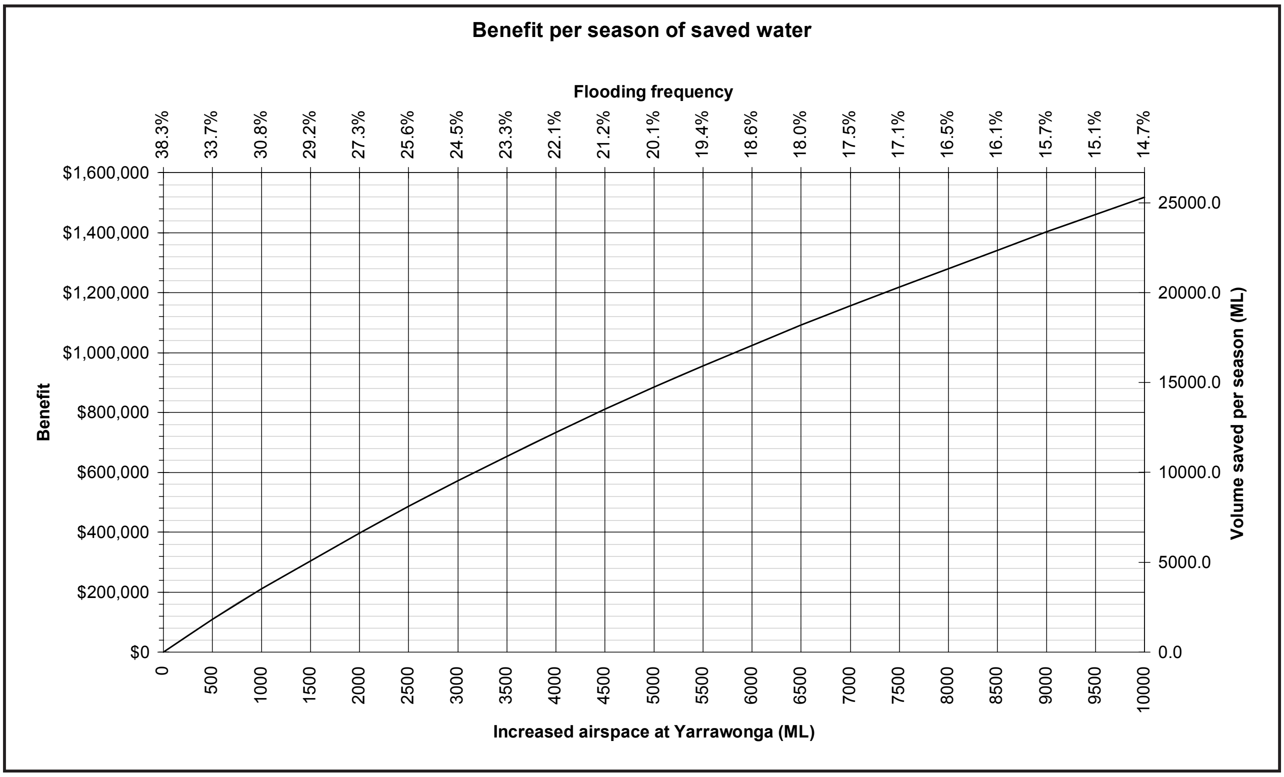


Figure 8.6 Benefit of Saved Water

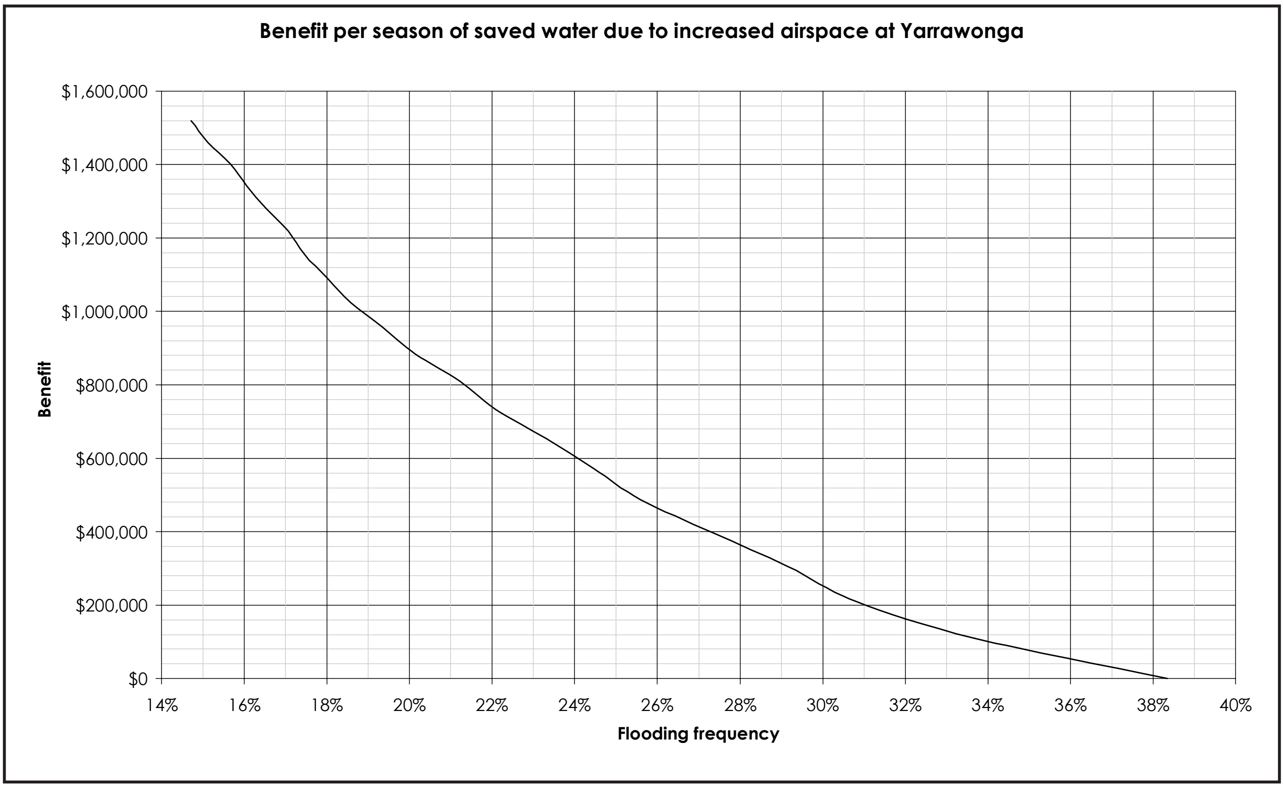


Figure 8.6 Benefit of Saved Water (continued)

Analysis

During 1980 - 2000, an average of 73,000 ML of unseasonal surplus water entered the forest each year (refer to section 7), corresponding to a flooding frequency of 38.3%. The equivalent cost of this (at a marginal value of $60/ML) is $4.4m.

At a marginal value of $60/ML, significant benefit accrues from reducing flooding frequency. If the flooding frequency was reduced to 15.5% (pre-regulation frequency), then the volume of surplus water entering the forest each year would be reduced by 24,000 ML to 49,000 ML, representing a saving of $1.44m.

8.3.4 Net Conservative Benefit

The costs of decreased hydroelectricity generation are insignificant compared to the benefits of saved water. (See Figure 8.7). Thus, net benefits accrue from increasing airspace to reduce flooding frequency, in the order of $1.44m (benefits of reducing flooding frequency to 15.5%).

8.4 Option 2: Costs and Benefits of Limiting Flow at Tocumwal

8.4.1 Cost: Reduced Water Supply Downstream of the Barmah-Millewa Forest

Methodology

Limiting the maximum flow at Tocumwal reduces the volume of water available for downstream users. Note that Victoria's total diversions may remain constant, i.e. part of the loss to downstream Victorian users will be offset by a gain in irrigation supply by upstream users. As this section only costs the loss to downstream users, it represents an overestimate of the net costs of reduced water supply downstream of the forest.

To calculate the volume of reduced water, daily flow data at Tocumwal was analysed for each day in December-April from 1980 - 2000.

To illustrate, consider the following imaginary daily flow sequence (see Table 8.1):

Table 8.1 Sample Flow Sequence at Tocumwal

Day	Flow at Tocumwal (ML/day)	Flow downstream of forest (ML/day)
1	10,200	10,200
2	10,250	10,250
3	10,350	10,350
4	10,500	10,500
5	10,700	10,700
6	10,800	10,800
7	10,300	10,300
Total (ML)		**72,800**

Note that on days 5 and 6, the flow available to downstream users is at a maximum 10,600 ML/day.

If the flow was maintained at 10,300 ML/day, the flow available to downstream users would be reduced (see Table 8.2).

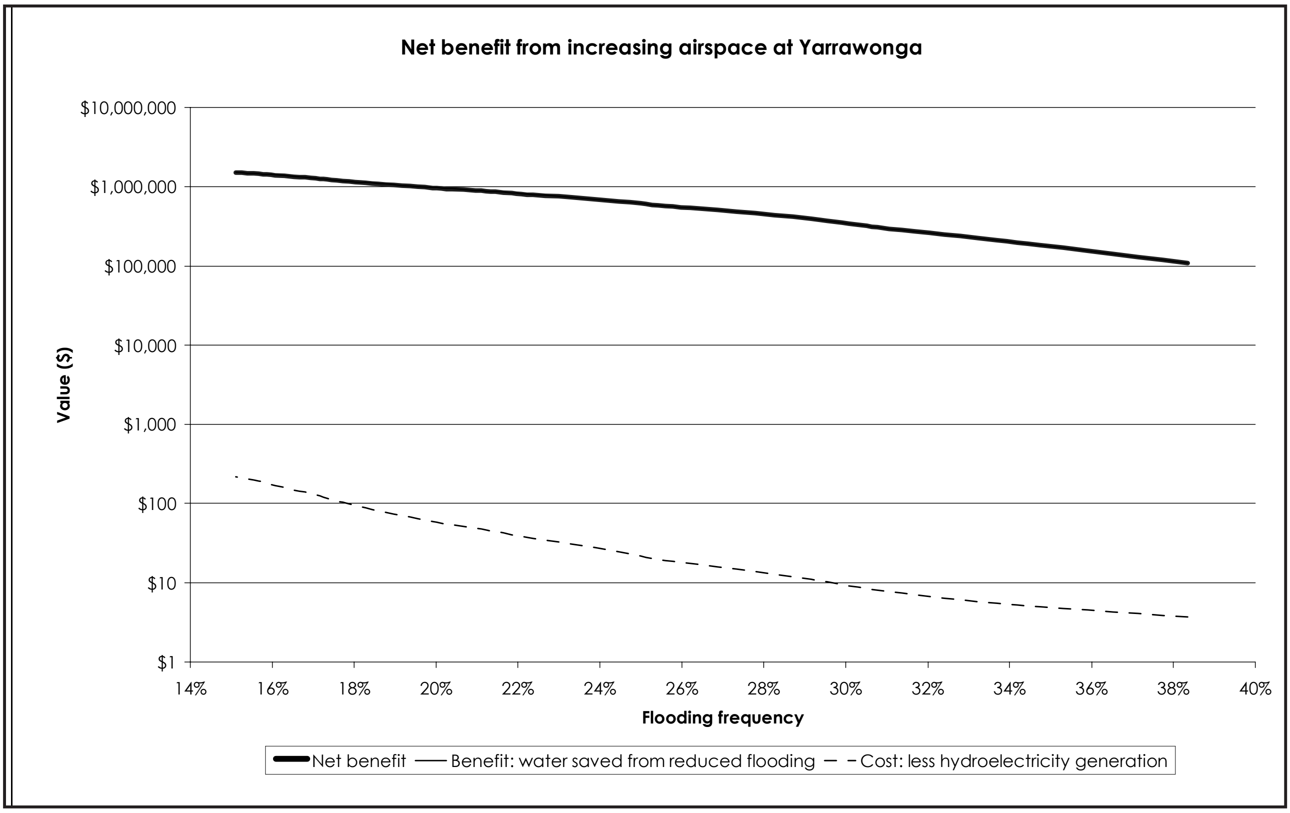


Figure 8.7 Benefit of Saved Water

Results

The cost to downstream irrigators of limiting flows at Tocumwal is shown in Figure 8.8.

Table 8.2 Effect of Limiting Flows at Tocumwal on Volumes Available to Downstream Users

Day	**Flow at Tocumwal (ML/day)**	**Flow available to downstream users (ML/day)**	**If flow limited to a maximum of 10,300 ML/day**	
			Flow (ML/day)	**Flow downstream (ML/day)**
1	10,200	10,200	10,200	10,200
2	10,250	10,250	10,250	10,250
3	10,350	10,350	10,300	10,300
4	10,500	10,500	10,300	10,300
5	10,700	10,600	10,500	10,500
6	10,800	10,600	10,600	10,600
7	10,300	10,300	10,300	10,300
Total (ML)		**72,800**		**72,550**

Note that on days 5 and 6, surplus flows occurred, with flow adjusted accordingly as in Section 7.

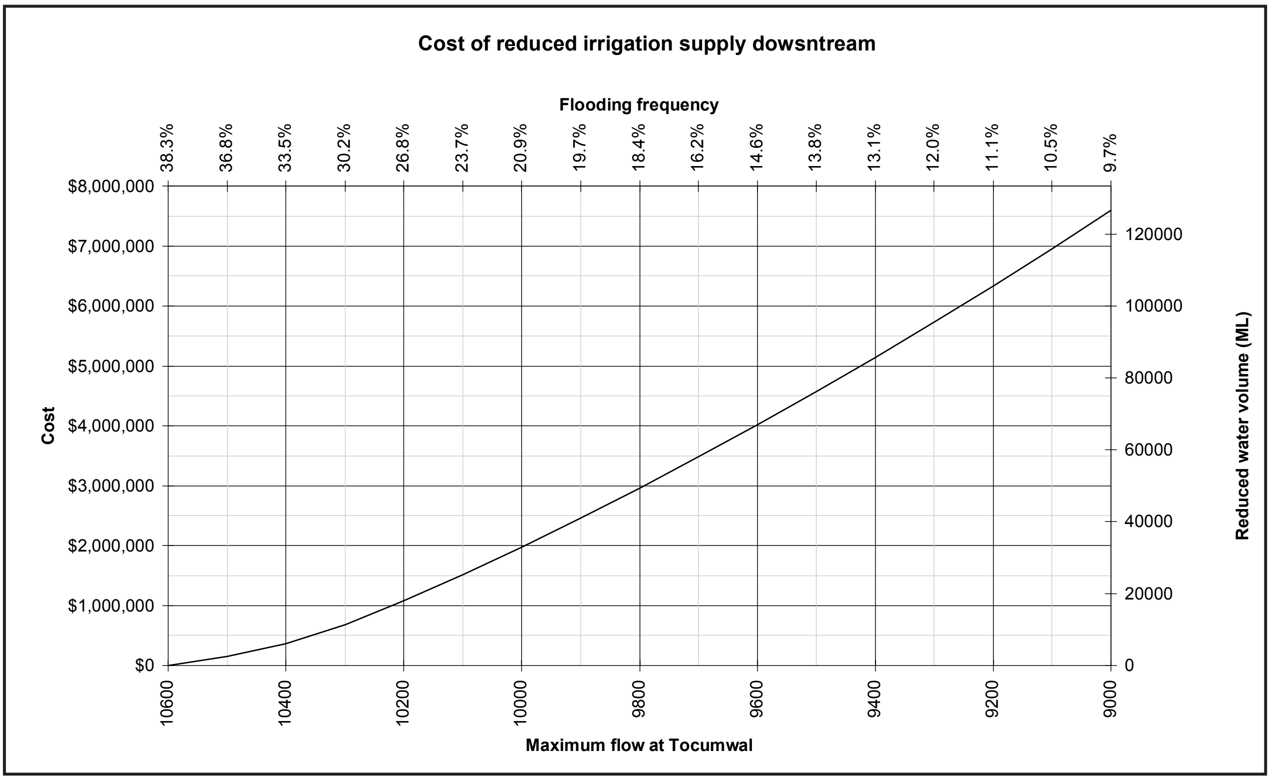


Figure 8.8 Costs of Reduced Downstream Water Supply

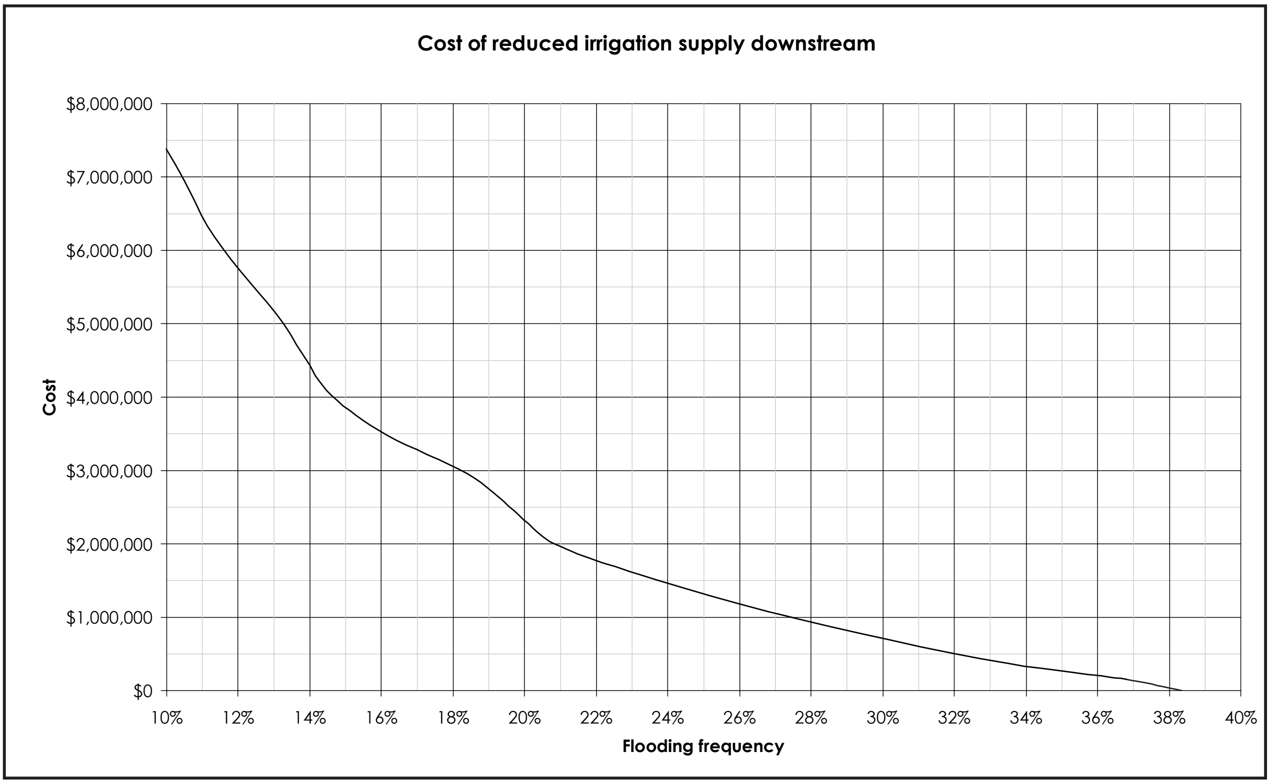


Figure 8.8 Costs of Reduced Downstream Water Supply (continued)

Analysis

The cost of reducing flooding frequency to 15.5% by limiting the maximum flow at Tocumwal to 9600 ML/day is in the order of $3.7m.

Significant decreases in flooding frequency (38.3% to 27.5%) can be achieved at a cost of $1m.

8.4.2 Benefit: Value of Water Saved from Reduced Flooding Frequency

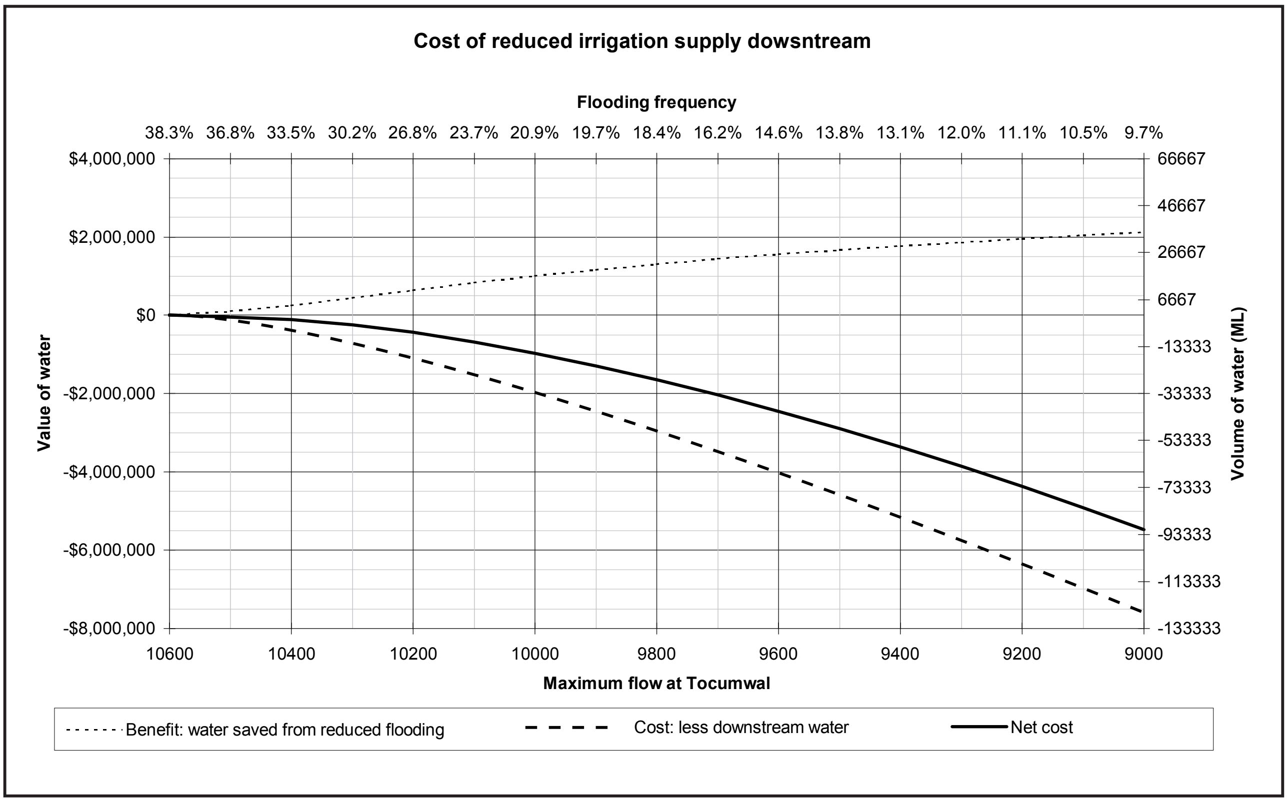
Refer to Section 8.3.3 for the methodology, data requirements and analysis of the benefit of water saved from reduced flooding frequency.

8.4.3 Net Conservative Cost

Analysis

The reduction of flooding frequency achieved by limiting maximum flow at Tocumwal incurs a net cost, because the volume of water saved is less than the reduced volume of water available to downstream Victorian irrigators. This cost is an "upper limit" estimate, which does not include analysis of the potential for increased upstream use.

The flooding frequency could be reduced to 15.5% at a net cost of $2.5m. However, the flooding frequency could be significantly reduced (from 38.3% to 21%) at a net cost of $1m. (See Figure 8.9).



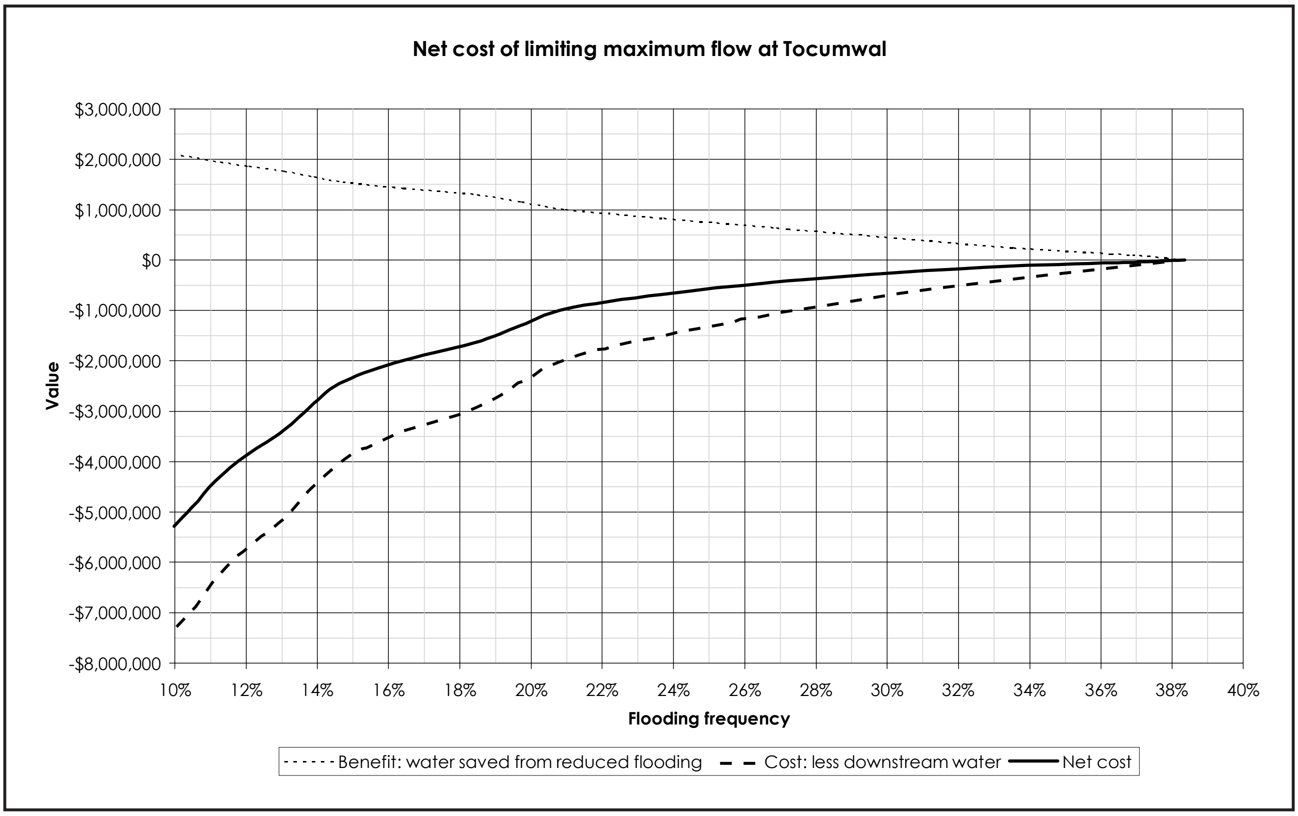


Figure 8.9 Net Cost of Limiting Maximum Flow at Tocumwal

8.5 Summary: Comparison Between Options

The reduction of flooding frequency to 15.5% can be achieved by:

- increasing airspace at Yarrawonga by 9100 ML, at a net benefit of $1.44m; or
- limiting maximum flow at Tocumwal to 9750 ML/day, at a net cost of $2.5m.

Clearly, it is preferable to increase airspace at Yarrawonga.

The benefit of $1.44m is understated, because it does not include:

- increased timber production due to reduced tree death;
- increased tourism and recreation;
- increased ecological, environmental and heritage values.

9. Conclusion and Recommendations

The detrimental impacts of summer-autumn flooding of the Barmah-Millewa Forest have been well documented since the early 1980's. Both the results of analytical research and anecdotal observations point to increased red gum tree death in low-lying areas and the increasing loss of moira grass plains.

The management agencies at State and Federal government level pay heed to this problem by highlighting its importance in their published management strategies and plans for the forest. However, recent priorities have concentrated on environmental flows for winter-spring flooding, rather than the management of unseasonal surplus flows. Little analytical work has been conducted to quantify the extent and severity of flooding, or to investigate the feasibility of management options.

This report investigated the potential for two management options related to increasing system flexibility, namely increasing airspace at Yarrawonga and limiting the maximum flow at Tocumwal. The main findings of this project are summarised below.

Historical Analysis

A comparison of historical flow data from 1908 - 1929 (before the construction of the Hume) and 1981 - 2001 (present regulation conditions) revealed that there have been significant changes in the patterns of River Murray flow at Tocumwal during summer and autumn. During December to April (particularly in February and March), flows are far more likely to be above 10,600 ML/day now (36.5% of the time) than before 1908 (15.5% of the time). This means that regulation has increased the number of days in summer-autumn during which flooding occurs in the Barmah-Millewa Forest.

However, an application of the relationship derived by Bren *et. al*. (1987) linking flow at Tocumwal to proportion of forest flooded revealed that more extensive floods (in which over 30% of the forest is flooded) are now less frequent. This is because the construction of dams, locks and weirs has enabled mitigation of larger River Murray flows. Consequently, there are some parts of the forest (~30% of the area) which are flooded more than twice as frequently in summer-autumn now than before 1929, which leads to tree stress and death. However, the remainder of the forest (~70% of the area) is flooded less frequently now than before 1929. Both these changes have resulted in changes to the "natural" vegetation associations and patterns in the forest.

Unseasonal Surplus Flow Events

There are three main methods identified from the literature for identifying unseasonal surplus flow events, which yield significantly different results. The method which involves analysing daily data for flows that exceed 10,600 ML/day at Tocumwal is the preferred method in terms of a computable data set and applicability to current conditions.

The use of this method revealed that during the period 1980 - 2000, there were 82 surplus flow events (4.1 per year), which caused flooding in the forest in 38.3% of days in December-April. The average event duration was 14.1 days (median 10 days); average peak excess flow was 2211 ML/day (median 1133 ML/day); and average total flow per event was 17,833 ML (median 7960 ML).

Relation to System Flexibility

If system flexibility had been greater over the period 1980 - 2000, then there would have been significantly less frequent flooding of the Barmah-Millewa Forest. If 1980 - 2000 is assumed to represent current water demand conditions, then flooding frequency can be reduced from 38.3% to 15.5% by:

- increasing airspace at Yarrawonga by 9100 ML (maintaining height at 124.9m, 0.195m below the maximum); OR
- limiting the maximum flow at Tocumwal to 9600 ML/day.

Smaller increases in system flexibility can also have a significant impact on reducing flooding frequency, e.g. a frequency of 20% will be achieved by increasing airspace by just 5000 ML or limiting the maximum flow at Tocumwal to 9900 ML/day.

Economic Analysis

Approximately $4.4m of water (73,000 ML/year) per year is currently "lost" to forest flooding during

December-April. Reducing flooding frequency from 38.3% to 15.5% would reduce the total surplus volume per year to 49000 ML (an equivalent saving of $1.4m).

Reducing Limiting the maximum flow at Tocumwal to 9600 ML/day to reduce flooding frequency to 15.5% results in a net cost of $2.5m (less water available to downstream users, but water saved from flooding for environmental flows). However, this figure is not a true indicator of net economic cost. Net economic cost will be far lower, due market (forestry and tourism) and non-market (environmental) benefits from reduced forest flooding and the potential for greater upstream use.

Increasing the airspace at Yarrawonga by 9100 ML does not limit the outflow into the irrigation areas through Yarrawonga Main Channel and Mulwala Canal. Very minor losses in hydroelectric power generation will be incurred, but they will be more than offset by the value of the water saved from flooding ($1.4m). This figure assumes a marginal value of water equivalent to the agricultural gross margin ($60/ML), which is likely to be an understatement of the value of water if it were used for environmental watering purposes. Furthermore, the $1.4m benefit does not include the value accrued from reducing flooding frequency.

The analysis conducted in this project indicates that significant net benefits will accrue from increasing airspace at Yarrawonga to reduce the frequency of summer-autumn forest flooding.

9.1 Recommendations for Further Research

There are three main areas in which further research could be undertaken

- Alternative modelling/analytical techniques;
- Extended economic analysis; and
- Investigation of other management options.

9.1.1 Alternative Modelling and Analytical Techniques

A more extensive system approach could be taken to modelling the River Murray flow, storage at Lake Mulwala and forest flooding (this would involve relaxing the assumption that individual unseasonal surplus flow events are independent, and enable the incorporation of forecasted changes in irrigation demand). The MDBC currently runs a model, which simulates these conditions on a monthly timestep, and is in the process of refining the model to generate daily data.

The results from this project could be used in a detailed analysis of the changes in forest ecology which will be experienced under "do-nothing" or "increase-flexibility" situations.

9.1.2 Extended Economic Analysis

A detailed investigation of forest ecology would facilitate the economic analysis of the changes to timber production. There may also be implications for salinity levels in the Murray River from the proposed operational changes and these could be investigated by the MDBC using their models.

Attempts could also be made to use and evaluate valuation techniques to determine the non-market gains from reduced forest flooding.

Alternative values for the agricultural gross margin could be adopted under different scenarios of water allocation, e.g. for the situation of limiting maximum flow at Tocumwal, the value of the water depends on which downstream regions/land uses will have restricted availability.

9.1.3 Investigation of Other Management Options

This project considered only two management options for reducing the frequency of unseasonal surplus flows. Other management options (some of which may require capital works) could be evaluated for their effectiveness in reducing the frequency of unseasonal surplus flows, and corresponding net discounted cost/benefit.

Possible management options are discussed below.

Hume to Yarrawonga Weir Operations

The current operational rules governing rates of drawdown in the Murray reach between Hume Dam and Yarrawonga (150mm/day maximum at Doctors Point) are designed to protect against the risk of bank slumping. The drawdown rates are based on empirical estimates and past observations of bank slumping. However, it has been suggested that the regulated drawdown rate may be conservative in comparison to rates of natural recession (DLWC 1996). The development of riparian vegetation may also allow the drawdown rate to be increased without compromising bank stability.

With a higher drawdown rate, releases from Hume can be reduced more quickly if rain rejections occur. Therefore Hume to Yarrawonga would be reduced, mitigating unseasonal flooding in the Barmah-Millewa forest.

On-Route Storages

The operation of on-route storages adjacent to the irrigation systems would allow rejected water orders to be captured for later use. On-route storages would increase flexibility of the operation of the water delivery system and may help to overcome current problems of inaccurate water ordering (DLWC 1996).

Forest Diversions

This involves the establishment of regulators in the eastern part of the forest to enable a diversion of unseasonal surplus flows to Bullatale Creek, increasing escape capacities and constructing a bypass system.

During summer and autumn, the escape capacity for excess water within the irrigation system is restricted because of operational requirements. This is so because Mulwala Canal is run at near-full capacity to supply irrigators, with limited capacity for excess water.

A combination of increased escape capacity and a system of channels to bypass the forest would reduce the volume of surplus irrigation water continuing to the forest.

Streamlining Water Ordering Procedure

Currently, there is no incentive in place for irrigators or irrigation authorities to cancel water orders early when localised rainfall occurs. Irrigators can reduce their water orders at short notice without decreasing their water entitlement or being charged for the water they ordered but did not use.

A water ordering system that encouraged irrigators to order accurately and cancel early could reduce the volume of unseasonal surplus flows.

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Appendix A: Development of Research Methodology

1. Research Methodolgy and Data Requirements

1.1 Overview

This section presents the development of a research methodology which enabled an evaluation of how the risk of unseasonal surplus flows, which affect the Barmah-Millewa forest, is related to flow in the River Murray system.

This section includes a brief review of the research methodology to date. The emphasis of the initial research phase was to document, investigate and understand the physical, regulatory, institutional and economic environment of the problem.

The information gained in the initial research phase was used to identify and evaluate possible avenues of research, and to determine data requirements and availability. This section should be read as a proposed research plan, as it is likely that the methodology will evolve as data and results become available.

Furthermore, it is recognised that this research project is constrained by limited time and resources. It is expected that the majority of "possible avenues of research" will become "recommendations for further research".

1.2 Initial Research Phase Methodology

The research steps conducted so far include:

- identification of problem;
- identification of stakeholders and management agencies responsible for the use of the Barmah-Millewa Forest and the River Murray;
- literature review of information available in refereed journals and other publications, including an overview of the evolution of management principles and practices for the region;
- documentation of background information relevant to the project.

These steps enabled an understanding of the complex physical system and the identification of agencies and institutions from which further information would be available. A record of personal correspondence is included in Appendix A.

1.3 Research Avenues

1.3.1 Components of Research Methodology

To enable the aims and objectives of this project to be met, the following research methodology components were identified:

1. Analyse historical data to investigate changes in River Murray flows (caused by regulation), and to investigate changes in patterns of flooding in the Barmah-Millewa Forest;
2. Define and establish a method for identifying individual unseasonal surplus flow events (for the period in which the current level of river regulation and irrigation demands is thought to apply), including calculation of event characteristics including total excess volume and peak excess flow rate;
3. Define what is meant by the "risk" of a unseasonal surplus flow event occurring, and establish a methodology for calculating this risk;
4. Use knowledge of physical environment to identify factors (including those relevant to the regulation of the Murray) which influence this "risk";
5. Establish a method establishing a relationship between the factors identified in Part 3 and the "risk" of unseasonal surplus flows; and
6. Evaluate the economic benefits and costs of increasing system flexibility to reduce the risk of unseasonal surplus flows.

1.3.2 Analyse Historical Data

Possible Research Avenues

Most of the material in Background Information (Section 3) about the changes caused by regulation is qualitative. Numerical analysis of historical data (for example through flow duration curves) will provide some quantification of the patterns of change.

These patterns of change could include:

- proportion of the Barmah Forest flooded during summer;

- flow characteristics at Tocumwal and Yarrawonga before and after the construction of the Hume (1934) and the increase of its capacity (1961);
- flow characteristics of the main irrigation diversion channels from Yarrawonga Weir (Mulwala Canal and Yarrawonga Main Channel).

Evaluation

The purpose of historical analysis is to support background information, to provide evidence that flow and flooding patterns have changed over time, and thus to validate the aim of this research project. Analysis of the changes in seasonality of flooding would support the choice of unseasonal surplus flow season (eg. November - May, or December - May).

1.3.3 Defining and Identifying Unseasonal Surplus Flow Events

Possible Research Avenues

Sections 2 and 3 outline the situation in which unseasonal surplus flow events (rain rejections and river freshes) occur, and the impacts of these events. Unseasonal surplus flows could thus be identified according to cause (cancellation of irrigation orders) or effect (on flow levels in the River Murray system, or flooding patterns in the Barmah-Millewa Forest).

Unseasonal surplus flow events should be defined in terms of duration (start date and end date), severity (peak excess flow volume and total excess flow volume), and season.

Proposal 1: Historical Analysis

This step analyses the patterns of change (to flows and floods) caused by regulation.

(a) ANALYSIS OF RIVER MURRAY FLOWS IN SUMMER-AUTUMN

Establish flow duration curves for daily flows during the summer-autumn period at Tocumwal. Analyse individual months as well as combinations of months.

i) Divide record sets according to periods of regulation, including one or both of the following:
- construction of the Hume Dam
- extension of the Hume Dam

ii) Divide record sets according to periods of time, eg. into periods of 10 or 20 years.

(b) ANALYSIS OF BARMAH FOREST FLOODING IN SUMMER-AUTUMN

Using the relationship derived by Bren, O'Neill and Gibbs (1986), analyse available daily flows at Tocumwal to determine changes in the proportion of Barmah Forest flooded during the summer-autumn period of November - May. Analyse individual months as well as combinations of months. Divide record sets as in (a).

The presentation of this analysis could include:

i) Time series graph of proportion of forest flooded, averaged over a month, for each month from November to May.

ii) Flow duration curves representing: vertical axis - frequency (% of days) during summer-autumn period that the forest is flooded; horizontal axis - proportion of forest flooded greater than (0 - 100)% of total area.

Possible ways to define the season in which unseasonal surplus flow events can be identified are:

(a) The irrigation season, which is that part of the year during which diversions are made from Yarrawonga Weir for irrigation purposes;

(b) The summer-autumn season during which flows in the Barmah-Millewa Forest are greater, more frequent and/or of greater duration than in pre-regulation (before 1934) times;

(c) A definition (such as November - May or December - April) based on references or definitions in other research papers.

Possible ways to identify the duration and severity unseasonal surplus flow events are:

(d) An unseasonal surplus flow event occurs when irrigator(s) cancel water orders, and the configuration of flowrates and volumes in the regulated system is such that the MDBC orders that flow must be diverted into the Barmah or the Millewa Forest (NSW and Victoria take unseasonal surplus flows in alternate years). The regulator capacity of the forest is insufficient to prevent all flows from overflowing the forest levees.

    The duration could refer to the time during which the MDBC has ordered that offtake regulators stay open, and the severity could refer to the peak flow and total volume of water released into the forest.

(e) An unseasonal surplus flow event occurs when flooding occurs in the Barmah Forest. The severity could refer to the proportion of area flooded, which could be determined from the relationship with peak flow at Tocumwal or monthly flow at Yarrawonga established by Bren, O'Neill and Gibbs (1986). The duration could refer the time in which the proportion of area flooded is greater than a specified level. Note that river freshes could exacerbate the flooding caused by rain rejections.

(f) An unseasonal surplus flow event occurs for the duration of flows exceeding the regulated flow limit (11,400 ML/day) downstream of Yarrawonga Weir. Indicators of severity could be the peak daily flow or total volume of flow for the event. This methodology was used by DLWC (1996). A similar method would set the threshold at 10,600 ML/day at Tocumwal (the capacity of the Choke).

(g) An unseasonal surplus flow event occurs when the flow at Picnic Point exceeds a gauge height of 2.53 m.

Evaluation

Option (a) for defining the season of unseasonal surplus flow events would require analysis of flows in the Mulwala Canal and Yarrawonga Main Channel to identify the start and end of irrigation season each year. This would be a simpler and more direct method than (b), but may extend beyond the summer-autumn period during which flows in the Forest are considered undesirable. Method (b) is a component of Proposal 1. It would involve analysis of flow data for Tocumwal and rely on the assumptions of Bren's model in calculating the proportion flooded of Barmah Forest.

Definition (c) proposes a standard season which could be used for all years of data to define unseasonal surplus flow events, but it is possible that using Definition (c) might exclude unseasonal surplus flow events which occurred outside the season, and include events which are largely natural floods and not rain rejection flows (depending on the method of identifying an event).

Method (a) of identifying the duration and severity of unseasonal surplus flow events requires operational information from the MDBC about flows in the Barmah-Millewa Forest. It is unlikely that this information is readily available. Data is obtainable to identify the duration and severity of unseasonal surplus flow events using Methods (b) or (c). The advantage of using Method (b) is that it relates unseasonal surplus flows directly to the impact on the Forest. However, the relationship derived by Bren relates only to the Barmah Forest, there are several assumptions implicit in this relationship, and the capacity of regulators to prevent flooding in the forest has increased since his study period (1963 - 1986). Method (c) relates unseasonal surplus flows to their impact on the forest only indirectly, but total volume of flow for the event is a useful indicator of severity. Method (d) relates to current operational rules established by the MDBC.

Proposal 2: Identifying Unseasonal Surplus Flow Events

(a) Use the results from "Historical Analysis" to identify the months of the year in which regulation has caused significant increases in forest flooding. Use these months as the established season for identifying unseasonal surplus flow events.

(b) Identify the start, end, duration, peak volume and excess volume of unseasonal surplus flow events for the period 1980 - 2000. The following methods can be used and their sensitivity to assumptions evaluated:

  i) Flow exceeds 11,400 ML/day downstream of Yarrawonga Weir (DLWC 1996);

  ii) Flow exceeds a gauge height of 2.53 m at Picnic Point (MDBC operating rule);

  iii) Flow exceeds 10,600 ML/day at Tocumwal (current capacity of the Choke);

If the methods identify significantly different unseasonal surplus flow events, then further evaluation could be conducted to determine which method is preferred.

1.3.4 Defining "Risk of Occurrence"

Possible Research Avenues

Having defined and identified individual unseasonal surplus flow events, a meaningful and working definition must be applied for the risk (or probability) of occurrence. In this context, the two aspects of probability are timing and severity. Possible definitions of risk are:

(a) the probability of a unseasonal surplus flow event commencing within the next 24 hours, the next two days, or within the next week (for example);

(b) the probability of a unseasonal surplus flow event of X severity and/or Y duration commencing within the next 24 hours, the next two days, or within the next week;

(c) an index value which encompasses the probability of a unseasonal surplus flow event of X severity and/or Y duration commencing within the next 24 hours, the next two days, or within the next week. The greater the probability, severity and duration, the higher the index value.

Evaluation

The selection of "within the next 24 hours" as the timing for risk would adequately satisfy the aims of this project. This is essentially an "instantaneous risk", i.e. it asks: given the current state of the system, what is the risk that a unseasonal surplus flow event will occur now?

Consideration should be given as to whether absolute risk (eg. the risk of an event occurring at a specific river flow) or relative risk (eg. the increase in risk due to higher river flows) is more relevant.

Further evaluation is required to determine whether sufficient data exists to create an index which provides a meaningful description of unseasonal surplus flow probability, severity and duration.

Measuring the severity of an event according to total excess volume will enable the analysis of how increasing air space at Lake Mulwala will reduce the number of unseasonal surplus flows.

Measuring the severity of an event according to peak or daily excess flow rates will enable the analysis of how restricting the flow of the River Murray upstream of the forest will reduce the likelihood of unseasonal surplus flow events and unseasonal surplus flow days respectively.

Proposal 3: Defining "Risk of Occurrence"

(a) The risk of occurrence has been defined as the instantaneous probability that a unseasonal surplus flow event will commence. This risk may be absolute or relative.

(b) Two measures of severity of a unseasonal surplus flow event are:

  i) total excess volume (which will onflow into the Forests).

  ii) peak and daily excess flowrates

1.3.5 Identifying Factors which Influence Risk

Possible Research Avenues

The following factors influence the risk of unseasonal surplus flow occurrence:

(a) Flow rates / levels in the Murray River System
- The flow variables could be measured at:
    - Tocumwal
    - Yarrawonga
    - Hume
- The flow variables could include
    - daily flows
    - previous daily flows
    - average flow over last X days/week(s)/month(s)

(b) Level of storages and channels (air space)
- Lake Mulwala
- Hume Dam
- Irrigation and bypass canals
- Forest offtake channels

(c) Climate
- rainfall (current daily, previous daily, current forecast, average over past day(s)/week(s)/month(s))
- temperature and evaporation

(d) Irrigation variable
- ordering and rejecting procedures
- volumes of current and future orders

(e) Rate of drawdown allowed for Hume reservoir

Evaluation

Many of these variables are likely to be highly correlated with each other. Some, such as ordering and rejecting procedures for irrigation water (d), may be difficult to quantify. The maximum rate of drawdown allowed for Hume reservoir has been constant since 1961.

This project aims to evaluate system regulation and flexibility with regards to unseasonal surplus flow events. A useful, and reasonable, simplification would be to assume rainfall patterns and irrigation variables have remained constant for the period of analysis.

Proposal 4: Identify Factors which Relate to Risk

(a) Possible flow rates (size of unseasonal surplus flows)
- i) daily flow of the River Murray at Tocumwal;
- ii) daily flow of the River Murray at Doctor’s Point;
- iii) daily flow of the River Murray at Picnic Point; and
- iv) daily flow of the River Murray at Yarrawonga.

Average previous weekly and monthly flow rates could also be analysed.

(b) Level of storages (ability to regulate)
- i) U/S Yarrawonga Weir (the day before a unseasonal surplus flow event commences);

Average previous weekly and monthly flow rates could also be analysed.

1.3.6 Determine Methodology for Testing Significance of Variables

Possible Research Avenues

Correlation analysis could provide an indication of which variables listed in (3) are significant in determining the risk of unseasonal surplus flow occurrence.

An important aspect of testing the significance of variables is establishing a relevant time period from which to draw data. This is likely to vary for different variables. The longest time period should be chosen which is relevant to all factors.

Evaluation

DLWC (1996) conducted some analysis of unseasonal surplus flow events for the period 1975-1996. Graeme Hannan of Goulburn-Murray Water (*pers. comm.* 2001, 21 March) suggested that unless changes to irrigation demands and operational procedures could be accounted for, flows should not be analysed before 1970. However, sensitivity tests and comparison of risk indices calculated for different time periods (eg. 1975-1985 compared with 1985-1995).

Proposal 5: Establish Relationships Between the Risk of Unseasonal Surplus Flows and Influencing Factors

(a) Calculate correlation coefficients to determine correlation between:
  i) total excess volume and risk of unseasonal surplus flow event;
  ii) peak excess flow rate and risk of unseasonal surplus flow event; and
  iii) daily excess flow rate and risk of unseasonal surplus flow event.

(b) Establish cumulative probability plots to illustrate:
  i) distribution of total excess volumes amongst unseasonal surplus flow events;
  ii) distribution of peak excess flowrates amongst unseasonal surplus flow events; and
  iii) distribution of daily excess flowrates amongst unseasonal surplus flow days.

1.3.7 Economic Analysis

Possible Research Avenues

A cost-benefit analysis could be conducted to determine the economic impacts of increasing system flexibility to reduce the likelihood of rain rejections. System flexibility includes increasing air space at Lake Mulwala and reducing the flowrate of the Murray between Yarrawonga and the Choke.

Costs include the reduction of supply flexibility to irrigators downstream of Lake Mulwala. Benefits include improved forestry yield, improved access, and the value of water that would otherwise cause summer-autumn flooding.

Evaluation

It is expected that this project will not involve quantification of the benefits of "intangibles" associated with reduced summer-autumn flooding, such as improved access to tourists, although methods such as travel cost and hedonic pricing are well documented.

An economic analysis requires establishment of the time period over which costs and benefits are to be identified, and the applicable discount rate.

Proposal 6: Economic Analysis

(a) Identify and quantify costs and benefits associated with increasing system flexibility and reducing rain rejections.

(b) Establish plots of: net discounted cost/benefit vs. reduction in unseasonal surplus flow events/days.

1.4 Proposed Research Methodolgy

This proposed research methodology was developed based on the evaluation of possible research avenues.

1.4.1 Part 1: Historical Analysis

As outlined in "Proposal 1", this analysis will determine:

- whether regulation has caused changes in the pattern of summer-autumn River Murray flows;
- whether regulation has caused changes in the pattern of summer-autumn Barmah Forest floods;
- which months in the summer-autumn period have experienced a significant increase in forest flooding;

1.4.2 Part 2: Identify Individual Unseasonal Surplus Flow Events

As outlined in "Proposal 2", this analysis will involve comparison of various methods of identifying individual rain rejection events. These methods will be used to identify:

- start and end dates of individual unseasonal surplus flow events;
- peak excess flow rate;
- total excess volume.

1.4.3 Part 3: Relation to System Regulation

As outlined in "Proposals 3 to 5", this analysis will use the unseasonal surplus flow events characterised in Part 2 to relate the instantaneous risk of occurrence to factors involving the regulation of the River Murray.

A preliminary methodology for characterising risk would involve the calculation of correlation coefficients and establishment of cumulative probability plots as outlined in "Proposal 5".

1.4.4 Part 4: Economic Analysis

As outlined in "Proposal 6", this analysis will use the risks characterised in Part 3 to determine the economic impacts of increasing system flexibility to reduce the likelihood of rain rejections. The two aspects of system flexibility are identified as:

- increasing air space at Lake Mulwala; and
- reducing the flowrate of the Murray between Yarrawonga and the Choke.

The results of this analysis can be presented in plots of net discounted cost/benefits vs. reduction in unseasonal surplus flow events/days.

1.5 Data Requirements

Table 1.1 summarises the data requirements identified in the proposed methodology.

Table 1.1 Data Requirements

	Data	Unit	Dates required	Possible source(s)
PART 1 Historical Analysis	River Murray flow at Tocumwal	ML/day	historical - present	RMW; DLWC; GMW
	Diversions to Mulwala Canal and Yarrawonga Main Channel	ML/day	historical - present	RMW; DLWC; GMW
	Choke capacity (flooding threshold)	ML/day	historical - present	Bren et. al. (1997); Hansard; Thoms *et. al.* (2000); RMC (1980)
	Flooding area	relation	historical - present	Bren et. al. (1997).
PART 2 Identify Events	River Murray flow at Yarrawonga	ML/day	1975 - present	RMW
	River Murray flow at Tocumwal	ML/day	1975 - present	RMW
	River Murray gauge height and flow at Picnic Point	mAHD; ML/day	1975 - present	RMW
PART 3 Relation to System Regulation	River Murray flow at Tocumwal	ML/day	1975 - present	RMW
	River Murray flow at Doctor’s Point	ML/day	1975 - present	RMW
	River Murray flow at Picnic Point	ML/day	1975 - present	RMW
	River Murray flow at Yarrawonga	ML/day	1975 - present	RMW
	Full storage level of Lake Mulwala	mAHD, ML	1975 - present	RMW
	Storage in Lake Mulwala	mAHD, ML	1975 - present	RMW
PART 4 Economic Analysis	Costs of lost timber production per ML or area of unseasonal flooding	$	current	Maunsell (1992a); Leslie and Harris (1996).
	Value of water to irrigators	$/ML	current	GMW; RMW

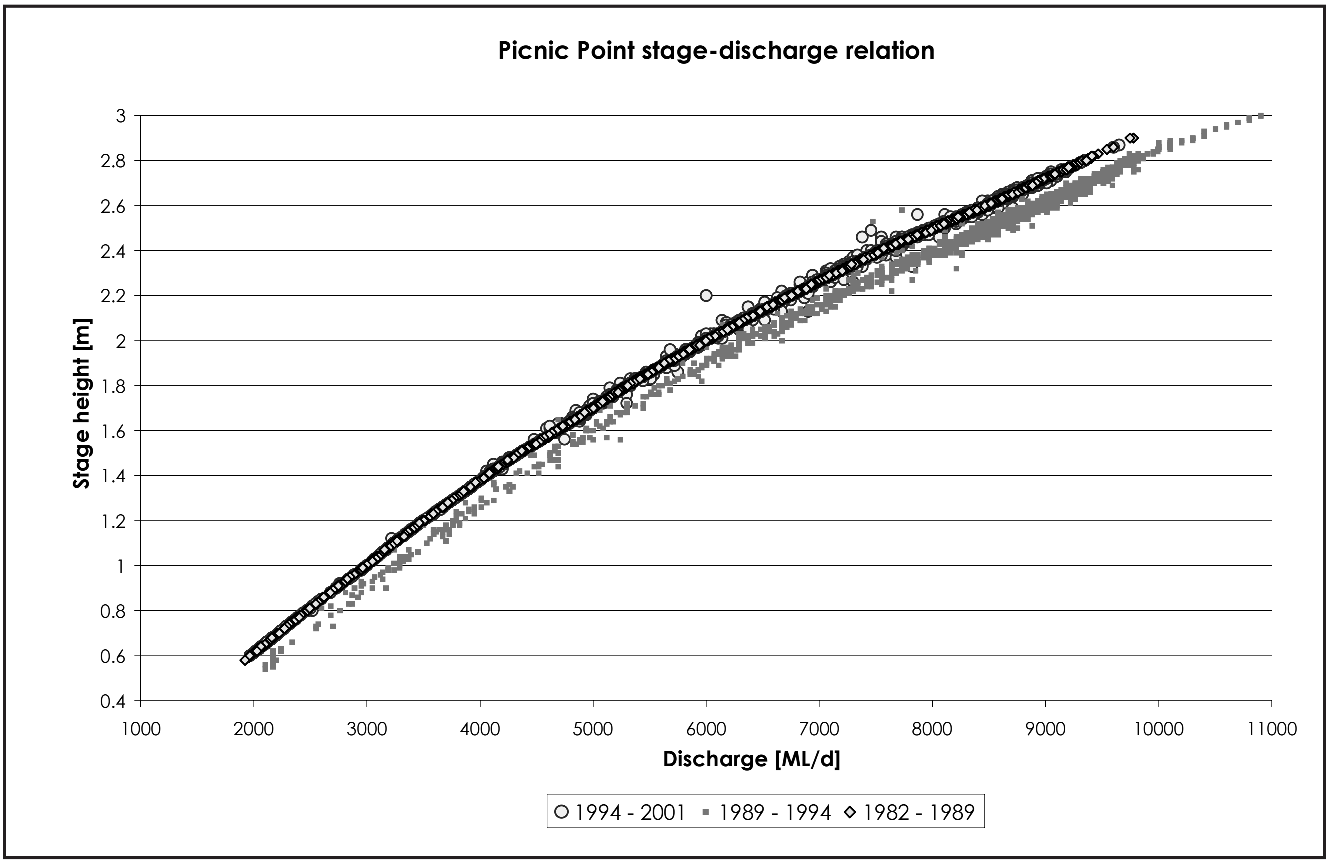
Appendix B: Historical Analysis

November	**1908-1929**	**1936-1960**	**1961-2001**	**1981-2001**	**1908-2001**
Mean	21552.02273	26561.116	18510.05583	17536.58	21969.67455
Standard Error	615.1121758	672.3189329	504.1766227	584.8924591	335.1771687
Median	16529	22031.5	10785.5	10701	15726
Mode	19137	7342	9028	10462	16784
Standard Deviation	15802.51792	18412.21227	17465.19053	14326.88079	17704.20908
Sample Variance	249719572.6	339009560.7	305032880.2	205259513.2	313439019
Kurtosis	1.215727519	-0.349074188	7.752152583	5.022917616	2.831435296
Skewness	1.287216593	0.703433629	2.443697111	2.098501994	1.551423458
Range	81948	83636	146243	86265	146907
Minimum	1232	3707	1896	5926	1232
Maximum	83180	87343	148139	92191	148139
Sum	14224335	19920837	22212067	10521948	61295392
Count	660	750	1200	600	2790
December	**1908-1929**	**1936-1960**	**1961-2001**	**1981-2001**	**1908-2001**
Mean	11933.18475	13423.49032	10918.41613	11672.50161	12286.1273
Standard Error	442.3933177	311.2924613	182.2384245	254.8991715	168.7871193
Median	7908	9640	9479.5	10069	9468
Mode	4446	5857	9468	10818	5857
Standard Deviation	11553.15888	8666.015361	6417.277131	6346.938185	9062.783856
Sample Variance	133475480	75099822.24	41181445.77	40283624.32	82134051.21
Kurtosis	4.770382866	2.296757647	10.76115203	15.16581969	6.411129636
Skewness	2.209381151	1.607071081	2.935817625	3.644172915	2.365330324
Range	60152	42652	51817	47638	60152
Minimum	985	4812	1783	5962	985
Maximum	61137	47464	53600	53600	61137
Sum	8138432	10403205	13538836	7236951	35420905
Count	682	775	1240	620	2883
January	**1908-1929**	**1936-1960**	**1961-2001**	**1981-2001**	**1908-2001**
Mean	6774.957416	8954.003871	10016.44847	10746.78034	8948.352214
Standard Error	200.8269423	141.6276785	128.4331565	97.71829785	89.60137048
Median	4886	7978	9748	10409	8367
Mode	8196	9640	8616	11922	8196
Standard Dev.	5240.775207	3942.747706	4578.781629	2493.253215	4835.984438
Sample Variance	27465724.77	15545259.47	20965241.21	6216311.593	23386745.49
Kurtosis	2.804626383	8.313359337	37.78416366	17.8506913	16.04957001
Skewness	1.593846129	2.68018389	5.026673166	3.052009599	2.709611767
Range	32145	27294	50181	26519	53134
Minimum	729	1771	3682	5846	729
Maximum	32874	29065	53863	32365	53863
Sum	4613746	6939353	12730906	6996154	26066550
Count	681	775	1271	651	2913

February	**1908-1929**	**1936-1960**	**1961-2001**	**1981-2001**	**1908-2001**
Mean	4719.488746	8365.468175	9434.564767	10284.85835	7765.26619
Standard Error	167.9634848	82.59761418	72.18143177	72.88996517	68.13392228
Median	3114	8073	9672.5	10342	8318.5
Mode	3195	8659	5162	10810	8659
Standard Dev.	4188.997189	2196.226916	2456.290746	1774.986644	3511.376725
Sample Variance	17547697.45	4823412.669	6033364.229	3150577.585	12329766.51
Kurtosis	2.608905999	11.80995994	2.049787152	6.125869411	0.6388524
Skewness	1.732218602	2.590821965	0.174008113	1.275819738	0.178838561
Range	22283	19169	17841	14517	23179
Minimum	430	4440	2373	5697	430
Maximum	22713	23609	20214	20214	23609
Sum	2935522	5914386	10925226	6098921	20624547
Count	622	707	1158	593	2656
March	**1908-1929**	**1936-1960**	**1961-2001**	**1981-2001**	**1908-2001**
Mean	4208.202346	8243.68129	9950.541036	10796.90394	7901.008627
Standard Error	135.8570162	96.70215973	62.50578515	60.89477448	66.8245392
Median	2836	7511	10229	10754	8467
Mode	330	8659	11033	11033	8659
Standard Deviation	3547.9236	2692.074194	2214.328643	1534.499987	3597.370453
Sample Variance	12587761.87	7247263.465	4903251.338	2354690.21	12941074.18
Kurtosis	1.910904996	7.650386603	2.608968289	5.986439577	0.299827257
Skewness	1.43756925	2.375444266	-0.064704551	1.488768016	-0.045846942
Range	18552	19983	16414	11764	22692
Minimum	330	3039	2459	7109	330
Maximum	18882	23022	18873	18873	23022
Sum	2869994	6388853	12487929	6856034	22897123
Count	682	775	1255	635	2898
April	**1908-1929**	**1936-1960**	**1961-2001**	**1981-2001**	**1908-2001**
Mean	4221.574242	8836.254667	8043.1725	8632.806667	7358.602509
Standard Error	134.5667579	288.6725284	74.37989939	87.25883406	99.52356904
Median	3012	7503	8171	8498	7300
Mode	2373	6459	8073	9301	6459
Standard Dev.	3457.082606	7905.622777	2576.595296	2137.39619	5256.879761
Sample Variance	11951420.14	62498871.49	6638843.321	4568462.473	27634784.82
Kurtosis	4.034830161	53.83247172	0.812309774	1.367078476	82.57693711
Skewness	1.738929644	6.727809698	-0.021565235	0.5933104	6.677837027
Range	20976	88903	17851	13939	89459
Minimum	330	886	1664	3225	330
Maximum	21306	89789	19515	17164	89789
Sum	2786239	6627191	9651807	5179684	20530501
Count	660	750	1200	600	2790

May	**1908-1929**	**1936-1960**	**1961-2001**	**1981-2001**	**1908-2001**
Mean	6963.55132	8304.093333	7218.16	5649.658333	7529.122222
Standard Error	313.4331115	382.8542453	294.8142157	134.7165276	183.356735
Median	4910	6300	5389	5164	5628.5
Mode	5856	9039	6669	2569	9039
Standard Dev.	8185.346364	10484.89532	10212.66401	3299.867525	9684.98536
Sample Variance	66999895.09	109933029.9	104298506.1	10889125.68	93798941.42
Kurtosis	17.83418796	24.06694032	113.8053627	7.648840382	71.3247196
Skewness	3.784645543	4.639593109	8.933686556	2.307596052	6.673640633
Range	56655	84101	181789	20423	182823
Minimum	539	795	1573	2069	539
Maximum	57194	84896	183362	22492	183362
Sum	4749142	6228070	8661792	3389795	21006251
Count	682	750	1200	600	2790

Appendix C: Unseasonal Surplus Flow Events



TOCUMWAL ANALYSIS	Duration	Peak excess flow (ML/day)	Total excess flow (ML)	Average excess flow (ML/day)
SUM	1160	181277	1462310	91711
AVERAGE	14.15	2210.70	17833.50	1118.42
MEDIAN	10.00	1132.50	7959.50	638.21
MAX	84	10807	162545	5424
MIN	1	8	12	6
SD	14.02	2571.63	28867.52	12841.33
10th percentile	2.00	115.50	194.50	81.70
20th percentile	4.00	259.20	981.80	164.08
30th percentile	6.30	421.80	2666.80	255.11
40th percentile	8.00	614.80	4882.40	348.21
50th percentile	10.00	1132.50	7959.50	638.21
60th percentile	11.60	1913.60	11351.80	925.52
70th percentile	16.00	2697.20	15771.80	1286.55
80th percentile	22.00	4104.80	22442.20	1811.30
90th percentile	29.80	6345.30	43139.80	2693.94
EVENTS	82			
Start record	1-Dec-80			
End record	1-Dec-00			
Years of record	20.0			
EVENTS PER YEAR	4.1			
Total days	3025			
PROPORTION OF FLOOD DAYS	38.3%			

YARRAWONGA ANALYSIS	Duration	Peak excess flow (ML/day)	Total excess flow (ML)	Average excess flow (ML/day)
SUM	497	147002	832720	80277
AVERAGE	8.57	2534.52	14357.24	1384.09
MEDIAN	6.00	1589.00	5188.00	820.60
MAX	53	10131	132654	4886
MIN	1	1	1	1
SD	8.29	2691.68	23784.05	1404.99
10th percentile	2.70	159.80	434.70	122.73
20th percentile	4.00	319.20	967.20	188.50
30th percentile	4.10	482.90	2770.20	295.40
40th percentile	5.00	807.40	3805.20	562.15
50th percentile	6.00	1589.00	5188.00	820.60
60th percentile	7.00	2214.80	8360.00	1383.91
70th percentile	8.90	3356.50	11105.10	1854.00
80th percentile	11.60	4673.40	18243.80	2363.65
90th percentile	16.00	6647.90	40472.60	3533.34
EVENTS	58			
Start record	16-Mar-83			
End record	15-Mar-01			
Years of record	18.0			
EVENTS PER YEAR	3.222467295			
Total days	2722			
PROPORTION OF FLOOD DAYS	18.3%			

PICNIC POINT ANALYSIS	Duration	Peak excess flow (ML/day)	Total excess flow (ML)	Average excess flow (ML/day)
SUM	1123	40570	647453	24948
AVERAGE	14.78	533.82	8519.12	328.26
MEDIAN	8.00	418.50	2690.50	251.95
MAX	100	1664	106750	1068
MIN	1	4	4	4
SD	20.63	446.02	18090.27	271.99
10th percentile	1.00	44.00	56.50	26.67
20th percentile	2.00	104.00	138.00	81.00
30th percentile	4.00	221.50	556.00	143.46
40th percentile	5.00	334.00	1036.00	209.00
50th percentile	8.00	418.50	2690.50	251.95
60th percentile	10.00	504.00	3514.00	330.82
70th percentile	13.50	751.00	4787.00	421.40
80th percentile	17.00	894.00	6650.00	602.33
90th percentile	37.50	1129.00	26417.00	695.19
EVENTS	76			
Start record	16-Mar-83			
End record	15-Mar-01			
Years of record	18.0			
EVENTS PER YEAR	4.22			
Total days	2722			
PROPORTION OF FLOOD DAYS	41.3%			

```
Sub getevents()

Dim peakdate, startdate, enddate
Dim peakflow, totalflow

peakflow = totalflow = 0

Do

   Do While ActiveCell.Value = 0
      ActiveCell.Offset(1, 0).Range("a1").Select
   Loop

   If ActiveCell.Value = 9999999 Then
   Exit Do
   End If
   peakflow = 0
   totalflow = 0
   startdate = ActiveCell.Offset(0, -2).Value
   Do While ActiveCell.Value <> 0
      totalflow = totalflow + ActiveCell.Value

      If ActiveCell.Value > peakflow Then
      peakflow = ActiveCell.Value
      peakdate = ActiveCell.Offset(0, -2).Value
      End If
      ActiveCell.Offset(1, 0).Range("a1").Select
      If ActiveCell.Offset(0, -2).Value - ActiveCell.Offset(-1, -2).Value > 1 Then
      Exit Do
      End If
   Loop
   enddate = ActiveCell.Offset(-1, -2).Value
   Sheets("Events").Select
   ActiveCell.Value = startdate
   ActiveCell.Offset(0, 1).Value = enddate
   ActiveCell.Offset(0, 3).Value = peakdate
   ActiveCell.Offset(0, 4).Value = peakflow
   ActiveCell.Offset(0, 5).Value = totalflow
   ActiveCell.Offset(1, 0).Range("a1").Select
   Sheets("Data").Select
   peakflow = 0
   totalflow = 0
Loop

End Sub
```

Appendix D: Analysis of System Flexibility

Maximum flow at Tocumwal (ML/day)	10600	10500	10400	10300	10200	10100	10000	9900	9800	9700	9600	9500	9400	9300	9200	9100	9000
TOTAL EXCESS FLOW	1462310	1427445	1378381	1315189	1247880	1184568	1128112	1075987	1025732	980998	941793	906236	872770	840512	809612	779916	752380
NUMBER OF DAYS	1160	1113	1014	915	811	716	633	596	556	489	442	418	395	364	337	317	292
NUMBER OF EVENTS	82	79	74	70	63	56	52	49	48	45	43	42	42	42	41	38	38
Frequency and Duration																	
Days per season	58.0	55.7	50.7	45.8	40.6	35.8	31.7	29.8	27.8	24.5	22.1	20.9	19.8	18.2	16.9	15.9	14.6
Proportion of season	38.3%	36.8%	33.5%	30.2%	26.8%	23.7%	20.9%	19.7%	18.4%	16.2%	14.6%	13.8%	13.1%	12.0%	11.1%	10.5%	9.7%
Events per season	4.1	4.0	3.7	3.5	3.2	2.8	2.6	2.5	2.4	2.3	2.2	2.1	2.1	2.1	2.1	1.9	1.9
Event duration	14.1	14.1	13.7	13.1	12.9	12.8	12.2	12.2	11.6	10.9	10.3	10.0	9.4	8.7	8.2	8.3	7.7
Surplus volume																	
Average excess flow per season	73115.5	71372.3	68919.1	65759.5	62394.0	59228.4	56405.6	53799.4	51286.6	49049.9	47089.7	45311.8	43638.5	42025.6	40480.6	38995.8	37619.0
Average excess flow per event	17833.0	18068.9	18626.8	18788.4	19807.6	21153.0	21694.5	21958.9	21369.4	21800.0	21902.2	21577.0	20780.2	20012.2	19746.6	20524.1	19799.5
Average excess flow per day	1260.6	1282.5	1359.4	1437.4	1538.7	1654.4	1782.2	1805.3	1844.8	2006.1	2130.8	2168.0	2209.5	2309.1	2402.4	2460.3	2576.6

Extra storage capacity (ML)	0	500	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000	6500	7000	7500	8000	8500	9000
TOTAL EXCESS FLOW	1462310	1425948	1392046	1360554	1330054	1299794	1271556	1244284	1217959	1192236	1167389	1143889	1121060	1098823	1076951	1055979	1035479	1014979	994955
NUMBER OF DAYS	1160	1019	931	882	827	774	740	705	668	642	609	586	562	545	528	516	500	486	474
NUMBER OF EVENTS	82	68	65	61	61	59	55	54	52	51	47	47	46	45	44	42	42	42	40
Frequency and Duration																			
Days per season	58.0	51.0	46.6	44.1	41.4	38.7	37.0	35.3	33.4	32.1	30.5	29.3	28.1	27.3	26.4	25.8	25.0	24.3	23.7
Proportion of season	38.3%	33.7%	30.8%	29.2%	27.3%	25.6%	24.5%	23.3%	22.1%	21.2%	20.1%	19.4%	18.6%	18.0%	17.5%	17.1%	16.5%	16.1%	15.7%
Events per season	4.1	3.4	3.3	3.1	3.1	3.0	2.8	2.7	2.6	2.6	2.4	2.4	2.3	2.3	2.2	2.1	2.1	2.1	2.0
Event duration	14.1	15.0	14.3	14.5	13.6	13.1	13.5	13.1	12.8	12.6	13.0	12.5	12.2	12.1	12.0	12.3	11.9	11.6	11.9
Surplus volume																			
Average excess flow per season	73115.5	71297.4	69602.3	68027.7	66502.7	64989.7	63577.8	62214.2	60898.0	59611.8	58369.5	57194.5	56053.0	54941.2	53847.6	52799.0	51774.0	50749.0	49747.8
Average excess flow per event	17833.0	20969.8	21416.1	22304.2	21804.2	22030.4	23119.2	23042.3	23422.3	23377.2	24838.1	24338.1	24370.9	24418.3	24476.2	25142.4	24654.3	24166.2	24873.9
Average excess flow per day	1260.6	1399.4	1495.2	1542.6	1608.3	1679.3	1718.3	1764.9	1823.3	1857.1	1916.9	1952.0	1994.8	2016.2	2039.7	2046.5	2071.0	2088.4	2099.1

Extra storage capacity (ML)	9500	10000	10500	11000	11500	12000	12500	13000	13500	14000	14500	15000	15500	16000	16500	17000	17500	18000	18500	19000
TOTAL EXCESS FLOW	975455	955955	937355	920218	903718	887790	872290	856790	841976	827774	814274	801310	788810	776310	764192	752192	740192	728496	717156	706156
NUMBER OF DAYS	457	445	427	413	400	389	381	372	361	350	341	335	329	322	312	305	301	295	289	281
NUMBER OF EVENTS	40	40	36	34	34	32	32	32	30	28	27	26	26	26	25	25	25	24	23	23
Frequency and Duration																				
Days per season	22.9	22.3	21.4	20.7	20.0	19.5	19.1	18.6	18.1	17.5	17.1	16.8	16.5	16.1	15.6	15.3	15.1	14.8	14.5	14.1
Proportion of season	15.1%	14.7%	14.1%	13.7%	13.2%	12.9%	12.6%	12.3%	11.9%	11.6%	11.3%	11.1%	10.9%	10.6%	10.3%	10.1%	10.0%	9.8%	9.6%	9.3%
Events per season	2.0	2.0	1.8	1.7	1.7	1.6	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.3	1.3	1.3	1.3	1.2	1.2	1.2
Event duration	11.4	11.1	11.9	12.1	11.8	12.2	11.9	11.6	12.0	12.5	12.6	12.9	12.7	12.4	12.5	12.2	12.0	12.3	12.6	12.2
Surplus volume																				
Average excess flow per season	48772.8	47797.8	46867.8	46010.9	45185.9	44389.5	43614.5	42839.5	42098.8	41388.7	40713.7	40065.5	39440.5	38815.5	38209.6	37609.6	37009.6	36424.8	35857.8	35307.8
Average excess flow per event	24386.4	23898.9	26037.6	27065.2	26579.9	27743.4	27259.1	26774.7	28065.9	29563.4	30158.3	30819.6	30338.8	29858.1	30567.7	30087.7	29607.7	30354.0	31180.7	30702.4
Average excess flow per day	2134.5	2148.2	2195.2	2228.1	2259.3	2282.2	2289.5	2303.2	2332.3	2365.1	2387.9	2392.0	2397.6	2410.9	2449.3	2466.2	2459.1	2469.5	2481.5	2513.0

Appendix E: Economic Analysis

	Marginal value of water **$60 per ML**				**Marginal value of electricity** **$46.36 per MWh**			
Increased airspace	**Level**	**Flooding frequency**	**Cost: less hydroelectricity generation**		**Benefit: water saved from reduced flooding**		**Net benefit**	
ML	**mAHD**		**MWh/ season**	**Value**	**ML/season**	**Value**	**Cost**	**Value**
0	125.1	38.35%	2.2196533	$0	0	$0	$0	$0
500	125.089263	33.69%	3.661138	$67	1818.1	$109,086	-$67	$109,019
1000	125.078525	30.78%	5.5133865	$153	3513.2	$210,792	-$153	$210,639
1500	125.067788	29.16%	8.033826	$270	5087.8	$305,268	-$270	$304,998
2000	125.057051	27.34%	11.090198	$411	6612.8	$396,768	-$411	$396,357
2500	125.046313	25.59%	14.860919	$586	8125.8	$487,548	-$586	$486,962
3000	125.035576	24.46%	19.260686	$790	9537.7	$572,262	-$790	$571,472
3500	125.024838	23.31%	24.542368	$1,035	10901.3	$654,078	-$1,035	$653,043
4000	125.014101	22.08%	30.879217	$1,329	12217.55	$733,053	-$1,329	$731,724
4500	125.003364	21.22%	38.19759	$1,668	13503.7	$810,222	-$1,668	$808,554
5000	124.992626	20.13%	46.749811	$2,064	14746.05	$884,763	-$2,064	882,699
5500	124.981889	19.37%	56.522234	$2,517	15921.05	$955,263	-$2,517	$952,746
6000	124.971152	18.58%	67.649458	$3,033	17062.5	$1,023,750	-$3,033	$1,020,717
6500	124.960414	18.02%	80.351678	$3,622	18174.35	$1,090,461	-$3,622	$1,086,839
7000	124.949677	17.45%	94.919913	$4,297	19267.95	$1,156,077	-$4,297	$1,151,780
7500	124.938939	17.06%	111.13294	$5,049	20316.55	$1,218,993	-$5,049	$1,213,944
8000	124.928202	16.53%	129.02644	$5,879	21341.55	$1,280,493	-$5,879	$1,274,614
8500	124.917465	16.07%	148.75123	$6,793	22366.55	$1,341,993	-$6,793	$1,335,200
9000	124.906727	15.67%	170.01591	$7,779	23367.75	$1,402,065	-$7,779	$1,394,286
9500	124.89599	15.11%	192.84751	$8,837	24342.75	$1,460,565	-$8,837	$1,451,728
10000	124.885253	14.71%	217.1941	$9,966	25317.75	$1,519,065	-$9,966	$1,509,099

	Marginal value of water **$60 per ML**						
Maximum flow at Tocumwal	**Flooding frequency**	**Cost: less downstream water**		**Benefit: water saved from reduced flooding**		**Net cost**	
ML/day		**ML/season**	**Value $**	**ML/season**	**Value $**	**ML/season**	**Value $**
10600	0.383	0	-	0	-	0	-
10500	0.368	2493	149,607.00	1743	104,595.00	750	-45,012
10400	0.335	6107	366,423.00	4196	251,787.00	1911	-114,636
10300	0.302	11414	684,867.00	7356	441,363.00	4058	-243,504
10200	0.268	17984	1,079,067.00	10722	643,290.00	7263	-435,777
10100	0.237	25248	1,514,904.00	13887	833,226.00	11361	-681,678
10000	0.209	32937	1,976,244.00	16710	1,002,594.00	16228	-973,650
9900	0.197	40948	2,456,883.00	19316	1,158,969.00	21632	-1,297,914
9800	0.184	49320	2,959,173.00	21829	1,309,734.00	27491	-1,649,439
9700	0.162	58002	3,480,111.00	24066	1,443,936.00	33936	-2,036,175
9600	0.146	66988	4,019,292.00	26026	1,561,551.00	40962	-2,457,741
9500	0.138	76184	4,571,010.00	27804	1,668,222.00	48380	-2,902,788
9400	0.131	85663	5,139,759.00	29477	1,768,620.00	56186	-3,371,139
9300	0.120	95449	5,726,961.00	31090	1,865,394.00	64359	-3,861,567
9200	0.111	105543	6,332,562.00	32635	1,958,094.00	72908	-4,374,468
9100	0.105	115957	6,957,429.00	34120	2,047,182.00	81837	-4,910,247
9000	0.097	126653	7,599,198.00	35497	2,129,790.00	91157	-5,469,408
		133333	8,000,000.00	41667	2,500,000.00		

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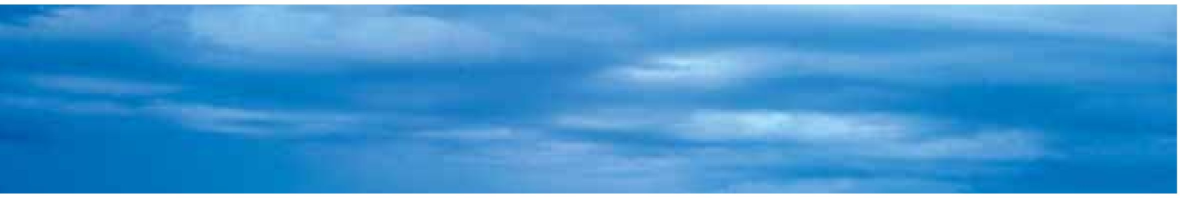

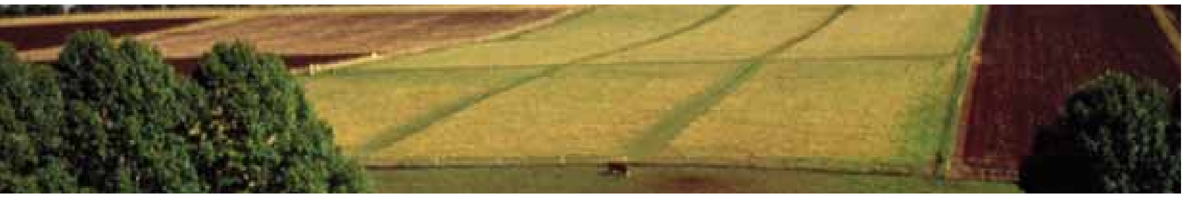

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