Please Note

This report was prepared in February 2002 by the Expert Reference Panel (ERP) for the Environmental Flows and Water Quality Objectives for the River Murray Project Board.

This report was submitted, on a confidential basis, for the consideration of the Murray-Darling Basin Ministerial Council on 12 April 2002 and is now publicly available.

An independent scientific peer review of this report is currently being undertaken.

A revised version of this report will be prepared, which incorporates the changes recommended by the independent scientific peer review. When finalised, the revised report will be available at www.thelivingmurray.mdbc.gov.au

Independent Report of the Expert Reference Panel on Environmental Flows and Water Quality Requirements for the River Murray System

Gary Jones, Terry Hillman, Richard Kingsford,
Tom McMahon, Keith Walker, Angela Arthington,
John Whittington, Sarah Cartwright

Prepared for the Environmental Flows and Water Quality Objectives for the River Murray Project Board

Cooperative Research Centre for Freshwater Ecology

February 2002

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The ERP thanks the following people and groups for their support and expert advice:

- MDBC Project Team – Trevor Jacobs, Tony McLeod, Julianne Martin, Andy Close, John Anderson, Kim Jenkins, Simon Pellatt - River operations, flow thresholds, and modelling
- Assoc. Prof. Martin Thoms – Ecohydrology
- Dr. Ben Gawne – Darling River anabranch ecology
- Dr. Paul Humphries – Fish passage and fish ecology
- Dr. Rory Nathan – GetSpells analysis
- Assoc. Prof. Richard Norris – River ecological condition assessment

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1.1 Setting the scene

i. The health of a river is determined by its flow regime, the condition of its catchment & floodplain lands and in-channel habitats, and its water quality. These attributes must be considered holistically. Environmental flow allocations are an essential component of river management, but not sufficient alone to ensure a healthy river. Any decision to trade off flow requirements against other necessary management actions must be made with an understanding of the potential negative consequences.

ii. From the outset, it was the unanimous and unequivocal opinion of this and previous expert panels that returning the River Murray System to a healthy working condition would require major improvements to river management – more environmental water, improved habitat condition, improved catchment & floodplain management, and better water quality.

iii. A *healthy working river* is one that is managed to provide a sustainable compromise, agreed to by the community, between the condition of the river and the level of human use (see section 2.5). It was not the role of the ERP, or scientists in general, to decide upon the compromise between the competing values of production, ecosystem services and the natural environment. Rather, the ERP was asked to identify the level of work that will sustain indefinitely the ecological objectives first articulated by the Community Reference Panel and adopted by the Ministerial Council (see section 2.6).

iv. The evolution of the degraded ecological condition of the River Murray is summarised. In the early 1900's abstraction of water for consumptive use was low compared with modern levels, but water quality impacts would have commenced as a result of catchment clearing. The construction of Hume Dam and the locks and weirs on the lower Murray initiated an increased rate of degradation in ecological condition. This was accelerated by the rapid expansion in water abstraction for irrigation from the mid-1950s onwards. It is likely that during the 1960s or 1970s, ecological condition deteriorated to a point where the River Murray could no longer be considered as healthy. By 2001, the ecological condition of the River Murray is described as significantly impaired, and therefore unhealthy.

v. The future condition of the River Murray System is clearly dependent on our actions now and over the coming years. Ecological condition continues to degrade under the present Cap and current river operations. Returning the River Murray System to a healthy condition will require major improvements to river management – significant environmental flow allocations, improved habitat condition, improved catchment & floodplain management, and better water quality.

1.2 Expert Reference Panel Assessment Process

vi. The Expert Reference Panel (ERP) was appointed by the MDBC Environmental Flows and Water Quality Objectives Project Board. It has worked independently but has maintained extensive consultation with the Project Board, Project Team, and Community & Jurisdictional Reference Panels.

vii. The ERP has adopted the Ministerial Council's project objectives and has linked these to a suite of desired system level ecological outcomes and system level attributes for a healthy, working River Murray System.

viii. The ERP has adopted a system level approach to assessing flow requirements and the potential ecological benefits offered by the flow management packages. This means that the net ecological benefits of any flow package or other management option (structural or operational) were considered across the entire length of the river system and its floodplain. Hence, the ecological assessments herein do not specifically address the management of individual river reaches, or floodplain wetlands and forests. Regional natural resource management agencies and river & catchment groups currently address issues at this scale. This report is designed to compliment their activities.

ix. The system level approach adopted by the ERP led to a focus on five system level eco-hydrological attributes for the River Murray System:

- flow volume
- flow distribution (pattern)
- flow variability
- connectivity (within and between the river channel and its floodplain)
- water quality

x. This report identifies the key threats to these attributes, and the Environmental Flow Requirements (EFRs) to address them. Key hydrological indicators used to assess short-term environmental benefits of the various options are described.

1.3 Performance Targets

xi. Because of the lack of precise knowledge linking river flows to ecological condition it is extremely difficult to develop quantitative performance targets for improved management of river health. But, the river health concept does lend itself to a risk-based assessment framework, and it is this approach that the ERP has adopted in setting specific targets for river management actions.

xii. The key outcome that the ERPs risk-based assessment has considered is: “Having a healthy, working River Murray System”. In this context, the key risk assessment is centred on the question: ”If we do x, what is the likelihood or probability of having a healthy working River Murray System?”.

xiii. It is the considered opinion of the ERP that there is a substantial risk a working river will not be in a healthy state when key system level attributes of the flow regime are reduced below two/thirds of their natural level.

xiv. Based on this ‘guidance value’ the ERP derived probability categories for successful environmental flows restoration. When key flow attributes are greater than two/thirds of their natural level, there is a high probability or likelihood of achieving a healthy river. When the same flow attributes are greater than half of their natural level, there is a moderate probability of achieving a healthy river. Below half natural, the probability of having a healthy river is low.

Key system level hydrological attributes (% of natural)	Probability of having a healthy working river
≥ two-thirds	**HIGH**
≥ half	**MODERATE**
< half	**LOW**

xv. Caveat: The 'two/thirds natural' guidance level applies only to regulated and other impounded rivers. It is a target for river restoration, not a level for 'acceptable degradation' or 'sustainable diversion' of minimally impacted rivers.

xvi. Caveat: These probability categories presume that the river offers suitable habitat and water quality for the growth and survival of native plants and animals. As already noted, the full benefits of environmental flow restoration will only be realised if river water quality, flood plain lands, and river habitat are also restored or protected.

1.4 Flow Option Packages assessment

xvii. The risk categories described in xii. were used to analyse the likelihood that the flow option packages provided by the MDBC project team would deliver a healthy working River Murray System. The summary results of this analysis are outlined in the table below.

Management Options	Probability of having a healthy working River Murray System
Do nothing more (Current operations) (MDBC Package 56740)	**LOW**
A. Improved operations (MDBC Package 57200)	**LOW**[1]
B. Improved operations plus 350 GL new environmental flows (Murray source) (MDBC Package 57150)	**LOW**[1]
C. Improved operations plus 900 GL new environmental flows (Basin-wide source) (MDBC Package 57210)	**LOW-MODERATE**
D. Improved operations plus 1950 GL new environmental flows (Basin-wide source) (MDBC Package 57220)	**MODERATE**
E. Improved operations plus 4000 GL new environmental flows (Basin-wide source) (MDBC Package 57300)	**HIGH**

[1] Some localised ecological benefits are delivered by these options ie. for specific wetlands, floodplain forests or river reaches, but the overall system level impact was insufficient to improve the probability category.

xv. The key outcomes are that there would be a high probability of achieving a healthy working River Murray System if 4000 GL of new environmental flow allocations were combined with the operational improvements described in options package 57200. The same operational improvements combined with 1950 GL of new environmental flow allocations would lead to a moderate likelihood of achieving a healthy system.

xvi. All other packages examined provide little confidence that a healthy river would be achieved in the future. Some localised ecological benefits are delivered by options A & B - for specific wetlands, floodplain forests or river reaches - but the overall system level impact was insufficient to improve the probability category.

xvii. Further improvements in river operations beyond those described in options package 57200 may lead to better ecological outcomes for the same volumes of new environmental flows. Further modelling developments and work by the MDBC Project Team would be required to make this determination. This new work should include coupling of hydrological models for the major tributaries to the current River Murray hydrological simulation models, and consideration of environmental outcomes in those tributaries.

xviii. None of the flow options packages considered herein provide significant ecological benefits for the Lower Darling River main channel and its adjacent floodplain (i.e. not enough to improve the river health probability category).

xxii. No hydrological or hydrodynamic models for the Lower Lakes and Coorong were available to the ERP. This made it very difficult to assess ecological benefits of River Murray environmental flow allocations on these important wetland and estuarine regions. Further work is required to address this shortcoming in knowledge and predictive capability.

xix. The full benefits of environmental flow allocations on the health of the river may not become apparent for many years – probably decades. Well designed monitoring programs will be essential to detect ecological response (both short and long term) to a change in the flow regime and the provision of environmental flows.

xx. In the short to medium term, the benefits of river management actions are likely to be assessed by performance against hydrological outcomes and indicators. However, we emphasise that hydrological outcomes are only an interim performance indicator and that ecological outcomes and indicators must be used to measure the ultimate effectiveness of river management.

xxi. Ecological outcomes of improved river management should be assessed using ecological indicators such as those developed in the Sustainable Rivers Audit, the National River Health Program and the National Land and Water Resources Audit.

1.5 Other river system requirements

xxii. A range of structural and operational requirements must be addressed to ensure that the environmental flow option package benefits are realised. Failure to address these recommendations is likely to significantly reduce the ecological benefits delivered by environmental flow allocations.

xxiii. Additional requirements addressed in this report are:

- Weir Management – permanent and seasonal removal
- Weir Management – partial draw-down
- Weir Management – fishways
- Thermal pollution – dam off-take design

- Dam releases – improved day to day variability in river height (flows)
- Barrage releases – fish passage and connection to the estuary
- Unseasonal flooding in Barmah-Millewa – increased capacity to deal with rain rejection flows
- Darling Anabranch Management – pipeline to supply water users
- Regulators – unseasonal wetting & drying
- Floodplain levees – improving natural floodplain inundation patterns and connectivity

1.6 Recommendations

1. Hydrological indicators are, at best, only surrogates for desired ecological outcomes. Ecological outcomes of improved river management should be assessed using ecological indicators such as those developed in the Sustainable Rivers Audit, the National River Health Program and the National Land and Water Resources Audit.

2. The health of a river is determined by its flow regime, the condition of its catchment, floodplain & in-channel habitats, and its water quality. These attributes must be considered holistically. Environmental flow allocations are an essential component of river management, but not sufficient alone to ensure a healthy river. Any decision to trade off flow requirements against other necessary management actions must be made with an understanding of the potential negative consequences.

3. Weir management - permanent and seasonal removal:
   -Non-essential locks and weirs should be removed;
   -Murray River lock and weir structures should be removed for two months each year, during periods of low irrigation demand (e.g. June-August); and
   -In the shorter term, Lock 8 should be decommissioned (empty weir pool and operate as a transparent structure) as an experimental trial with measurements of the positive (eg. fish passage) and negative (eg. saline groundwater discharge) ecological outcomes being undertaken.

4. Weir management - partial draw-down:
   If recommendation 3 cannot be achieved in its entirety, then weir pools should be lowered by at least 1 metre for 3 months each winter-spring.

5. Weir management - fishways:
   If recommendation 4 cannot be achieved, then all locks and weirs should have fishways installed.

6. Weir management - raising height caveat:
   Undertake proper ecological assessment and cost-benefit analysis before any proposal to raise weir height proceeds.

7. Thermal pollutin - Dam off-take design:
   Undertake appropriate thermal mitigation works at Lake Hume and Dartmouth Dam, to provide release temperature close to natural.

8. Dam and weir release:
   Improve (promote towards natural) day-to-day variability in release patterns below all storages and weirs.

9. Barrage release:
   -Provide volume and timing of flows to promote significant fish recruitment in the Lower Lakes and Coorong;
   -Provide appropriate flows for the remainder of the year to maintain connectivity and fish passage between Coorong and ocean (i.e. keep the Murray mouth open); and
   -Undertake ecological and hydrodynamic studies to determine the volume and pattern of flows required to achieve the above.

10. Unseasonal flooding in Barmah-Millewa:
    -Reduce the frequency and volume of rain rejection events by improving management of water ordering, removing unnecessary structure, and clawing back operational airspace at Yarrawonga Weir.

11. Darling anabranch Management:
    -Implementation of pipelines to supply stock and domestic water to users along the Darling Anabranch; and
    -Removal of unnecessary structures (block banks, regulators and weirs) along Anabranch and associated Lakes.

12. Regulators:
    In cases where it is not possible in the short to medium term to modify weir heights or flow regime, consideration should be given to installing regulators on important wetlands and operating these structures to mimic natural wetting and drying regimes.

13. Floodplain levees:
    An audit should be undertaken of all floodplain levees and other structures (block banks, roads) that alter the natural movement of water across the floodplain. Unnecessary and illegal levees should be removed as a matter of priority.

2. INTRODUCTION

2.1 Convening of the Expert Reference Panel

The Expert Reference Panel (ERP) was convened by the River Murray Environmental Flows and Water Quality Objectives Project Board to provide independent expert advice on the environmental flow requirements of the River Murray. Prof. Gary Jones, of the CRC for Freshwater Ecology, was appointed Chair of the ERP by the Project Board. Members of the ERP were appointed based on their broad expert knowledge and experience across the Murray-Darling Basin.

The roles and responsibilities of the ERP, as defined by the Terms of Reference agreed with the Project Board, were to:

1. Advise the Project Board, Jurisdictional Reference Panel (JRP) and Community Reference Panel (CRP) on the likely ecological outcomes, at agreed assessment localities, of flow scenarios being developed and modelled by the Project Team;

2. Advise the Project Board, JRP and CRP on management scenarios based on flow, operational and realistic structural modification actions, that will provide desirable ecological outcomes (to be agreed with the JRP and CRP) at agreed assessment localities;

3. Document interactions and advice provided by discipline specialists on suitable environmental flow requirements (EFRs) and flow management scenarios;

4. Liase with the MDBC Project Team on option initiation, appropriate EFRs to deliver desirable ecological outcomes, additional hydrologic (model) indicators, modelling, testing, interpretation and assessment of results;

5. Meet with Combined Group of Reference Panels as necessary to provide opinions and receive information; and

6. Provide the Project Board with an independent report for presentation to the Ministerial Council in October 2001.

2.2 Report Structure

This report provides ecological advice on environmental flow packages developed by the MDBC Project Team. The Flow Option Packages considered and discussed in this report are:

Current operations = the “do nothing more” option
Package A = “Making better use of what we have through improved operations”
Package B = A plus 350 GL new environmental flows allocation (River Murray source)
Package C = A plus 900 GL new environmental flows allocation (Basin-wide source)
Package D = A plus 1950 GL new environmental flows allocation (Basin-wide source)
Package E = A plus 4000 GL new environmental flows allocation (Basin-wide source)

Packages A-C were provided to the ERP by the MDB Project Team for assessment of potential ecological benefits. Packages D and E were selected by the ERP from a number of additional environmental flow allocation packages provided by the Project Team to deliver against the moderate and high probability healthy working river risk categories respectively (see section 4.1).

This report also provides a list of recommended structural and operational changes that need to be made to the Murray and Lower Darling Rivers in addition to the environmental flows packages being considered.

The ERP has consulted closely with the Project Board and MDBC Project Team, and on a regular basis with the JRP and Community Reference Panel (CRP) in preparing this report.

2.3 System Level Approach

The ERP adopted a system level approach to assessing the flow requirements and the potential ecological benefits offered by the flow management packages. In other words, the net ecological benefits of a flow package or other management option (structural or operational) were evaluated across the entire length of the river system and its floodplain.

Hence, the ecological assessments herein do not specifically address the management of individual river reaches, or floodplain wetlands and forests. Regional natural resource management agencies and river & catchment groups currently address issues at this scale. This report is designed to compliment their activities.

Nevertheless, the broad ecological principles presented in this report could reasonably be added to local knowledge and experience to develop performance targets and assess management actions at the local scale.

The details of the system level approach, and the basis for our system level ecological assessment, is outlined further in section 3.

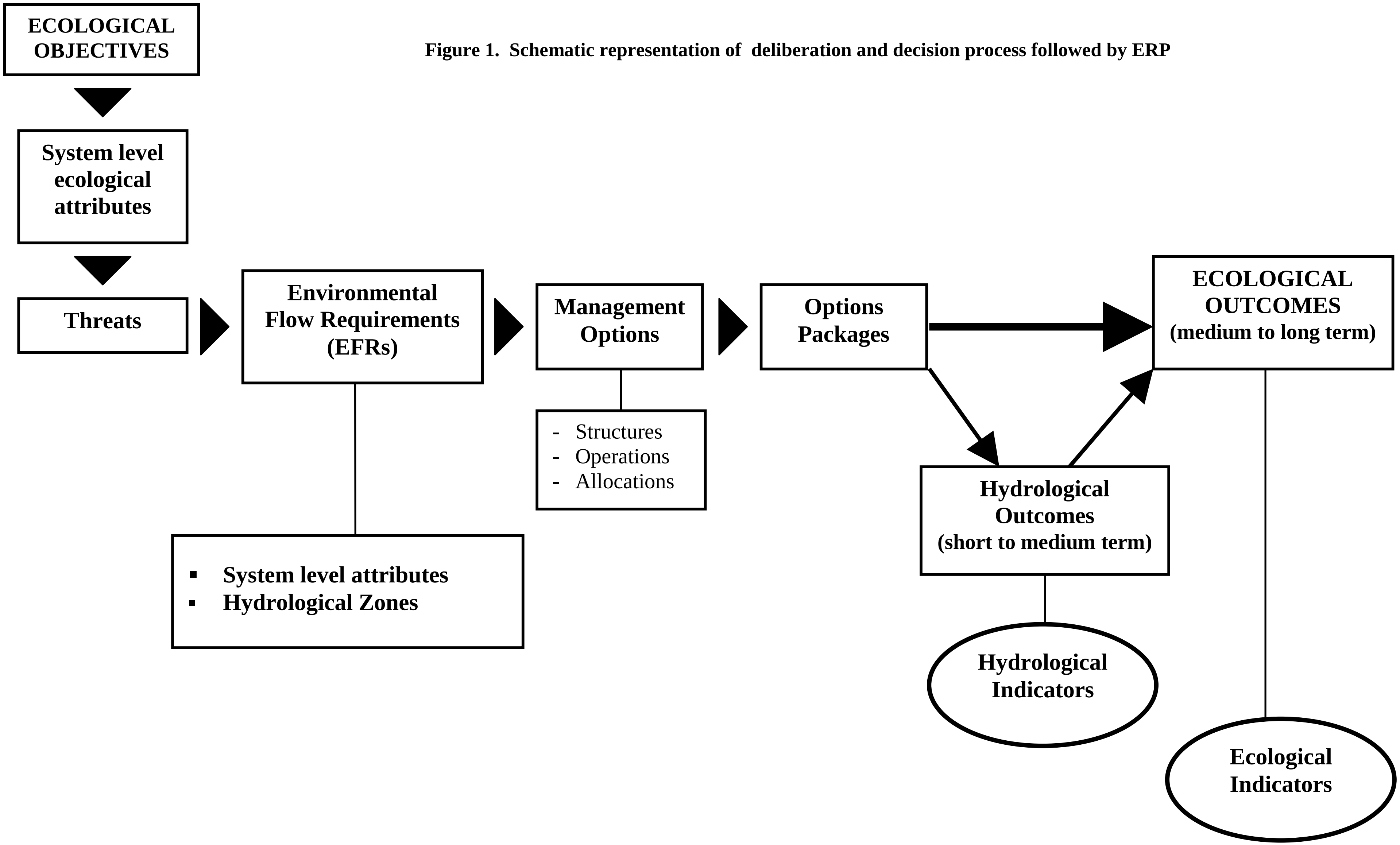
2.4 ERP Processes and Procedures

The approach to deliberation and decision making taken by the ERP is outlined in Figure 1. In summary, we identified the system level ecological attributes currently threatened in the River Murray, determined the EFRs that would mitigate these threats, and considered the ecological benefits (outcomes) that a number of Flow Option Packages, combined with improved structural and operational management, would provide. The options presented are assessed on their ability to provide the medium to long term ecological outcomes required to meet the identified ecological objectives.

In the short to medium term river management actions are likely to be assessed by performance against hydrological outcomes. However, we emphasise that hydrological outcomes are only an interim performance indicator and that ecological outcomes must be used to measure the efficacy of river management.

Recommendation 1.
Hydrological indicators are, at best, only surrogates for desired ecological outcomes. Ecological outcomes of improved river management should be assessed using ecological indicators such as those developed in the Sustainable Rivers Audit, the National River Health Program and the National Land and Water Resources Audit.

Figure 1. Schematic representation of deliberation and decision process followed by ERP



2.5 Healthy working river - definition

A *healthy working river* is one that is managed to provide a sustainable compromise, agreed to by the community, between the condition of the river and the level of human use.

A healthy working river will not look like nor will it function in the same way as a pristine river. There is a relationship between the type and level of work we make a river do and its naturalness. In general, the more work the river is made to do the less natural it becomes. By most definitions a loss of naturalness represents a reduction in ecological integrity[1]. For this report, ecological integrity is synonymous with river health.

A key component of the healthy working river concept is that the river is managed to sustain an agreed level of work and an agreed state of river health indefinitely. If the level of work reduces the health of the river below what the community desires it is not a *healthy* working river, regardless of the economic gains we may make in the interim.

As well as deriving benefit from working a river, humans also value the ecosystem services that are provided by a natural river ecosystem. These include provision of clean drinking water, nutrient cycling, sustaining river and coastal fisheries and providing an aesthetically appealing environment for tourism and recreation. In determining the trade off between river health and the economic gains from the work the river is made to do, one must also consider the associated loss of ecosystem services that occur when a river is made to work.

It was not the role of the ERP, or scientists in general, to decide upon the compromise between the competing values of production, ecosystem services and the natural environment. Rather, the ERP was asked to identify the level of work that will sustain indefinitely the ecological objectives first articulated by the Community Reference Panel and adopted by the Ministerial Council (see section 2.6). For the purpose of this report, a healthy working River Murray is where the level of work allows these ecological objectives to be sustained indefinitely.

The current debate over an appropriate mix of environmental and other uses for the River Murray is essentially a debate to determine how much water can be taken from the system with a tolerable reduction in ecological integrity. We support the argument that for 'working rivers' like the River Murray, natural condition (pristine) is not an achievable nor desirable objective. Whilst the river must 'give up' some water for human consumptive use, this volume must be less than that which significantly risks the health and long-term functioning of the river system. All assessments in this report are based on this definition of a healthy working river.

2.6 Ecological objectives and outcomes

The Ministerial Council adopted a suite of Objectives for the River Murray Environmental Flows and Water Quality Objectives Project (Table 1). These objectives define the communities aspirations for a healthy working River Murray System (Table 2). The ERP has adopted the Ministerial Council objectives and linked these to a suite of desired system level ecological outcomes. The ecological outcomes describe improvements in the ecological patterns (diversity, abundance and distribution of native biota, habitat and water quality) and processes (biologically

[1] Ecological integrity is defined as the capacity of a river to support and maintain a balanced, integrated, adaptive biological system having the full range of elements and processes expected in the natural habitat of a region. See for example: Frey, DG (1977). *Biological integrity of water – an historical approach*. In: RK Ballantine & LJ Guarraia (eds), The Integrity of Water. Proceedings of a Symposium, March 10-12, 1975; Boulton, AJ and Brock MA (1999). *Australian Freshwater Ecology. Processes and Management*. Gleneagles Publishing, Glen Osmond, SA; Norris et al. (2001). *The Assessment of River Condition (ARC): An Audit of the Ecological Condition of Australian Rivers*. Report Submitted to the National Land and Water Resources Office, May 2001.

mediated transformations in nutrients and organic matter, food web linkages, recruitment and connectivity) in the River Murray System. They underpin and directed the assignment of EFRs and assessments of the options packages made by the ERP.

Table 1. Ministerial Council Project Objectives pertaining to River Health, Environmental Flow and Water Quality Objectives

River Health Objectives	Environmental Flow Objectives	Water Quality Objectives
1. Protect and restore key habitat features in the river, riparian zone, floodplain and estuary to enhance ecological processes	5. Reinstate ecologically significant elements of the natural flow regime	8. Substantially improve water quality in the Murray system to a level that sustains ecological processes, environmental values and productive capacity
2. Protect and restore healthy riverine and estuarine environments and high value floodplain and wetlands of national and international importance	6. Keep the Murray Mouth open to maintain navigation and fish passage and to enhance estuarine conditions in the Coorong	9. Manage salinity to minimise impacts on ecological processes and productivity levels
3. Prevent the extinction of native species from the riverine system	7. Significantly improve connectivity between and within riverine, wetland, floodplain and estuarine environments	10. Manage nutrient levels to reduce the occurrence of blue-green algal blooms*
4. Overcome barriers to the migration of native fish species		11. Minimise the impact of potential pollutants such as sediments and pesticides within riverine environments

*The ERP notes that the primary driver of toxic blue-green algal blooms in lowland rivers is low flow. See Webster et al., 2000. *Control strategies for cyanobacterial blooms in an impounded lowland river*. Regulated Rivers Research and Managament. 16: 513-515.

Table 2. ERP Ecological Outcomes, highlighting links to the Project Objectives

Ecological Patterns	Ecological Processes
Improved diversity, abundance and distribution of native riverine biota *(Addresses Project Objective 3)*	Improved rates of biologically mediated transformations of nutrients and organic matter *(Addresses Project Objectives 1 and 10)*
Reduced abundance and distribution of exotic and nuisance biota *(Addresses Project Objectives 2 and 3)*	Improved foodweb dynamics and linkages *(Addresses Project Objective 1)*
Improved diversity, quality and availability of physical habitats *(Addresses Project Objectives 1 and 2)*	Improved rates of biotic reproduction and recruitment *(Addresses Project Objective 1)*
Improved water quality to sustain key ecological patterns and processes *(Addresses Project Objectives 8, 9 and 10)*	Improved hydrological connectivity and movement of matter and biota *(Addresses Project Objectives 4, 5, 6, and 7)*

In arriving at these ecological outcomes, the principal ecological threats to the health of the River Murray System previously identified on a reach by reach basis by three Expert Panel Reports [1 2 3]. were recognised. At the system level the ERP summarised these as:

- Altered hydrology
- Reduced in-channel and floodplain connectivity
- Degradation and loss of physical habitat
- Poor catchment and floodplain management
- Degraded water quality
- Exotic and invasive plants and animals

All these threats must be addressed if the River Murray system is to return to a healthy state.

Recommendation 2.
The health of a river is determined by its flow regime, the condition of its catchment, floodplain & in-channel habitats, and its water quality. These attributes must be considered holistically. Environmental flow allocations are an essential component of river management, but not sufficient alone to ensure a healthy river. Any decision to trade off flow requirements against other necessary management actions must be made with an understanding of the potential negative consequences.

Complying with its terms of reference, this report deals only with flow related threats to river health.

2.7 Summary of current river condition and future directions

The consensus of expert opinion is that the River Murray System can no longer be considered as healthy. This view is supported by the data and analysis presented in the first Murray-Darling Basin Snapshot Assessment of River Health[4]. The evolution of the current unhealthy condition of the River Murray is conceptually described in Figure 2. The figure indicates a continuum of river ecological condition from healthy to unhealthy. The transition zone between the two can be defined in a number of ways eg. a shift in ecological indicator scores from ‘reference’ to ‘significantly impaired’ condition. Whatever the choice of definition, the outcome is the same.

While Figure 2 shows a smooth decline, this should be seen as a long term ‘running average’ of ecological condition. In reality, ecological condition has a natural variation from year to year in response to natural variations in hydrology, climate, and biota reproduction and survival rates.

By the early 1900’s water quality impacts would have commenced due to catchment clearing, but abstraction of water for consumptive use was low compared with modern levels. The construction of Hume Dam and the locks and weirs on the lower Murray initiated an increased rate of degradation in ecological condition, accelerated by the rapid expansion in water abstraction for irrigation from the mid-1950s onwards.

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[1] Thoms et al. 2000. *Report of the River Muray Scientific Panel on Environmental Flows. Murray River – Dartmouth to Wellington and the Lower Darling River*. Murray-Darling Basin Commission.
[2] Jensen et al. 2000. *River Murray Barrages Environmental flows*. Murray-Darling Basin Commission.
[3] Roberts et al. 2001. *A scientific panel assessment of modelled flow and technical options for the River Murray*. A report to the Murray-Darling Basin Ministerial Council.

[4] Norris et al. 2001. *Snapshot of Murray-Darling Basin River Condition*. Report to the Murray-Darling Basin Ministerial Council.

It is likely that during the 1960s or 1970s, ecological condition deteriorated to a point where the River Murray could no longer be considered healthy. By 2001, the ecological condition of the River Murray is described as significantly impaired and therefore unhealthy.

The future condition of the River Murray System is clearly dependent on our actions now and over coming years. The ecological condition continues to degrade under the present Cap and current river operations. If no further imposts on the river system are allowed (ie. no increases to water abstraction, no more dams, no worsening of water quality, no more exotic pests) then ecological condition will continue to decline for some years before reaching equilibrium.

From the outset, it was the unanimous and unequivocal opinion of this and other exert panels that returning the Murray River System to a healthy working condition would require major improvements to river management – more environmental water, improved habitat condition, improved catchment & floodplain management, and better water quality.

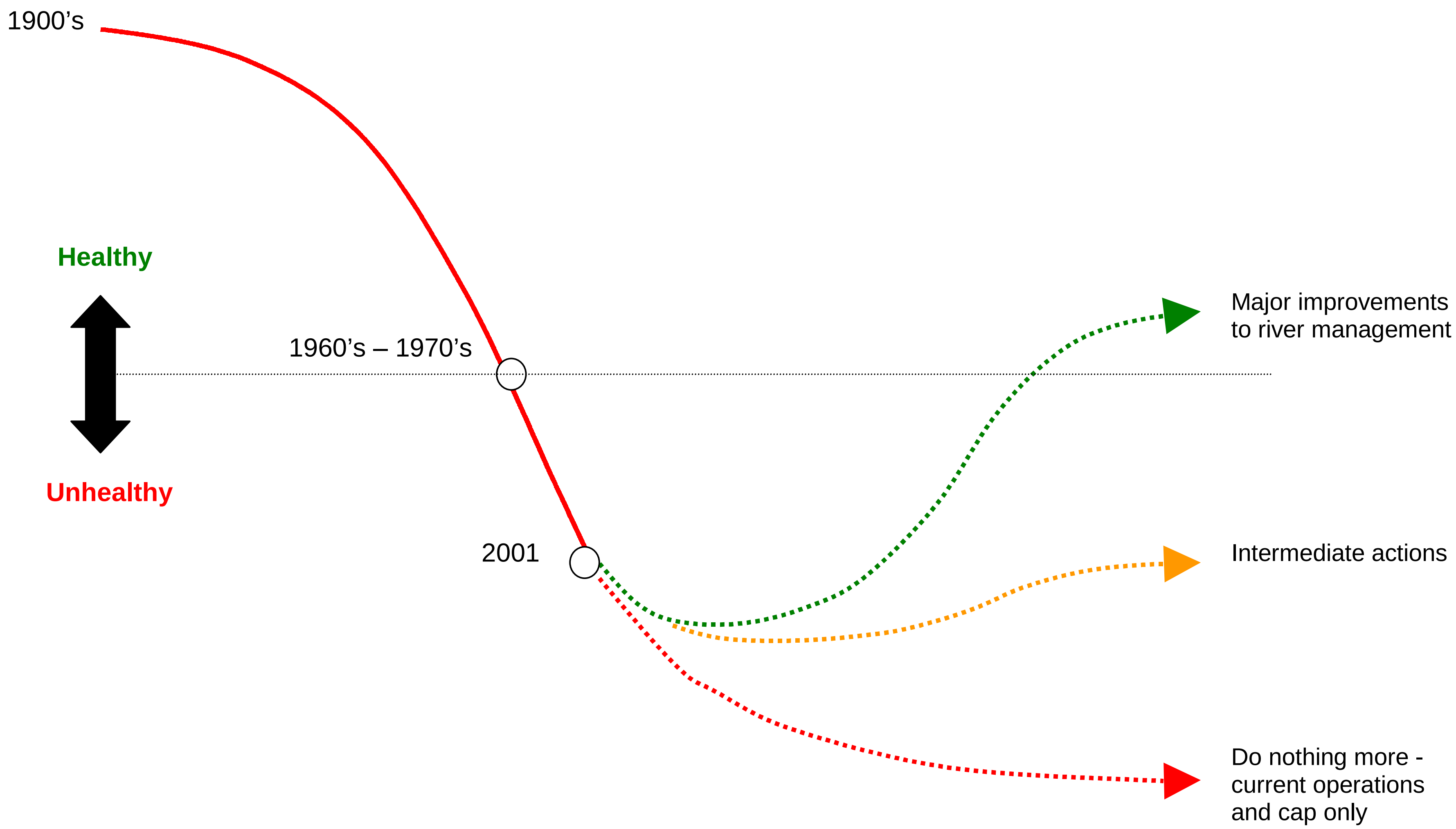

Figure 2. Evolution of ecological condition of Murray River system, with current and possible future conditions indicated

2.8 Risk-based approach to river health

River health is an important management concept. A healthy, or conversely an unhealthy, ‘condition’ is identifiable when a broad range of indicators are within a natural or ‘normal’ range. This is true whether speaking of human health, or river health. The exact transition between healthy and unhealthy states is impossible to define, and can be separated only using an arbitrary criterion e.g. a certain percentage departure from ‘normal’ in the range of agreed indicators.

This is essentially the approach taken by the NLWRA and the Snapshot Assessment of the Murray Darling Basin, and as advocated by the Sustainable Rivers Audit.

Because of the lack of precise knowledge linking river flows to ecological condition it is extremely difficult to develop quantitative performance targets for improved management of river health. But, the river health concept does lend itself to a risk-based assessment framework, and it is this approach that the ERP has adopted in setting specific targets for river management actions.

The key outcome that the ERP’s risk based assessment has considered is:

“A healthy working River Murray System”.

In this context, the key risk assessment is centred on the question:

”If we do x, what is the likelihood or probability of obtaining a healthy working River Murray System?”

It is within this context that the Flow Option Packages outlined in section 2.2 have been assessed for their ecological merit.

3. ECOLOGICAL BASIS FOR OPTION EVALUATION

3.1 System level attributes

As noted in section 2.5 there are several important components or attributes of a healthy river. Flow related aspects are just one part of the ecological jig saw puzzle. The terms of reference for this study directed us to make assessments and recommendations on management actions that would lead to a significant improvement in river hydrology. As some components of water quality are influenced by flow - salinity, turbidity, water temperature, toxic cyanobacterial blooms, for example – we have also been able to make some assessments of the effects of flow changes on these parameters.

The ERP derived five system level eco-hydrological attributes for the River Murray System. These were:

- flow volume
- flow distribution (pattern)
- flow variability
- connectivity (within and between the river channel and its floodplain)
- water quality

Table 3 identifies the key threats to these attributes and the Environmental Flow Requirements (EFRs) to address these threats. Key hydrological indicators used to assess short-term environmental benefits of the various options are described.

In arriving at its final system level assessment for each Flow Option Package (section 4), the ERP considered the EFRs and indicators outlined in Table 3 in five managed hydrologic zones – the Upper Murray (Dartmouth to Lake Mulwala), Mid-Murray (Yarrawonga Weir to Darling Junction), Lower Murray (Darling Junction to Wellington), the Lower Darling (Menindee Lakes to Murray Junction), and the Lower Lakes & Coorong (see Appendix 1).

3.2 Environmental flow requirements and indicators

i. The flow volume discharged through the River Murray, or across its floodplains, during any period of time broadly describes the total amount of water available for use by the environment. The significantly reduced flow volume downstream of major irrigation diversions, combined with evaporation from large storages, threatens almost the entire river system – with the exception of the Upper Murray. The environmental flow requirement is to increase flow volume in the river channel and across the floodplain. The ERP have considered this flow requirement using three indicators - median annual flow throughout the river system, total flow volume across the floodplain (out of channel), and average time the floodplain is significantly inundated (50-75% of flood plain area covered).

ii. Flow distribution relates to the pattern and sequence of flows over time. Key threats to this pattern are high summer flows causing loss of natural drying periods (Upper Murray), and loss of flood-flow sequencing. These threats result primarily from the capture of floodwaters in dams (loss of small to medium floods), and subsequent delivery of water for irrigation (high summer flows). The environmental flow requirements are to promote seasonal distribution of flows toward natural (with a focus on reducing high summer flows), and to promote the interval between floodplain-inundating flows toward natural. Indicators used by the ERP to consider these ERFs were; median summer flow, and flow interval at two critical stages – floodplain commence to flow and significant floodplain inundation (50-75% of flood plain area covered).

Table 3. System-level attributes for the River Murray system and key threats. The environmental flow requirements and hydrological indicators to assess these are indicated.

System Level Attribute	Key Threats	Environmental Flow Requirements (EFRs)	Hydrological Indicator	Code[#]
Flow Volume	Reduced flow volume	Increase flow volume in the river channel and across the floodplain	Median annual flow (GL/year)	MAF
			Total volume of flow > channel capacity (GL)	FGC
			Spell Analysis* - Average time above significant floodplain inundation threshold (months/year)	ATS
Flow Distribution	High summer flows	Reduce summer flows in Upper Murray	Median summer flow (Nov-March) flow (GL/m)	MSF
	Loss of flood flow sequence (small to medium floods)	Ensure flood flows are followed by a flow of similar magnitude at an interval promoted towards natural	Spell Analysis* - Median event interval (commence to flow)	FIC
			Spell Analysis* - Median event interval (significant floodplain inundation)	FIS
Flow Variability	Reduced flow range	Increase range of flows on a seasonal basis	SRA Seasonal Amplitude index	SAM
	Constant flows	Avoid unnaturally prolonged periods of constant river height	75^{th} percentile of daily change in river level (cm/d), November to February	SDC
	Unnatural rates of change in river height	The rate of change of the rising and falling limbs of the hydrograph should remain within the natural range	Not subject to modelling using the Monthly Simulation Model (MSM)– no indicator to assess	-

Connectivity	Barriers to in-channel fish movement	Enhance opportunities for weir drown-out	Weir drown out (% years): Lock 1 drowned out, September-March Weir 32 drowned out, August-November	WDO
	Reduced floodplain inundation	Promote towards natural the frequency and duration of floodplain inundation	Spell Analysis* - Median event duration (commence to flow)	MDC
			Spell Analysis* - Frequency of events above commence to flow threshold	FRC
			Spell Analysis* - Frequency of events above significant floodplain inundation threshold	FRS
			Spell Analysis* - Median event duration (significant floodplain inundation)	MDS
Flow Related Water Quality	Cold water releases from large dams	Ensure downstream water temperature is within natural seasonal range and changes at close to natural rates	Downstream Temperature. Not subject to modelling using the Murray Simulation Models – no indicator to assess	-
	Reduced in-stream productivity due to high summer turbidity	More natural proportion of Darling River discharge to the Murray during November-March	% Darling water of total at Lock 10 (Average: November - February)	PDA
	Unnatural salinisation	Maximise river flows for salt dilution purposes, within the natural range	Salinity (average level in EC at Morgan)	ECM
	Increased frequency of toxic cyanobacterial blooms	Reduce weir pool residence times to less than 10 days	% years Lock 3 < 4,000 ML/d November-April (Moderate security threshold)	ABM

Refers to ERP hydrological indicator codes used in Tables 7 and 8
*Refer to Appendix 2 for more detailed explanation of spell analysis indicators

iii. Constant flows, reduced seasonal flow range, or unnaturally rapid changes in river height threaten river health by altering the natural variability in river flows. These generally result from the operation of storages, though rapid draw-down may occur when diversions are a significant proportion of total flow. The environmental flow requirement is to avoid prolonged periods of constant river height and unnatural changes in river height. Indicators assessed by the ERP (as outputs of the MDBC Monthly or Daily Simulation Models) were the SRA Seasonal Amplitude Index[1], and the 75%ile of the variation in daily change in river height.

iv. Maintenance of hydrological connectivity between the river channel and the surrounding floodplain (e.g. Flood Pulse Concept[2]; the (extended) Serial Discontinuity Concept[3]) and along the river, from source to sea (e.g. River Continuum Concept[4]) is critical to a healthy river. Lateral connectivity with the floodplain is threatened by reduced number and duration of high in-channel (connecting with flood runners) and over bank flows, and the development of infrastructure on the floodplain (e.g. levees, roads, block banks). Connectivity along the rivers length is threatened by a series of weirs and reservoirs that disrupt the longitudinal continuum. The environmental flow requirements include the promotion of the natural frequency and duration of high flow events and the enhancement of opportunities for weir drown out. Indicators used by the ERP to evaluate improved connectivity were the frequency and duration of flows at two key thresholds – floodplain commence to flow and significant floodplain inundation (50-75% of flood plain area covered) – and frequency (% of years) of flows causing weir drown out (Lower Murray and Darling).

v. A healthy river requires water quality that sustains key ecological patterns and processes. Key threats to water quality in the River Murray System include unnatural (cold) temperature levels and fluctuations below major storages[5] [6] [7], elevated turbidity in the Lower River Murray during summer[8], toxic cyanobacterial blooms and increased salt concentrations in the river and on the floodplains. The environmental flow requirements include operational and structural changes to the release patterns from Hume and Dartmouth Dams and promoting a more natural proportion of summer Darling and Murray flows in the lower Murray. The flow requirement to improve salinity levels is to promote towards natural the flushing of wetlands and floodplain. For mitigation of cyanobacterial blooms, the flow requirement is to increase flows in summer or reduce weir pool residence time[9]. Indicators used by the ERP were; weir pool residence time < 10 days (moderate security threshold[8]), percentage of Darling flow in the Lower Murray during summer, and salinity levels in EC at Morgan.

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[1] Whittington et al. 2001. *Development of a framework for a sustainable rivers audit*. CRCFE Report.
[2] Junk et al. 1989. *The flood pulse concept in river-floodplain systems.* In: DP Dodge (ed), p. 110-127. Proceedings of the International Large River Symposium. Canadian Special Publication on Fisheries and Aquatic Sciences.
[3] Ward, JV and Stanford, JA. 1995. *The serial discontinuity concept: extending the model to floodplain rivers*. Regulated Rivers: Research and Management. 10: 159-168.
[4] Vannote et al. 1980. *The river continuum concept*. Canadian Journal of Fisheries and Aquatic Sciences 37:130-137.
[5] Harris, JH. 1997. *Environmental rehabilitation and carp control*. In: J Roberts and R Tilzey (eds), p. 21-36. Controlling Carp: exploring the options for Australia, CSIRO Land and Water.
[6] Lugg, A. 1999. *Eternal winter in our rivers: Addressing the issue of cold water pollution*. NSW Fisheries, Nowra, NSW, 17 pp.
[7] Astles et al. 2000. *Experimental study of the effects of cold water pollution on native fish*. NSW Fisheries Office of Conservation; Cooperative Research Centre for Freshwater Ecology, Port Stephen. Report to the NSW Water Management Fund, 53pp.
[8] Thoms et al. 2000. *Report of the River Muray Scientific Panel on Environmental Flows. Murray River – Dartmouth to Wellington and the Lower Darling River*. Murray-Darling Basin Commission.
[9] Webster et al. *Control strategies for cyanobacterial blooms in an impounded lowland river*. Reg Rivers. Res. Man. 16, 513-515.

3.3 Comparison of ERP and JRP Indicators

The River Murray simulation models developed by the MDBC Project Team provide hydrological (and some economic) output for operational and planning purposes. These are, by definition, hydrologic models – not ecological models. Deriving ecological indicators from hydrological models will always be difficult and constrained by the model outputs.

The ERP addressed this problem by running a series of post-model analysis to derive seven of its sixteen indicators, using flow data generated from model runs for each of the Flow Option Packages. A spell analysis program called GetSpells was used for this purpose, and is described in detail in Appendix 2. The spell analysis indicators provided high quality statistical information on the frequency and duration of floodplain inundation and flood interval at two key flow thresholds for Ramsar wetlands - commence to flow and significant floodplain inundation (50-75% floodplain area inundated). This information could not be provided by the MDBC river models directly, but was required to assist the ERP in the evaluation of Flow Option Packages.

The ERP (and others previously) found it very difficult to link many of the JRP indicators to specific ecological attributes, outcomes or benefits. In contrast, all the ERP indicators have been linked to the key system level ecological attributes and environmental flow requirements, as described in Table 3.

Finally, very recent work by the MDBC Project Team (jurisdictional and regional consultation and review, and geomorphic analysis) has led to a revision of several of the commence to flow and floodplain inundation flow thresholds for key River Murray (Ramsar) wetlands. These were not included in the JRP indicators - the ERP indicators use these new flow thresholds.

4. ECOLOGICAL ASSESSMENT OF OPTIONS PACKAGES

4.1 Development of a risk-based targets for environmental flow allocations

In section 2.8 it was stated that the river health concept lends itself to a risk-based framework for assessment and target setting. The key risk assessment required was stated as: "If we do x, what is the likelihood or probability of obtaining a healthy working River Murray System?". The linking of this broad risk framework to river management and environmental flow restoration performance targets is described in Figure 3.

It is the considered opinion of the ERP that, assuming suitable water quality and physical habitat, there is a substantial risk a working river will not be in a healthy state when key system level attributes of the flow regime are reduced below two/thirds of their natural level (left half of Figure 3).

In the context of this report, the key system level attributes are those described in Table 3.

Support for this 'guidance value' exists for a number of studies conducted in Australian river systems. Sheldon et al. 2000[1] developed a series of reference curves for key ecological indicators that describe ecological response to hydrological change for six large dryland rivers in the Murray Darling Basin (Condamine-Balonne, Gwydir, Lachlan, Macquarie, Murrumbidgee and Namoi Rivers). These curves were developed using an extensive biological data set and simulated flow data from the IQQM model, and indicate marked ecological response to hydrological change associated with water resource development. In particular, they provide supporting evidence for significant and unacceptable negative ecological impacts at as little as 30% deviation from the natural condition for key flow regime attributes.

Further support for the 'two/thirds natural guidance value' can also be found in the analyses carried out by the Technical Advisory Panel for the Condamine-Balonne and Fitzroy Basin WAMP in Queensland[2]. These reports clearly identify that for a range of key hydrological indicators, assessed across several Australian river systems, the limit for an increased risk of unacceptable environmental degradation (environmental flow limit) generally lies within the range of 65 - 75% natural (Table 4).

Important note - the 'two-thirds natural' level applies only to regulate or other impounded rivers. It is a target for river restoration, not a level for 'acceptable degradation' or 'sustainable diversion' of minimally impacted rivers.

[1] Sheldon et al. 2000. *Using disaster to prevent catastrophe: referencing the impacts of flow changes in large dryland rivers*. Regulated Rivers: Research and Management. 16: 403-420.
[2] Condamine-Balonne WAMP Environmental Flows Technical Report. 2000. Department of Natural Resources, Queensland; Water Allocation and Management Plan (Fitzroy Basin) 1999 WAMP. Department of Natural Resources, Queensland.

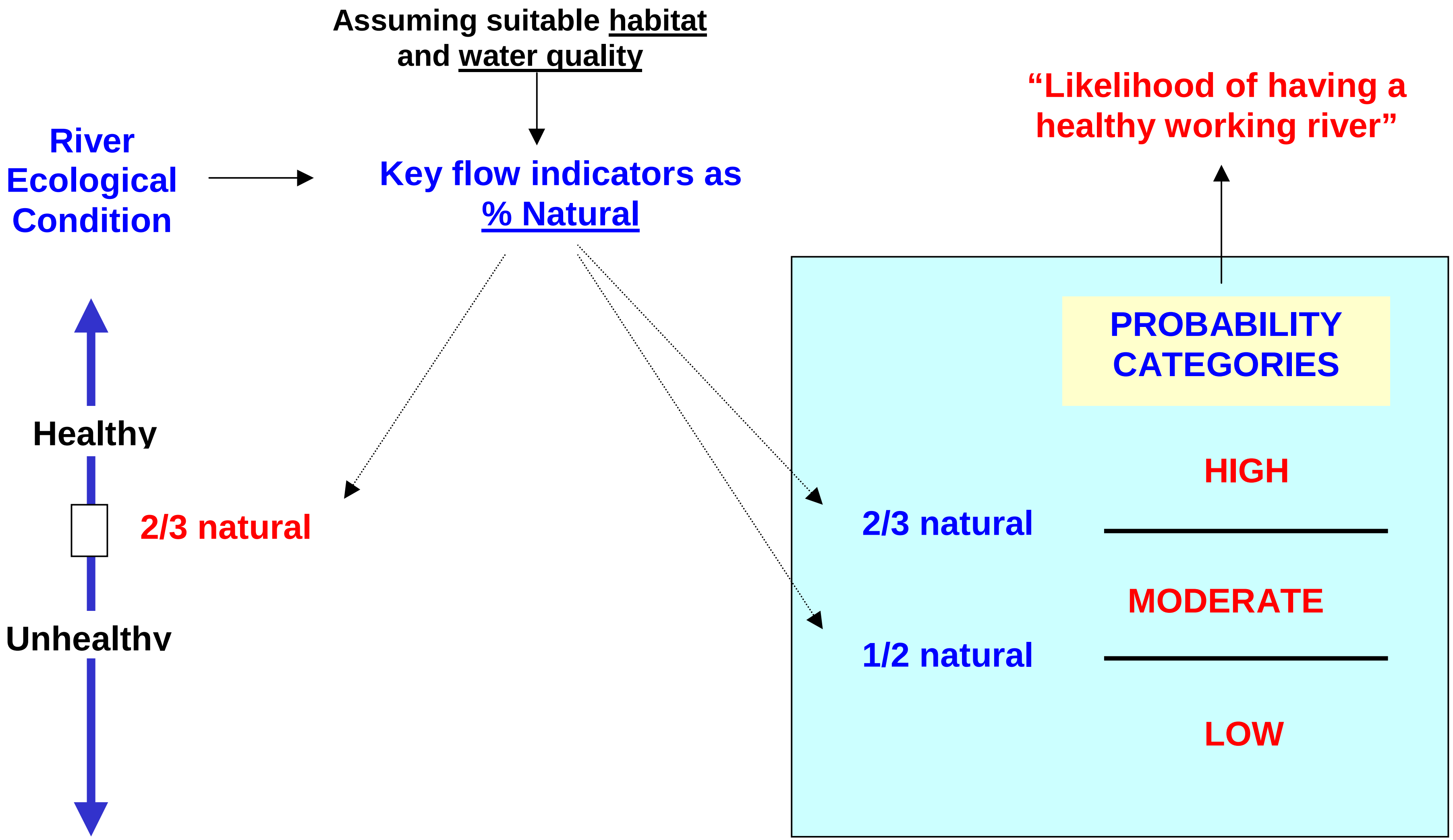

Figure 3. Linking ecological condition to key flow attributes and indicators (left half), and to probability categories that environmental flow allocations and improved river operations will deliver a healthy working River Murray System (right half).

Table 4. Summary of environmental flow limits for key hydrological indicators identified by the Condamine-Balonne Draft WAMP (2000)[1] and Fitzroy Basin WAMP (1999)[2].

River system	Indicators	Environmental Flow Limit (% natural)
Condamine-Balonne *approximate average across 17 river nodes	Median annual flow (change in the median annual streamflow)	62-65%
	High flow (change in the high flow event frequency)	65-67%
	Medium flow (change in the medium flow event frequency)	65-67%
	Low flow (change in the low flow duration percentile)	65-67%
	No flow (change in the no flow duration percentile)	1/160 = 63%
Fitzroy *approximate average across 7 river nodes	Mean annual flow (change in the average annual streamflow)	75%
	Median annual flow (change in the median annual streamflow)	50%
	Floodplain zone (change in the number of flows that cause floodplain inundation)	73%
	Upper riparian zone (change in the number of flows that inundate vegetation on the upper river bank)	86%
	In-channel riparian zone (change in the number of flows that inundate in-channel vegetation)	75%
	Channel morphology (indication of general river stability)	67%
	Key biological trigger processes (Indication of the proportion of the first post-winter flow event allowed to pass without diversion)	72%

From this 'guidance value' the ERP derived probability categories for environmental flows restoration action. When key flow attributes were indicated as being greater than <u>two/thirds</u> of their natural level, there was a high probability or likelihood of achieving a healthy working river (right half fig. 3). When the same flow attributes were indicated as being greater than only <u>half</u> of their natural level, there was a moderate probability of achieving a healthy working river. Below half natural, the probability of having a healthy working river was low.

Caveat: The environmental flow restoration probability categories listed in Figure 3 presume that the river offers suitable habitat and water quality for the growth and survival of native plants and animals. As noted in section 2.5, river health is an indivisible, holistic package – the full benefits of environmental flow restoration will only be realised if river water quality, flood plain lands, and river habitat are also restored or protected.

4.2 Summary Assessment of Option Packages

The risk categories described in Figure 3 were applied by the ERP to the analyses of the likelihood that the flow options packages provided by the MDBC project team (section 2.2) would provide for a healthy working River Murray System. The summary results of this analysis are outlined in table 5.

Table 5. Final summary assessment of flow option packages - probability of success of management actions

Management Options	Probability of having a healthy working River Murray System
Do nothing more (Current operations) (MDBC Package 56740)	LOW
A. Improved operations (MDBC Package 57200)	LOW[1]
B. Improved operations plus 350 GL new environmental flows (Murray source) (MDBC Package 57150)	LOW[1]
C. Improved operations plus 900 GL new environmental flows (Basin-wide source) (MDBC Package 57210)	LOW-MODERATE
D. Improved operations plus 1950 GL new environmental flows (Basin-wide source) (MDBC Package 57220)	MODERATE
E. Improved operations plus 4000 GL new environmental flows (Basin-wide source) (MDBC Package 57300)	HIGH

[1] Some localised ecological benefits are delivered by these options eg. for specific wetlands or floodplain forests, but the overall system level impact was insufficient to improve the probability category

The key outcomes of the ERP's risk assessment are that there would be a high likelihood of achieving a healthy working River Murray System if 4000 GL of new environmental flow allocations was combined with the operational improvements described in options package 57200. The same operational improvements combined with 1950 GL of new environmental flow allocations would lead to a moderate likelihood of achieving a healthy working River Murray System.

All other packages examined, and the 'do nothing more' option (current cap and operations), provide little confidence that a healthy working river would be achieved some time in the future. Some localised ecological benefits are delivered by options A and B - for specific wetlands or floodplain forests - but the overall system level benefit was insufficient to improve the probability category.

Further improvements in river operations beyond those described in options package 57200 may lead to better ecological outcomes for the same volumes of new environmental flows. However, it is not certain whether these improvements would lead to an improvement in the assessed probability category. Further modelling developments and work by the MDBC Project Team would be required to make this determination. This new work should include coupling of hydrological models for the major Murray tributaries to the current Murray River hydrological simulation models.

4.3 Detailed Assessment of Option Packages

The summary assessment presented in Table 5 was underpinned by several levels of data and analyses. The first of these is the probability category analysis for the flow options packages summarised against the individual system level ecological attributes previously described (Table 6).

The probability categories for the ecological attributes were based on the assignment of probability categories to individual indicators for each system level attribute (Table 7).

The information in Table 7 is derived from the ‘precent natural’ scores for the key hydrological indicators. These are presented graphically for each river management zone (as % of natural) in Appendix 3, along with a table presenting the absolute values for each hydrological indicator (Appendix 4).

4.4 Darling River impacts

“Improved operations” options package 57200 was based on the use of major Murray tributary flows – Lower Darling, Murrumbidgee, Goulburn - to augment natural flow events in the river. The potential ecological benefits and impacts of the options packages on the Murrumbidgee and Goulburn rivers cannot be assessed as these rivers are not part of the River Murray hydrologic simulation models. However, the Lower Darling (below the Menindee Lakes) is considered in these models.

The ERP concludes that little ecological benefit is provided to the Darling River by these options packages. Indeed, degradation of some ecological attributes may occur (Table 8).

4.5 Time line for responses

With any hydrological change there will always be a 'lag time' before the ecological response is observed. Higher order flora and fauna communities (e.g red gums, large fish) may take years to decades to respond to a change in the flow regime. Populations of organisms with relatively shorter generation times may respond relatively more quickly (e.g. macrophytes, invertebrates, small fish) (Fig. 4). The message is that the benefits of environmental flows on the health of the river may not become apparent for some time. Well designed monitoring programs will be essential to detect the ecological response (both short and long term responses) to a change in the flow regime and the provision of environmental flows.

Table 6. Assessment of flow option packages - probability of success of management actions listed against system level ecological attributes

Management Options	Murray River System Level Attributes – Likelihood of healthy condition				
	Flow volume	Flow distribution	Flow variability	Connectivity	Water Quality
Do nothing more (Current operations) (MDBC Package 56740)	LOW	LOW-MOD	LOW	LOW-MOD	LOW
A. Improved operations (MDBC Package 57200)	LOW	LOW-MOD	LOW	MODERATE	LOW
B. Improved operations plus 350 GL new environmental flows (Murray source) (MDBC Package 57150)	LOW	LOW-MOD	LOW-MOD[2]	MODERATE	LOW
C. Improved operations plus 900 GL new environmental flows (Basin-wide source) (MDBC Package 57210)	LOW	LOW-MOD	LOW-MOD[2]	MODERATE	LOW
D. Improved operations plus 1950 GL new environmental flows (Basin-wide source) (MDBC Package 57220)	MODERATE	MODERATE	LOW-MOD[2]	MOD-HIGH	LOW-MOD
E. Improved operations plus 4000 GL new environmental flows (Basin-wide source) (MDBC Package 57300)	MODERATE	MOD-HIGH[1]	MODERATE	HIGH	HIGH

[1] Lower benefit at Barrages

[2] Variability in flow (river height) is only weakly addressed by the operations modelled herein – other operational gains should be achievable by improved weir and storage operations (see section 5)

Table 7. 'Healthy working river' probability assessments for individual hydrologic indicators. L = low, M = moderate, H = high. [1] % current condition

Upper Murray	Mid Murray
Lower Murray	Lower Lakes & Coorong
System level	

***See Appendix 3 & 4 for supporting data ; ±5% accuracy in indicator values**

Except FRC, FRS, MDC, MDS, FIC, FIS & ATS (from Spells analysis). Upper left Barmah-Millewa, Upper right – Gunbower; Lower left – Hattah; Lower right – Chowilla .
Empty 'quadrant' means indicator not assessed in this zone

Management Options	Flow volume			Flow distribution			Flow variability		Connectivity					Flow-related Water Quality		
	MAF	FGC	ATS	MSF	FIC	FIS	SAM	SDC	FRC	MDC	FRS	MDS	WDO	ABM	PDA	ECM[1]
Do nothing more (Current operations) (Package 56740)	L L L L	L L L	L L L L L	L L	H M L M M	M L L L L	M M L L L	L L L	H H M M M	L M M H M	L L L L L	H M H H M	 L L	L L	L L	N/A
A. Improved operations (Package 57200)	L L L L	L L L	L L L L L	L L	H M L M M	M L L L L	M M L L L	L L L	H H M M M	M M M H M	M M L L L	H M H H M	 M M	L L	L L	100 % L
B. Improved operations plus 350 GL (Package 57150)	L L L L	L L L	M L L L L	L L	H M L M M	M L L M L	H H M L M	L M L	H H M M M	H M M H M	M M L L L	H M H H M	 M M	L L	L L	97 % L
C. Improved operations plus 900 GL (Package 57210)	M L L L	L L L	M L L L L	L L	H M H M M	M L L M L	H H M L M	L M L	H H M H H	H M M H M	M M L L L	H M H H M	 M M	L L	L L	95 % M
D. Improved operations plus1950 GL (Package 57220)	M M L M	L M M	M L M L L	M M	H M H H H	H M L M M	H H M L M	L M L	H H M H H	H H H H H	H M M L M	H H H H H	 M M	L L	M M	92 % M
E. Improved operations plus 4000 GL (Package 57300)	H M M M	M M M	H M M M M	M M	H H H H H	H M M H M	H H H M H	L L L	H H H H H	H H H H H	H H M M M	H H H H H	 H H	H H	H H	86 % H

[1] Expressed as a percentage of 'current' (56740) for ECM indicator. As percentage decreases, the indicator is improving.

Table 8. Assessment of flow option packages - probability of success of management actions listed against system level ecological attributes – Lower Darling

Management Options	Flow volume		Flow distribution		Connectivity	
	MAF	FGC	ATS	FPS	FRC	FRS
Do nothing more (Current operations) (MDBC Package 56740)	LOW	MOD	MOD	HIGH	LOW	MOD
A. Improved operations (MDBC Package 57200)	LOW	MOD	MOD	HIGH	LOW	MOD
B. Improved operations plus 350 GL new environmental flows (Murray source) (MDBC Package 57150)	LOW	MOD	MOD	MOD	LOW	MOD
C. Improved operations plus 900 GL new environmental flows (Basin-wide source) (MDBC Package 57210)	LOW	MOD	MOD	HIGH	LOW	MOD
D. Improved operations plus 1950 GL new environmental flows (Basin-wide source) (MDBC Package 57220)	LOW	MOD	MOD	MOD	LOW	MOD
E. Improved operations plus 4000 GL new environmental flows (Basin-wide source) (MDBC Package 57300)	LOW	MOD	MOD	MOD	LOW	MOD

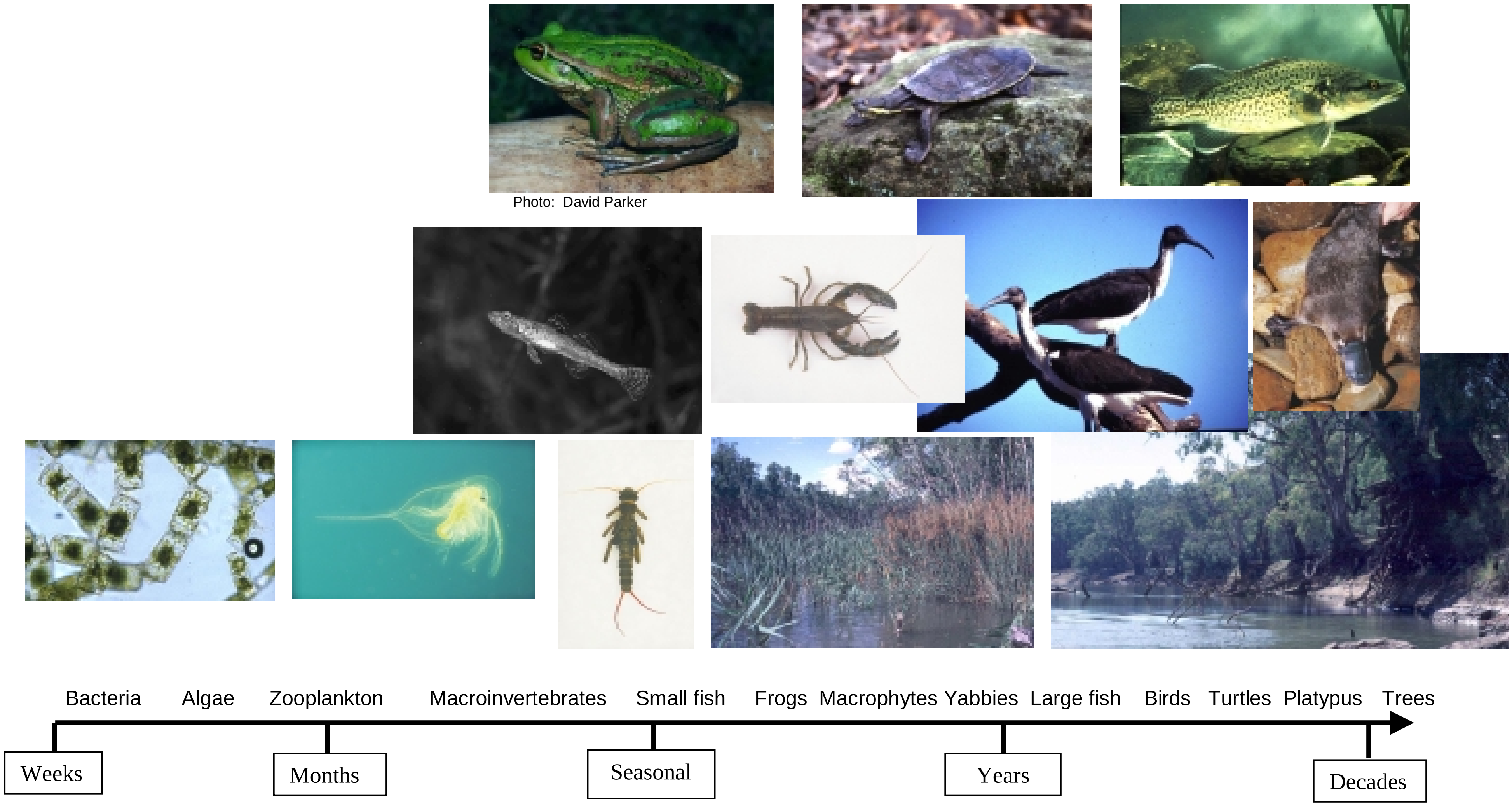

Figure 4. Relative time scale for recovery of healthy populations of riverine communities. Response times are relative to the generation times of the organisms and may depend upon favourable conditions.

5. Structural and Operational Requirements

The following structural and operational requirements must be addressed to ensure that the environmental flow option package benefits described in section 4 are realised.

Failure to address these recommendations could lead to a failure to deliver significant ecological benefits from any environmental flow allocations.

5.1 Weir Management – permanent and seasonal removal

Recommendation 3

- **Non-essential locks and weirs should be removed;**
- **Murray River lock and weir structures should be removed for two months each year, during periods of low irrigation demand (e.g. June-August); and**
- **In the shorter term, Lock 8 should be decommissioned (empty weir pool and operate as a transparent structure) as an experimental trial with measurements of the positive (eg. fish passage) and negative (eg. saline groundwater discharge) ecological outcomes being undertaken.**

Ecological threat addressed:

- Weirs result in unnaturally high and stable water levels and reduce in-channel (longitudinal) connectivity.

Ecological outcomes:

- Improved fish passage. It should be noted that the absence of in-channel structures (weirs) will always provide better fish passage compared with construction of a fishway;
- Improved littoral habitat and riparian vegetation from increased variation in river height;
- Improved wetland condition for wetlands normally drowned by the weir pool; and
- Improved benthic and biofilm communities.

5.2 Weir Management – partial draw-dawn

Recommendation 4

If recommendation 3 cannot be achieved in its entirety, then weir pools should be lowered by at least 1 metre for 3 months each winter-spring.

Ecological threat:

- Locks and weirs result in unnaturally high and stable water levels; and
- Loss of natural drying periods.

Ecological outcome:

- Improved littoral habitat and riparian vegetation from increased variation in river height;
- Improved wetland condition for wetlands normally drowned by the weir pool; and
- Improved benthic and biofilm communities.

5.3 Weir Management – fishways

Recommendation 5
If recommendation 4 cannot be achieved, then all locks and weirs should have fishways installed.

Ecological threat:
- Locks and weirs reduce longitudinal connectivity.

Ecological outcome:
- Improved fish passage resulting in improved native fish populations.

5.4 Weir Management – raising height caveat

Recommendation 6
Undertake proper ecological assessment and cost-benefit analysis before any proposal to raise weir height proceeds.

Ecological threat addressed:
- Reduced inundation of floodplain upstream of major weirs which could be overcome by raising height of weir pool to simulate effect of large floods in localised areas; and
- May create new threat which is increased risk of unseasonal floodplain inundation if not combined with other management structures (regulators) and actions.

Ecological outcome:
- Localised flooding will irrigate floodplain and wetlands upstream of structure but may not sustain major recruitment of larger fauna; and
- Ecological outcomes not likely to be as significant as those from a natural flood event of equivalent height because of the lack of longitudinal connectivity.

5.5 Thermal pollution – Dam Off-take design

Recommendation 7
Undertake appropriate thermal mitigation works at Lake Hume and Dartmouth Dam, to provide release temperature close to natural. Reference to be made to recent work of Dr. Bradford Sherman, CSIRO Land & Water[1].

Ecological threat addressed:
- Water quality unsuitable for sustaining key ecological patterns and processes.

Ecological outcome:
- Improved communities of native fish and other biota downstream of major dams.

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[1] Sherman, B. 2000. *Scoping options for mitigating cold water discharges from dams*. Report to Agriculture, Fisheries and Forestry – Australia, NSW Fisheries, CRC for Freshwater Ecology, and NSW Department of Land and Water Conservation as part of the NHT Murray-Darling 2001 FishRehab Program. CSIRO Land and Water, Canberra. Consultancy Report 00/21, May 2000.

5.6 Dam and weir releases

Recommendation 8
Improve (promote towards natural) day-to-day variability in release patterns below all storages and weirs.

Ecological threat addressed:
- Loss of extremely low flow events; and
- Constant flows resulting in loss of habitat and increased suspended sediment load through bank erosion.

Ecological outcome:
- Improved littoral and riparian habitat; and
- Improved diversity of biofilm and benthic communities.

5.7 Barrage releases

Recommendation 9
- **Provide volume and timing of flows to promote significant fish recruitment in the Lower Lakes and Coorong;**
- **Provide appropriate flows for the remainder of the year to maintain connectivity and fish passage between Coorong and ocean (i.e. keep the Murray Mouth Open); and**
- **Undertake ecological and hydrodynamic studies to determine the volume and pattern of flows required to achieve the above.**

Ecological threat addressed:
- Reduced abundance and diversity of native fish and other biota; and
- Reduction in quality and quantity of estuarine habitat in the Coorong.

Ecological outcome:
- Improved native fish recruitment;
- Improved diversity and abundance of Coorong biota; and
- Provides fish passage between the ocean and the Coorong.

5.8 Unseasonal flooding in Barmah-Millewa

Recommendation 10
- **Reduce the frequency and volume of rain rejection events by improving management of water ordering, removing unnecessary structure, and clawing back operational airspace at Yarrawonga Weir.**

Ecological threat addressed:
- Unseasonal flooding (summer and autumn) resulting in reduction in the of Moira grass communities in the floodplain forests below Yarrawonga Weir.

Ecological outcome:
- Improve floodplain forest and wetland ecosystem.

5.9 Darling Anabranch Management

Recommendation 11

- **Implementation of pipelines to supply stock and domestic water to users along the Darling Anabranch; and**
- **Removal of unnecessary structures (block banks, regulators and weirs) along Anabranch and associated Lakes.**

Ecological threat addressed:

- Unnatural flooding (prolonged flooding and drying of sections of the main anabranch channel);
- Reduced flooding of Anabranch Lakes; and
- Reduced flow volume in Lower Darling and Murray Rivers.

Ecological outcomes:

- Reduced opportunities for colonisation of the Anabranch by exotic and nuisance species (e.g. Carp and Cumbungi);
- Improved and increased habitat for native biota in the Anabranch and associated Lakes; and
- Improved feeding and breeding habitat for native waterbirds, amphibians, invertebrates and fish.

5.10 Regulators

Recommendation 12

In cases where it is not possible in the short to medium term to modify weir heights or flow regime, consideration should be given to installing regulators on important wetlands and operating these structures to mimic natural wetting and drying regimes.

Ecological threat addressed:

- Unseasonal flooding; and
- Wetlands permanently drowned by weir-pools.

Ecological outcome:

- Improved wetland habitat;
- Increased area of ephemeral wetland;
- Improved feeding and breeding habitat for waterbirds, amphibians, invertebrates and native fish; and
- Improved nutrient and carbon cycling resulting from more natural wetting and drying cycles.

5.11 Floodplain levees

Recommendation 13

An audit should be undertaken of all floodplain levees and other structures (block banks, roads) that alter the natural movement of water across the floodplain. Unnecessary and illegal levees should be removed as a matter of priority.

Ecological threat addressed:

- Reduced floodplain connection; and
- Reduction in area of floodplain inundated.

Ecological outcome:

- Improved floodplain forest and wetland condition; and
- Improved distribution and abundance of water birds.

APPENDIX 1 – MANAGED HYDROLOGICAL ZONES

River Murray managed hydrologic zones (and corresponding nodes) at which ERP system level indicators were assessed. Flow at nodes indicative of flooding in Ramsar sites is shown.

Major Geomorphic Zones	Managed Hydrologic Zone	Indicator Node	Ramsar site
Upper Murray	Dartmouth-Hume	Mitta Mitta downstream of Dartmouth - Tallandoon	
	Hume-Yarrawonga	Albury (Doctor's Point)	
Mid Murray	Yarrawonga-Torrumbarry	Yarrawonga downstream	Barmah-Millewa
	Torrumbarry-Lock 11	Torrumbarry Euston	Gunbower Hattah
Lower Murray	Lock 11-Lock 3	Flow to SA Lock 10	Chowilla
	Lock 3-Wellington	Downstream Lock 3	
Lower Lakes and Coorong	Wellington-Mouth	Barrages	Coorong
Lower Darling	Menindee-Darling Junction (including the Lower Darling River and the Great Darling Anabranch)	Weir 32	

APPENDIX 2 – GETSPELLS ANALYSIS

A Windows-based software program called 'GetSpells' has been developed for the Department of Natural Resources and Environment by Sinclair Knight Merz, to assist Victoria's Water for the Environment Program in environmental flow provisions for rivers across the state[1,2]. The GetSpells program was used here to undertake various post-run analysis of modelled natural and current monthly flow data produced by the MDBC Monthly Simulation Model (MSM). These data were then assessed against flow option packages developed by the MDBC.

The program extracts various spell characteristics that relate to the **duration** of events that exceed selected flow thresholds and the **interval** between these events, as defined below.

Definitions:

- A **spell** is the total period of time when flows are continouosly either entirely above or entirely below a nominated threshold value[1]. For example, in Figure 1 the numbers 1-4 indicate the spells that occur above threshold flow A.
- A **spell duration** is the number of days (or months) when the streamflow is continuously above (or below) a given threshold[1]. In Figure 1, the duration of spell 1 is the number of days the flow remains above threshold flow A. Spell 1 ends immediately when the flow goes below the threshold and a new spell begins when the flow rises above the threshold.
- A **spell interval** is the number of days (or months) between spells[1]. In Figure 1 the spell interval is the number of days (or months) the flow remains below threshold flow A between spell 1 and 2.

It was specified in the analysis that flow events (spells) were to be considered independent if separated by at least 1 month.

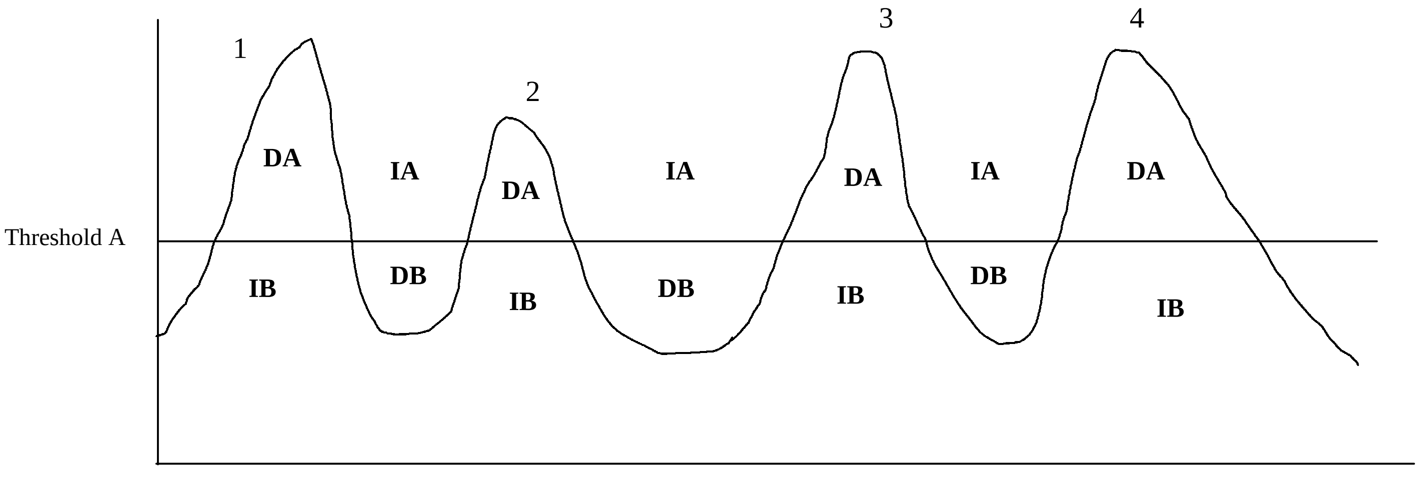


Figure 1. Hydrograph showing how 'GetSpells' defines spell durations and spell intervals both above and below threshold flows. DA=spell duration above threshold; DB=Spell duration below threshold; IA=spell interval above threshold; IB=spell interval below threshold. Note: DA=IB and DB=IA.

[1] Sinclair Knight Merz. 1999. *User manual for GetSpells program*. Developed for the Department of Natural Resources and Environment by Sinclair Knight Merz.

[2] Donald et al. 1999. *Use of spell analysis as a practical tool to link ecological needs with hydrological characteristics*. Proceedings of the Second Australian Stream Management Conference, 8-11 Frebruary 1999, Adelaide, South Australia.

Following the approach of Sinclair Knight Merz and the principles advocated by the ERP, a comparison of natural and current conditions and the relative influence of Options A-E on key hydrologic indicators was used to assist the ERP in their assessment of flow option packages.

Indicator nodes

Flow data were analysed from four key locations (nodes) along the River Murray System that are indicative of flooding in Ramsar wetlands. These were:

1. Yarrawonga (Barmah-Millewa Forest);
2. Torrumbarry (Gunbower Forest);
3. Euston (Hattah Lakes); and
4. Flow to South Australia (Chowilla).

Flow Thresholds

Key flow thresholds used to assess the option packages were:

1. Commence to flow: This corresponds to the flow (ML/d) that begins to wet the primary flood-runners connecting the floodplain wetlands to the river; and
2. Significant floodplain inundation: This corresponds to the flow (ML/d) required to inundate approximately 75% of the floodplain area.

These are considered to be ecologically significant flow thresholds. The commence to flow threshold represents the flow at which a range of in-channel habitats, riparian vegetation communities, low-lying wetlands, primary flood-runners and anabranches may receive water. The second threshold represents flows that activate a significant degree of floodplain inundation and connectivity with the floodplain and associated habitats.

Node (Ramsar site)	**Flow Threshold**	
	Commence to Flow	**Significant Floodplain Inundation**
Yarrawonga (Barmah-Millewa Forest)	**12,000ML/d**	**30,400ML/d**
Torrumbarry# (Gunbower Forest)	**12,000ML/d** (actual=13,700ML/d)	**35,000ML/d** (actual=40,000ML/d)
Euston (Hattah Lakes)	**36,700ML/d**	**48,900ML/d**
Flow to South Australia# (Chowilla)	**30,000ML/d**	**100,000ML/d**

threshold used in the analysis has been modified to represent the flow that would inundate an equivalent area under the assumption that weir pools are raised (Torrumbarry weir raised 0.3m and Lock 6 raised 0.6m). Actual flow threshold is in brackets.

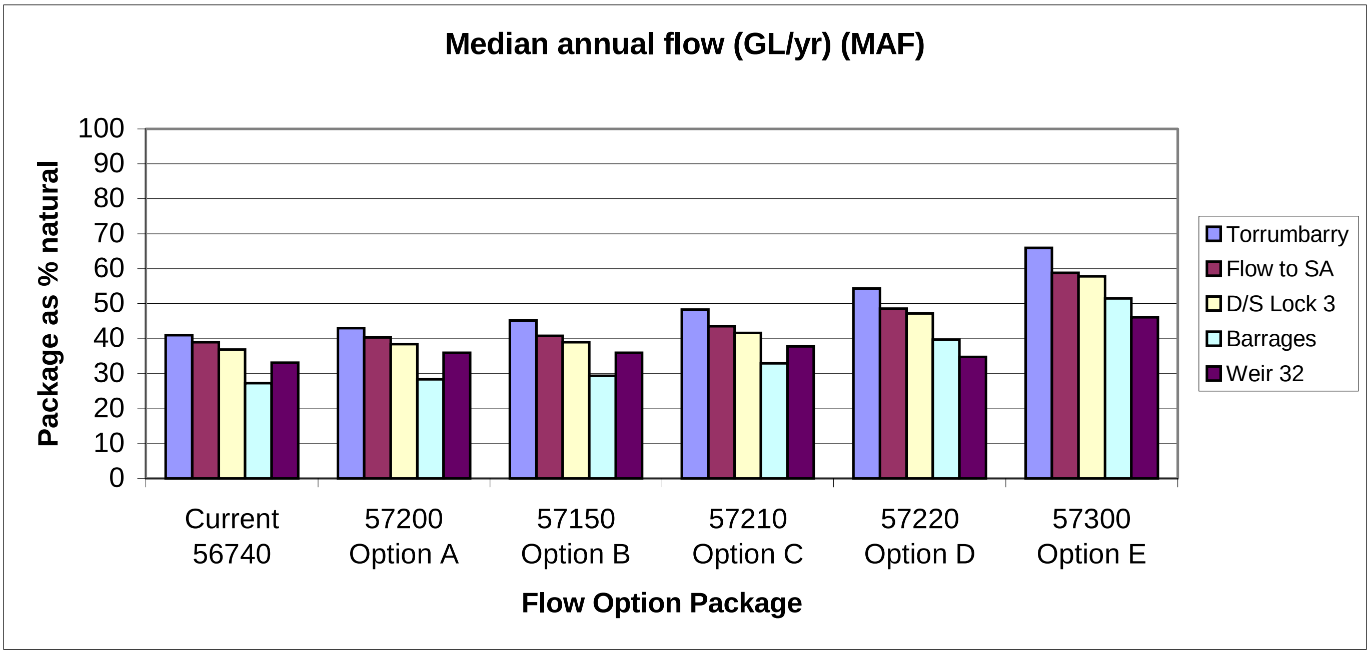
Spell Analysis Indicators

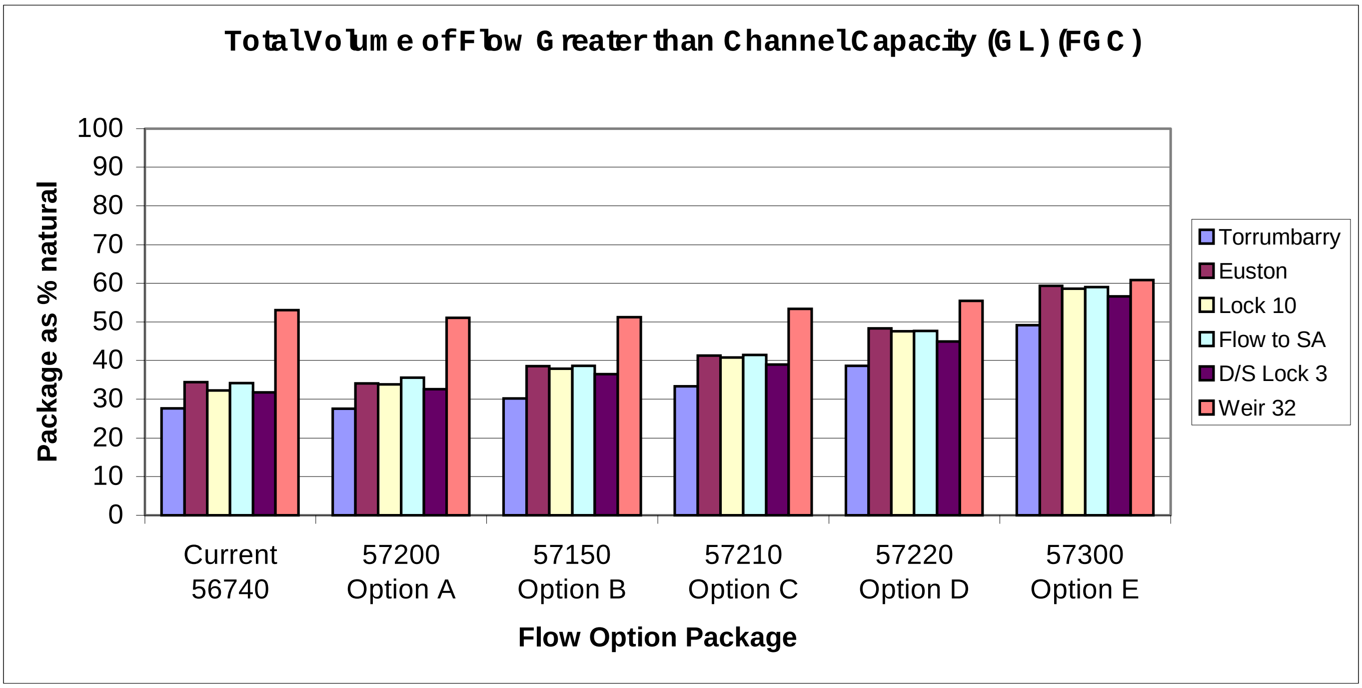
Flow Option Packages were assessed against modelled monthly natural and current flows at each of these four locations in relation to their influence on:

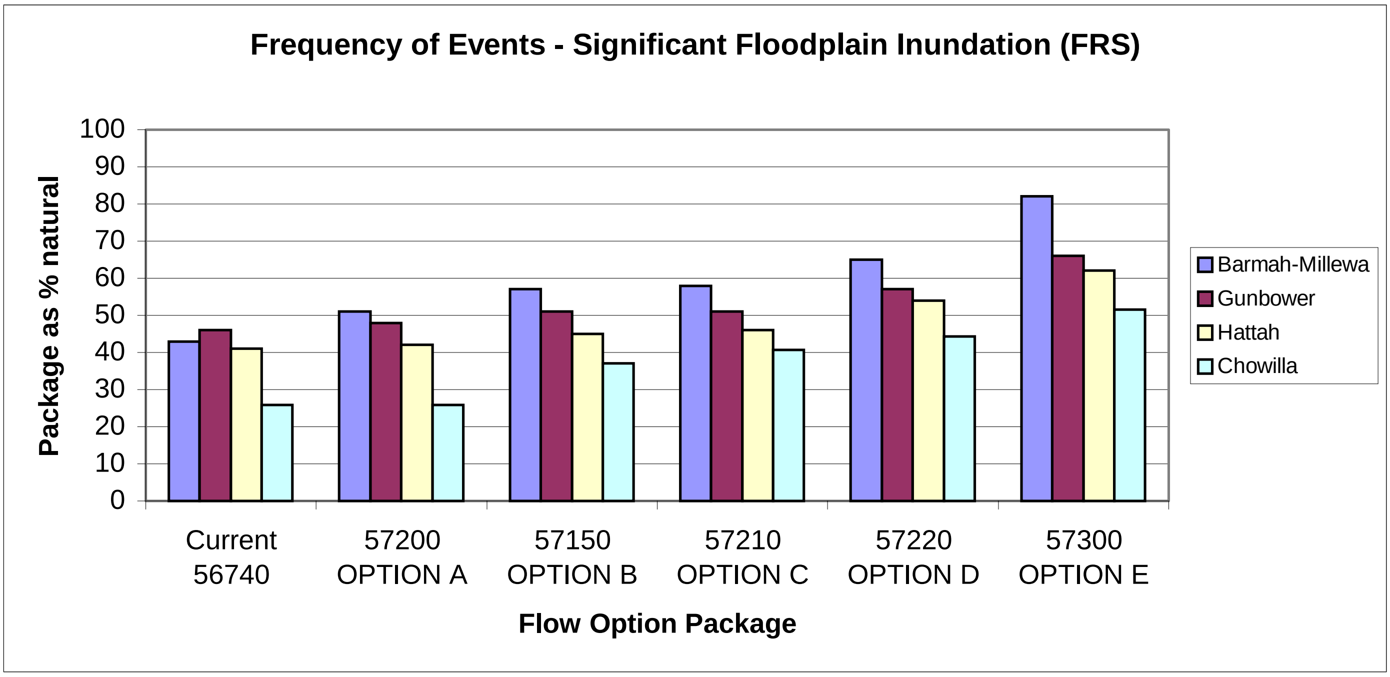
1. **Frequency of events** (indicators **FRC, FRS**) exceeding key flow thresholds (number of spells per 100 years);
2. **Median duration** (indicators **MDC, MDS**) of events that exceed key flow thresholds in months (median spell duration above threshold = period 'wet');
3. **Median interval** (indicators **FIC, FIS**) between floods that exceed key flow thresholds in months (median spell duration below threshold = period 'dry'); and
4. **Average time above** (indicator **ATS**) key flow thresholds in months/year (product of frequency and average duration).

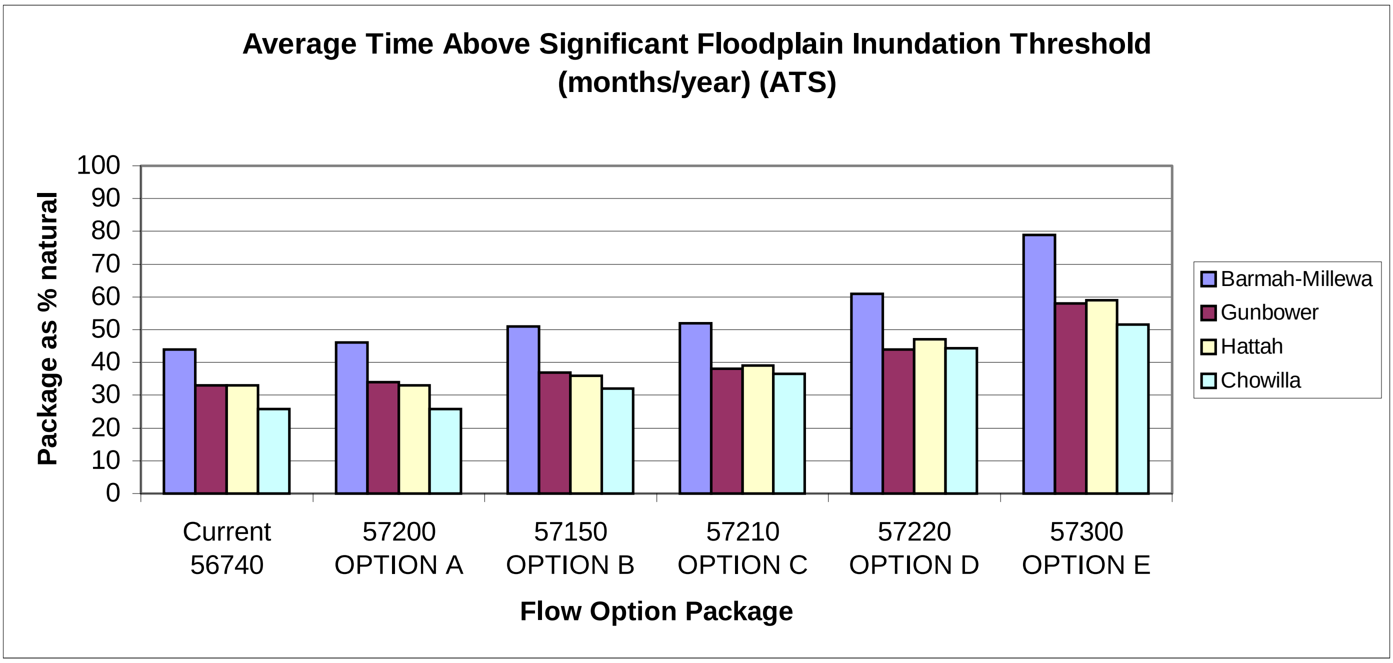
APPENDIX 3 – ERP INDICATOR GRAPHS

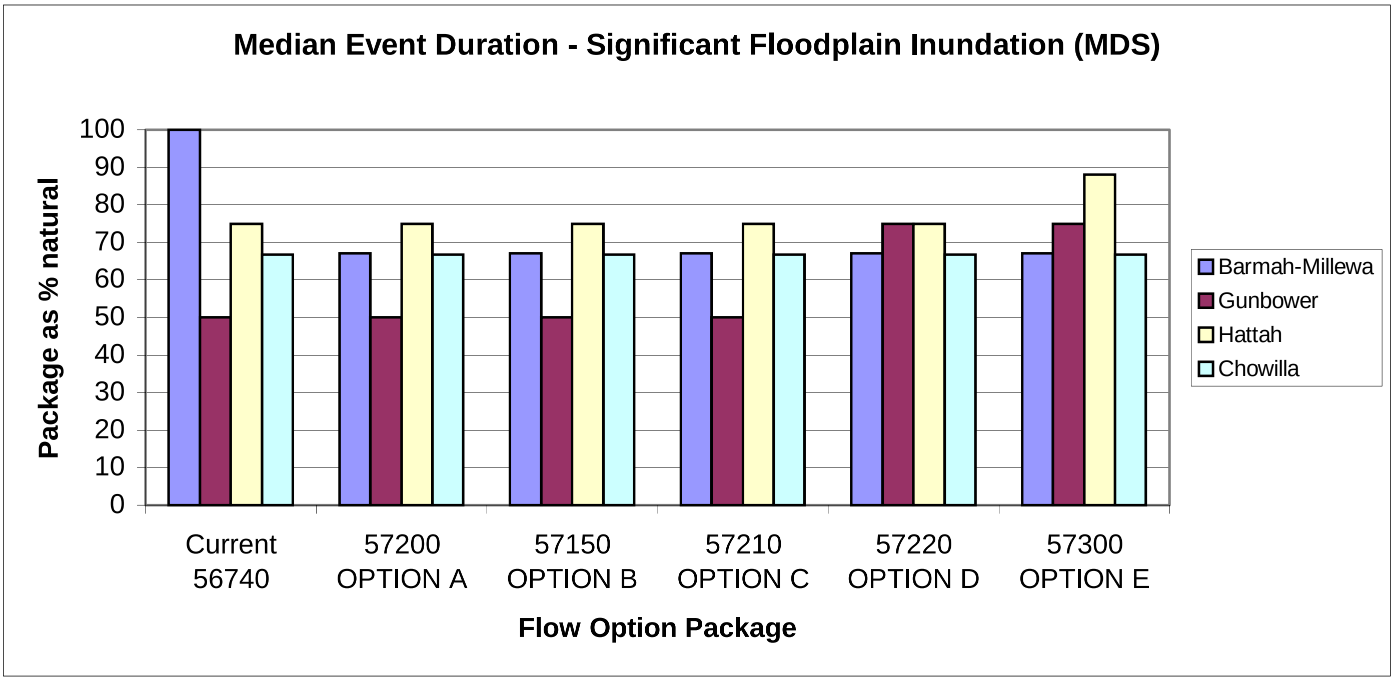
ERP Hydrologic Indicators for system level attributes of the River Murray System, expressed as a % of natural against flow option packages A-E. Note, abbreviations for indicators refer to those on Tables 3, 7 and 8. Refer to Appendix 1 for list of key nodes at which indicators were assessed.

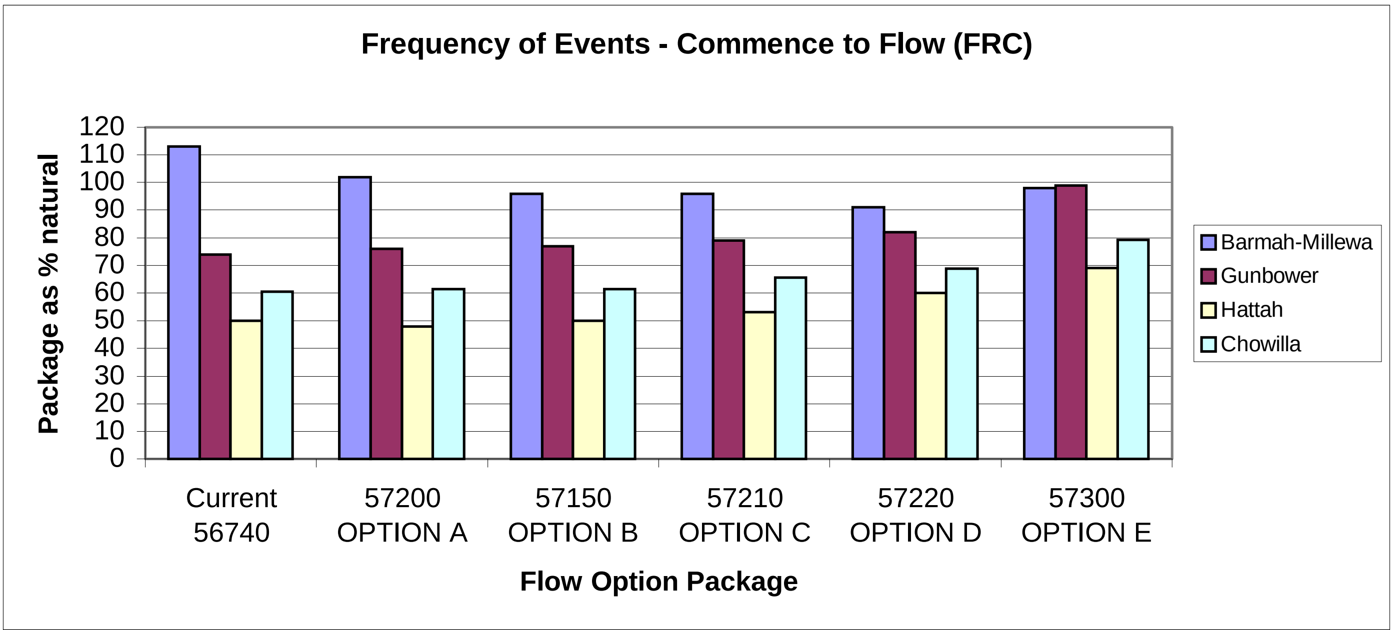


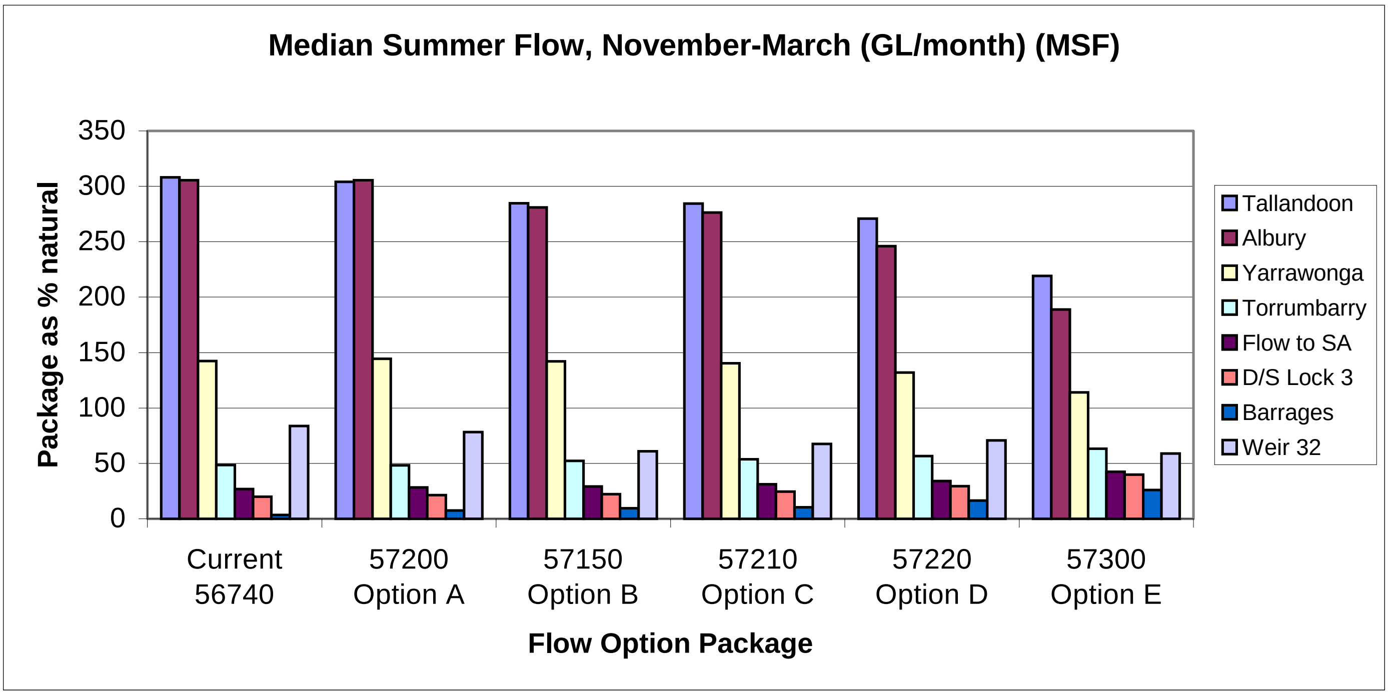


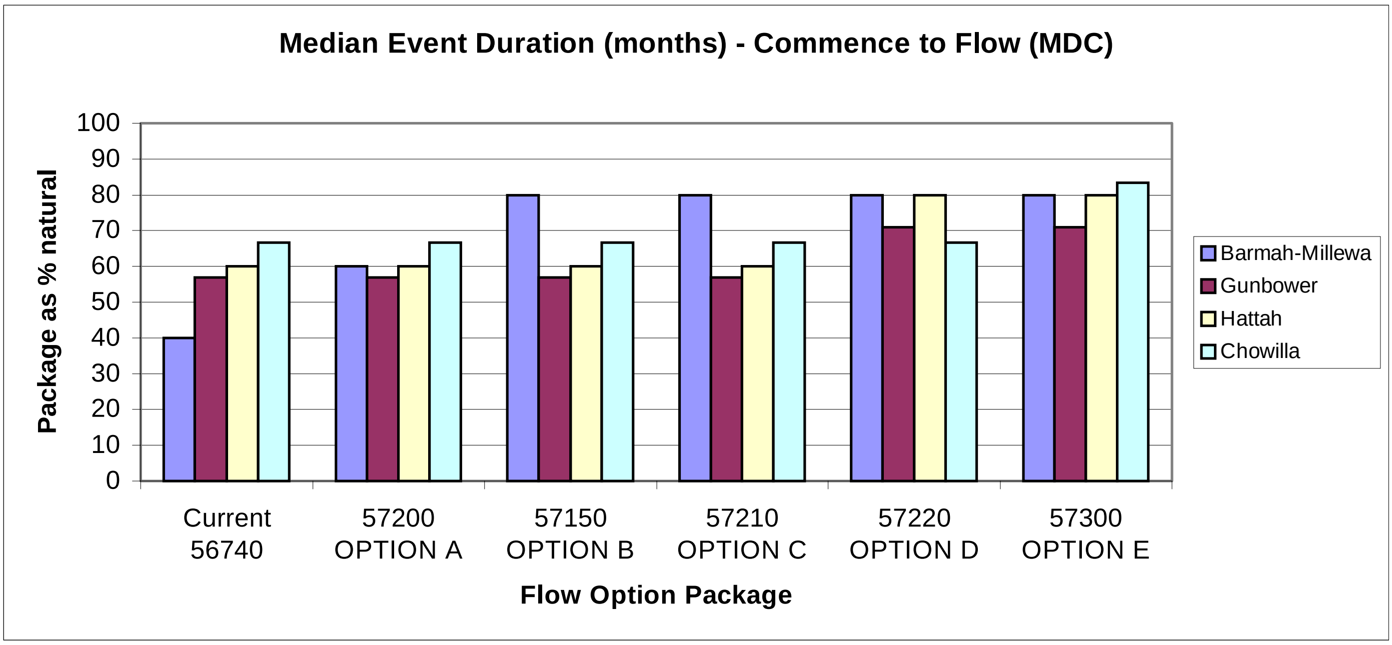

Frequency of Events - Significant Floodplain Inundation (FRS)
Package as % natural
100
90
80
70
60
50
40
30
20
10
0
Current 56740
57200 OPTION A
57150 OPTION B
57210 OPTION C
57220 OPTION D
57300 OPTION E
Flow Option Package
Barmah-Millewa
Gunbower
Hattah
Chowilla

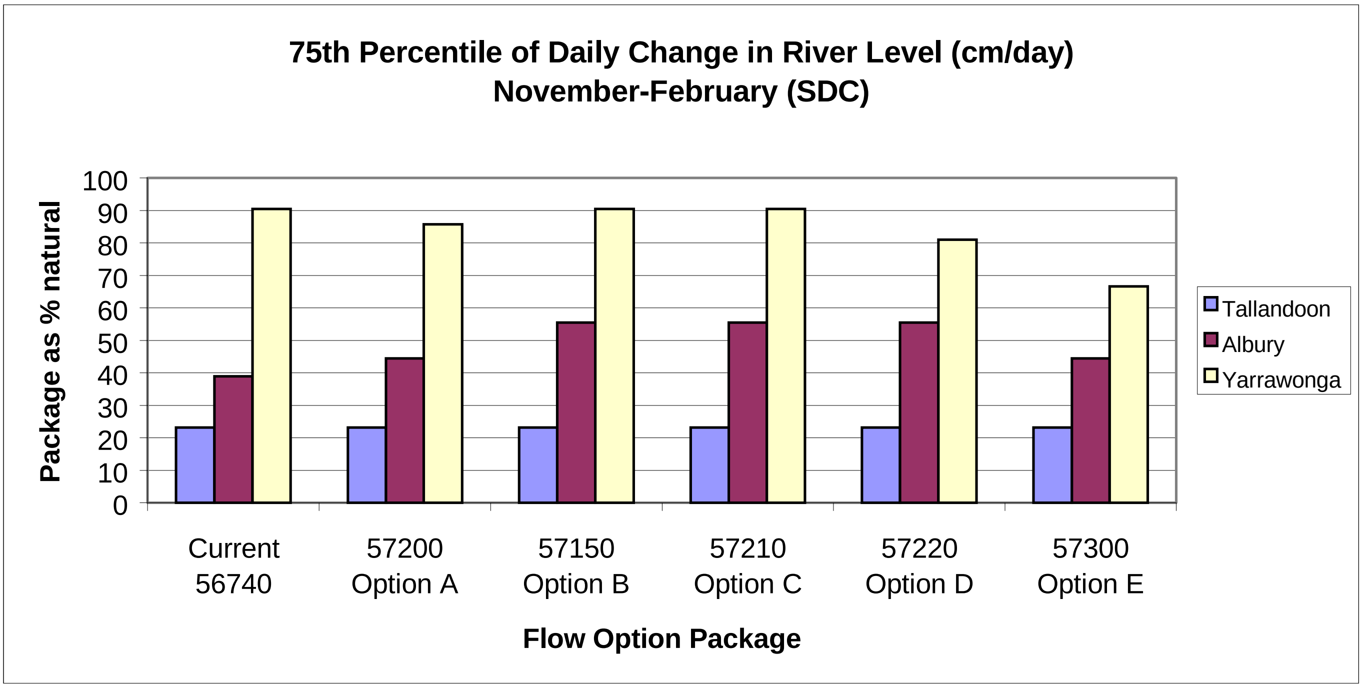

Average Time Above Significant Floodplain Inundation Threshold (months/year) (ATS)
Package as % natural
100
90
80
70
60
50
40
30
20
10
0
Current 56740
57200 OPTION A
57150 OPTION B
57210 OPTION C
57220 OPTION D
57300 OPTION E
Flow Option Package
Barmah-Millewa
Gunbower
Hattah
Chowilla

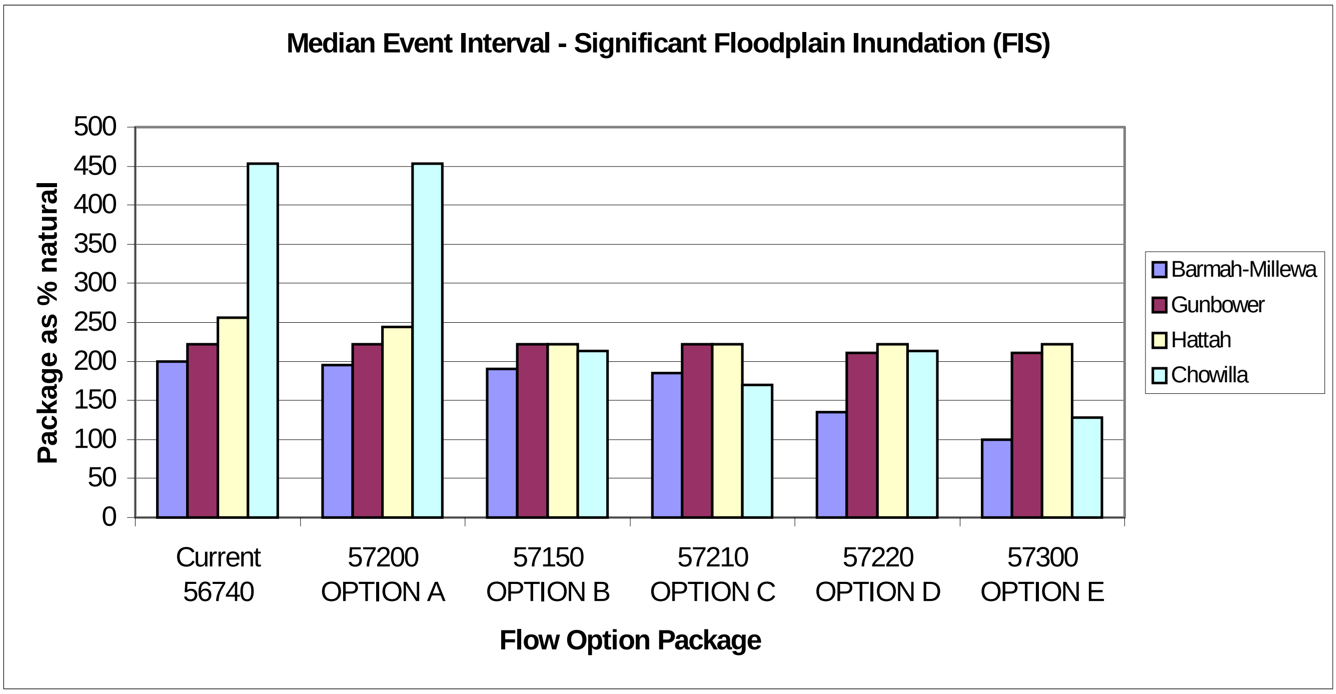

Median Event Duration - Significant Floodplain Inundation (MDS)
Package as % natural
100
90
80
70
60
50
40
30
20
10
0
Current 56740
57200 OPTION A
57150 OPTION B
57210 OPTION C
57220 OPTION D
57300 OPTION E
Flow Option Package
Barmah-Millewa
Gunbower
Hattah
Chowilla

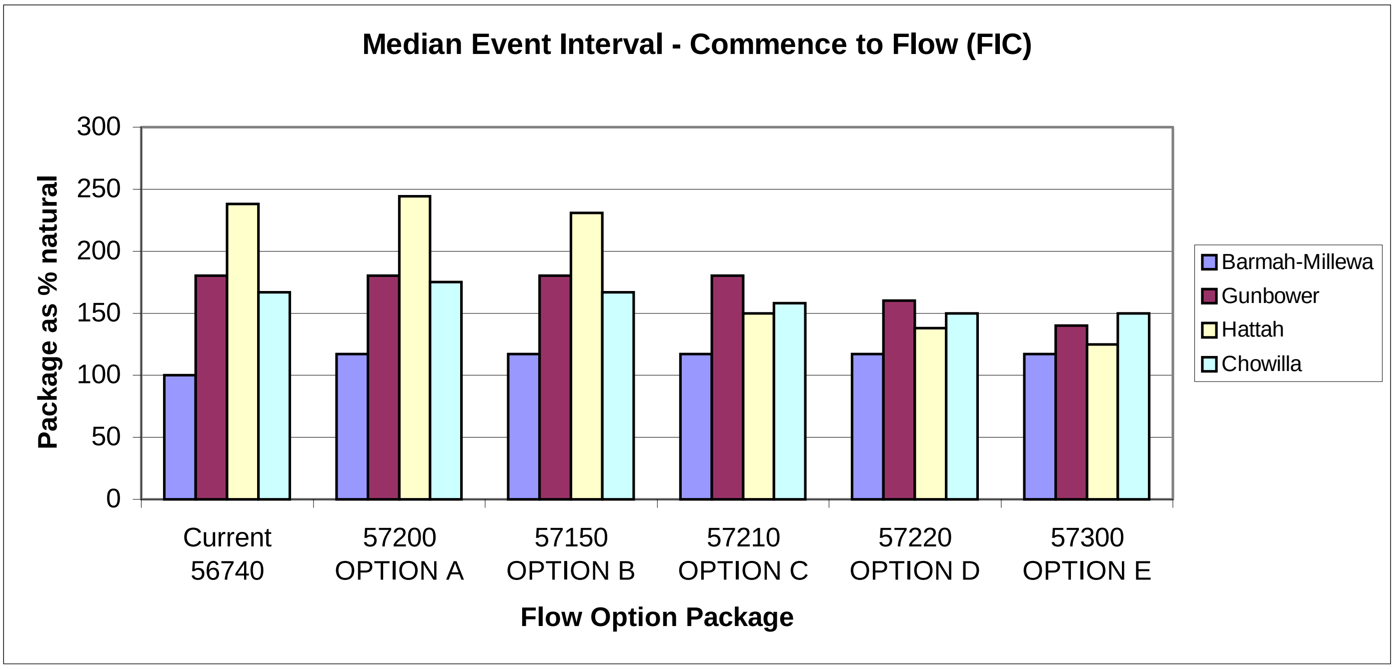

Frequency of Events - Commence to Flow (FRC)
Package as % natural
120
110
100
90
80
70
60
50
40
30
20
10
0
Current 56740
57200 OPTION A
57150 OPTION B
57210 OPTION C
57220 OPTION D
57300 OPTION E
Flow Option Package
Barmah-Millewa
Gunbower
Hattah
Chowilla

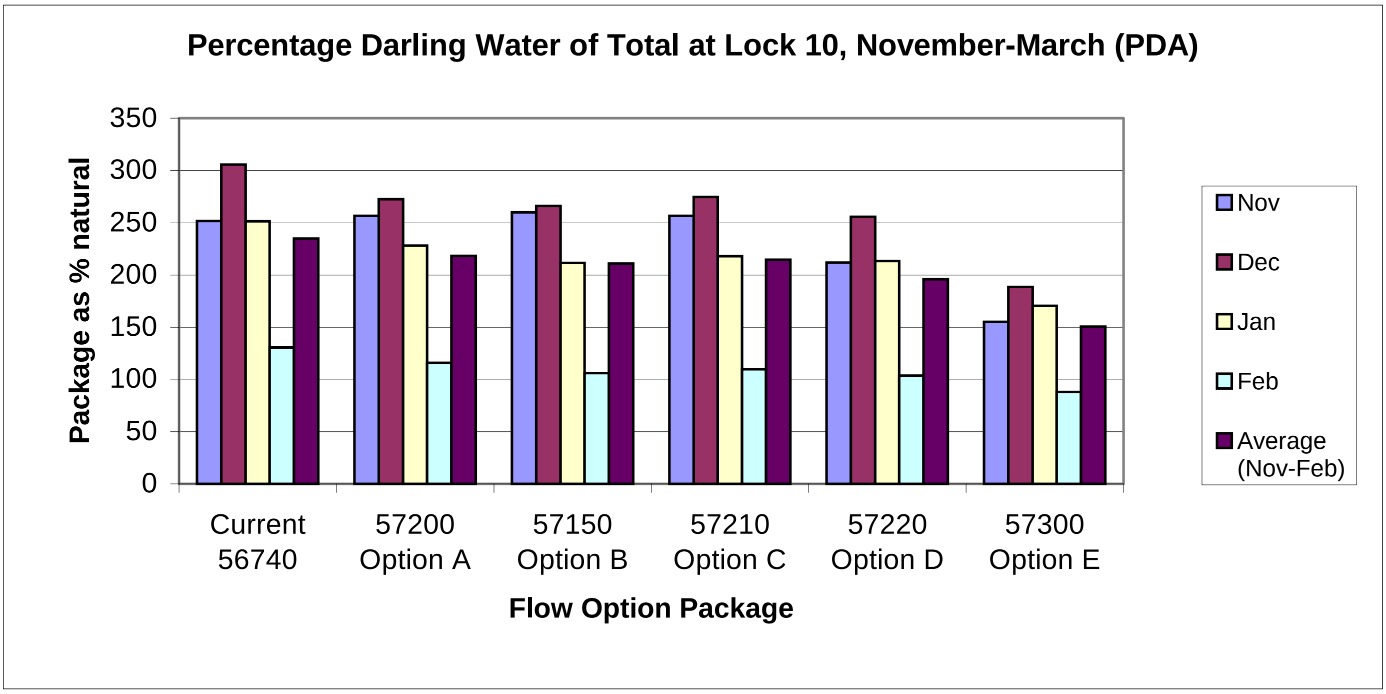

Median Summer Flow, November-March (GL/month) (MSF)
Package as % natural
350
300
250
200
150
100
50
0
Current 56740
57200 Option A
57150 Option B
57210 Option C
57220 Option D
57300 Option E
Flow Option Package
Tallandoon
Albury
Yarrawonga
Torrumbarry
Flow to SA
D/S Lock 3
Barrages
Weir 32

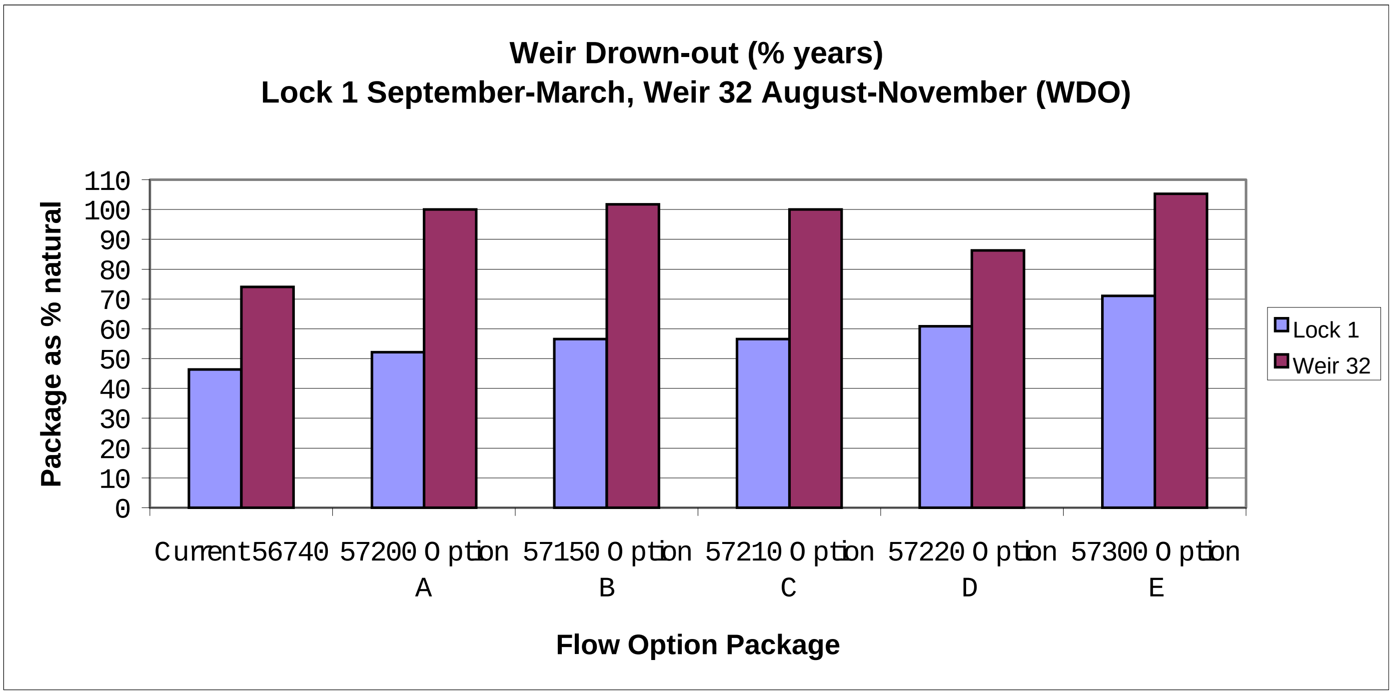

Median Event Duration (months) - Commence to Flow (MDC)
Package as % natural
100
90
80
70
60
50
40
30
20
10
0
Current 56740
57200 OPTION A
57150 OPTION B
57210 OPTION C
57220 OPTION D
57300 OPTION E
Flow Option Package
Barmah-Millewa
Gunbower
Hattah
Chowilla

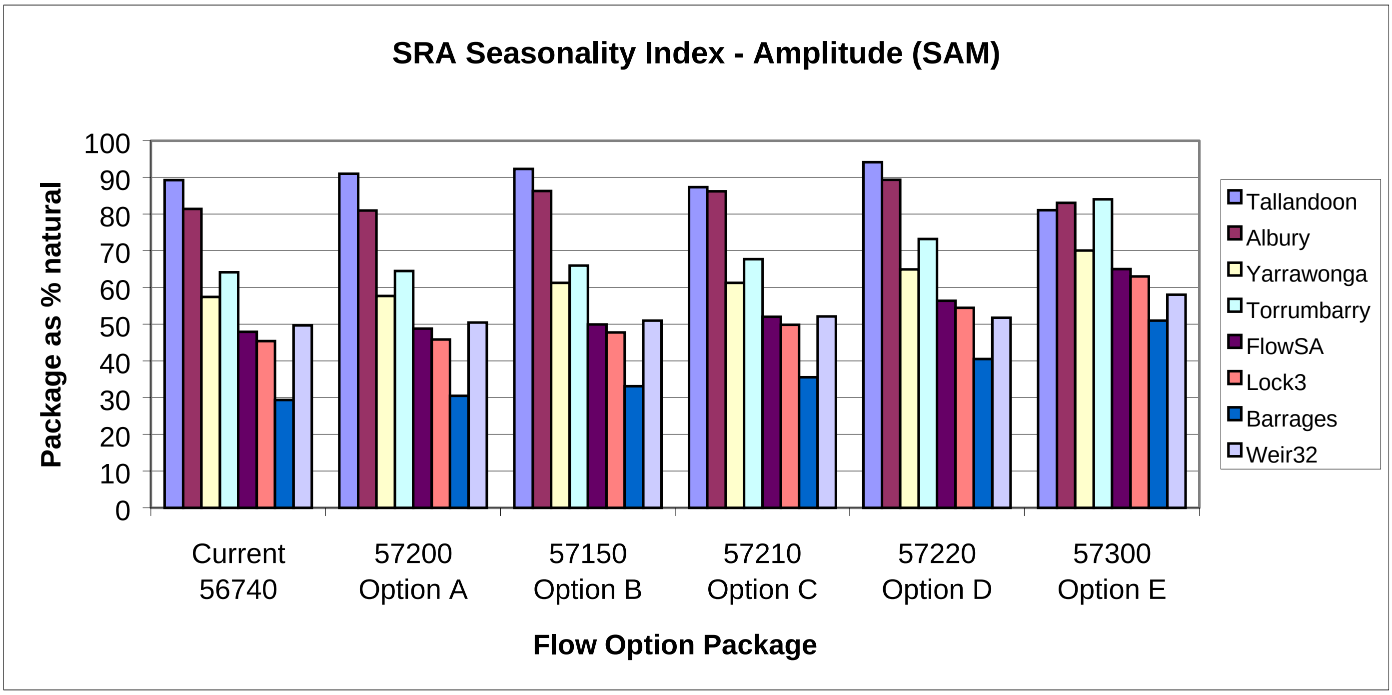

75th Percentile of Daily Change in River Level (cm/day)
November-February (SDC)
Package as % natural
100
90
80
70
60
50
40
30
20
10
0
Current 56740
57200 Option A
57150 Option B
57210 Option C
57220 Option D
57300 Option E
Flow Option Package
Tallandoon
Albury
Yarrawonga

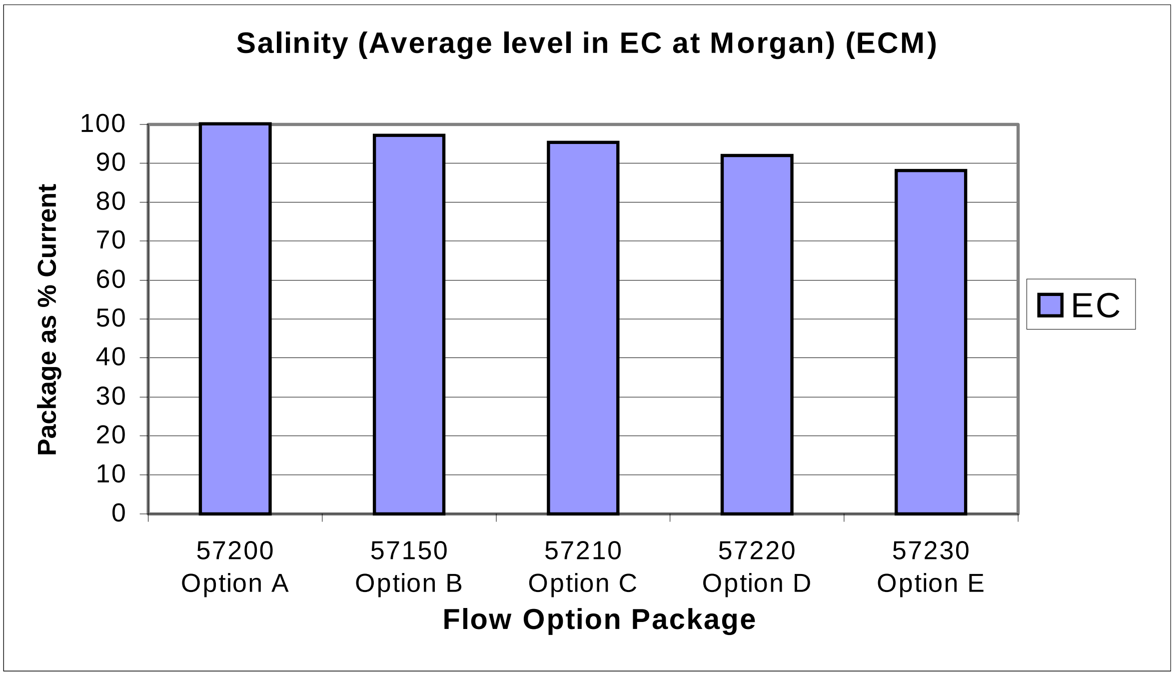

Median Event Interval - Significant Floodplain Inundation (FIS)
Package as % natural
500
450
400
350
300
250
200
150
100
50
0
Current 56740
57200 OPTION A
57150 OPTION B
57210 OPTION C
57220 OPTION D
57300 OPTION E
Flow Option Package
Barmah-Millewa
Gunbower
Hattah
Chowilla

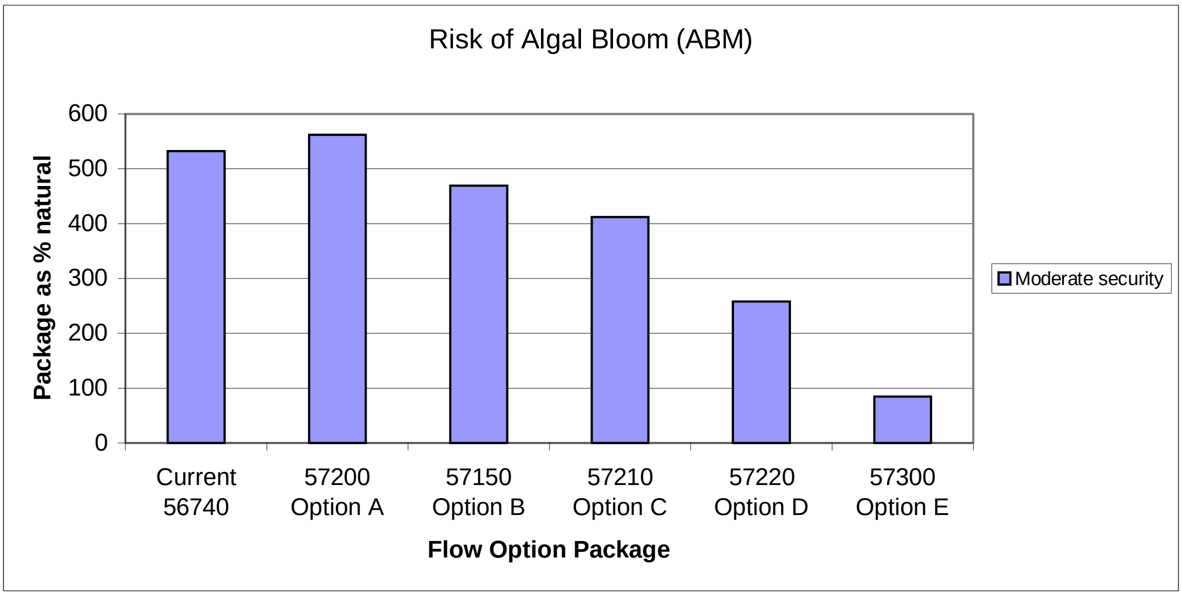

Median Event Interval - Commence to Flow (FIC)
Package as % natural
300
250
200
150
100
50
0
Current
56740
57200
OPTION A
57150
OPTION B
57210
OPTION C
57220
OPTION D
57300
OPTION E
Flow Option Package
Barmah-Millewa
Gunbower
Hattah
Chowilla


Percentage Darling Water of Total at Lock 10, November-March (PDA)
Package as % natural
350
300
250
200
150
100
50
0
Current
56740
57200
Option A
57150
Option B
57210
Option C
57220
Option D
57300
Option E
Flow Option Package
Nov
Dec
Jan
Feb
Average
(Nov-Feb)


Weir Drown-out (% years)
Lock 1 September-March, Weir 32 August-November (WDO)
Package as % natural
110
100
90
80
70
60
50
40
30
20
10
0
Current 56740
57200 Option A
57150 Option B
57210 Option C
57220 Option D
57300 Option E
Flow Option Package
Lock 1
Weir 32


SRA Seasonality Index - Amplitude (SAM)
Package as % natural
100
90
80
70
60
50
40
30
20
10
0
Current 56740
57200 Option A
57150 Option B
57210 Option C
57220 Option D
57300 Option E
Flow Option Package
Tallandoon
Albury
Yarrawonga
Torrumbarry
FlowSA
Lock3
Barrages
Weir32


Salinity (Average level in EC at Morgan) (ECM)
Package as % Current
100
90
80
70
60
50
40
30
20
10
0
57200 Option A
57150 Option B
57210 Option C
57220 Option D
57230 Option E
Flow Option Package
EC


Risk of Algal Bloom (ABM)
Package as % natural
600
500
400
300
200
100
0
Current 56740
57200 Option A
57150 Option B
57210 Option C
57220 Option D
57300 Option E
Flow Option Package
Moderate security

APPENDIX 4 – ERP INDICATOR RAW VALUES

ERP Hydrologic Indicators used to assess flow option packages A-E. Values are absolute (see Appendix 3 for indicator as % natural).

ERP Indicator / Node at which indicator was assessed#	VALUES ARE ABSOLUTE						
Median annual flow (GL/yr) (MAF)			OPTION A	OPTION B	OPTION C	OPTION D	OPTION E
	Natural	Current (56740)	57200	57150	57210	57220	57300
Torrumbarry	7386	3030	3179	3334	3564	4011	4870
Flow to SA	12385	4827	5001	5061	5383	6016	7284
Lock3	12199	4498	4688	4759	5081	5751	7045
Barrages	11318	3092	3214	3332	3729	4502	5830
Weir32	1764	585	635	635	667	614	813
Total volume of flow > channel capacity (GL) (FGC)			OPTION A	OPTION B	OPTION C	OPTION D	OPTION E
	Natural	Current (56740)	57200	57150	57210	57220	57300
Torrumbarry	86620	23941	23914	26182	28867	33480	42598
Euston	350152	120509	119507	135072	144570	169133	207696
Lock 10	397529	128328	134438	150612	162338	188939	232842
Flow to SA	630819	215392	224045	243497	261488	300357	372239
Lock 3	221722	70547	72382	80957	86454	99787	125515
Weir 32	170012	90218	86846	87053	90851	94313	103364
Average time above significant floodplain inundation threshold (months/year) (ATS)*			OPTION A	OPTION B	OPTION C	OPTION D	OPTION E
	Natural	Current (56740)	57200	57150	57210	57220	57300
Yarrawonga	2.2	1.0	1.0	1.1	1.2	1.4	1.8
Torrumbarry	2.6	0.9	0.9	1.0	1.0	1.2	1.5
Euston	2.6	0.9	0.9	0.9	1.0	1.2	1.5
Flow to South Australia	0.7	0.2	0.2	0.2	0.3	0.3	0.4

Median Summer Flow, Nov-March flow (GL/m) **(MSF)**	Natural	Current (56740)	OPTION A 57200	OPTION B 57150	OPTION C 57210	OPTION D 57220	OPTION E 57300
Tallandoon	188	579	571	535	535	509	412
Albury	1018	3111	3110	2859	2813	2505	1923
Yarrawonga	1212	1725	1751	1721	1702	1601	1384
Torrumbarry	1890	915	914	987	1014	1072	1196
Flow to SA	4491	1203	1277	1314	1402	1525	1902
Lock 3	4890	978	1046	1090	1206	1441	1951
Barrages	4902	177	373	474	515	806	1277
Weir 32	534	447	418	326	360	378	315
Median event interval (commence to flow) **(FIC)***	Natural	Current (56740)	OPTION A 57200	OPTION B 57150	OPTION C 57210	OPTION D 57220	OPTION E 57300
Yarrawonga	6.0	6.0	7.0	7.0	7.0	7.0	7.0
Torrumbarry	5.0	9.0	9.0	9.0	9.0	8.0	7.0
Euston	8.0	19.0	19.5	18.5	12.0	11.0	10.0
Flow to South Australia	6	10	10.5	10	9.5	9	9
Median event interval (significant floodplain inundation) **(FIS)***	Nat	Current (56740)	OPTION A 57200	OPTION B 57150	OPTION C 57210	OPTION D 57220	OPTION E 57300
Yarrawonga	10.0	20.0	19.5	19.0	18.5	13.5	10.0
Torrumbarry	9.0	20.0	20.0	20.0	20.0	19.0	19.0
Euston	9.0	23.0	22.0	20.0	20.0	20.0	20.0
Flow to South Australia	32	145	145	68	54.5	68	41

SRA Seasonality Index AMPLITUDE **(SAM)**			OPTION A	OPTION B	OPTION C	OPTION D	OPTION E
	Natural	Current (56740)	57200	57150	57210	57220	57300
Tallandoon	1	0.89	0.91	0.92	0.87	0.94	0.81
Albury	1	0.81	0.81	0.86	0.86	0.89	0.83
Yarrawonga	1	0.57	0.58	0.61	0.61	0.65	0.70
Torrumbarry	1	0.64	0.64	0.66	0.68	0.73	0.84
Flow to SA	1	0.48	0.49	0.50	0.52	0.56	0.65
Lock3	1	0.45	0.46	0.48	0.50	0.54	0.63
Barrages	1	0.29	0.30	0.33	0.36	0.41	0.51
Weir32	1	0.50	0.50	0.51	0.52	0.52	0.58

75th Percentile daily change in River level (cm/d), Nov-Feb **(SDC)**			OPTION A	OPTION B	OPTION C	OPTION D	OPTION E
	Natural	Current (56740)	57200	57150	57210	57220	57300
Tallandoon	1.3	0.3	0.3	0.3	0.3	0.3	0.3
Albury	1.8	0.7	0.8	1.0	1.0	1.0	0.8
Yarrawonga	2.1	1.9	1.8	1.9	1.9	1.7	1.4

Frequency of events commence to flow **(FRC)***			OPTION A	OPTION B	OPTION C	OPTION D	OPTION E
	Natural	Current (56740)	57200	57150	57210	57220	57300
Yarrawonga	102.8	116.5	104.6	99.1	98.2	93.6	100.9
Torrumbarry	98.2	72.5	74.3	75.2	77.1	80.7	97.2
Euston	86.2	43.1	41.3	43.1	45.9	51.4	59.6
Flow to South Australia	88.1	53.2	54.1	54.1	57.8	60.6	69.7

Median event duration (months) commence to flow **(MDC)***			OPTION A	OPTION B	OPTION C	OPTION D	OPTION E
	Natural	Current (56740)	57200	57150	57210	57220	57300
Yarrawonga	5	2	3	4	4	4	4
Torrumbarry	7	4	4	4	4	5	5
Euston	5	3	3	3	3	4	4
Flow to South Australia	6	4	4	4	4	4	5

Frequency of events significant floodplain inundation **(FRS)***			OPTION A	OPTION B	OPTION C	OPTION D	OPTION E
	Natural	Current (56740)	57200	57150	57210	57220	57300
Yarrawonga	77.1	33	39.4	44.0	45.0	50.5	63.3
Torrumbarry	75.2	34.9	35.8	38.5	38.5	43.1	49.5
Euston	67.9	27.5	28.4	30.3	31.2	36.7	42.2
Flow to South Australia	24.8	6.4	6.4	9.2	10.1	11	12.8

Median event duration significant floodplain inundation **(MDS)***			OPTION A	OPTION B	OPTION C	OPTION D	OPTION E
	Natural	Current (56740)	57200	57150	57210	57220	57300
Yarrawonga	3	3	2	2	2	2	2
Torrumbarry	4	2	2	2	2	3	3
Euston	4	3	3	3	3	3	4
Flow to South Australia	3	2	2	2	2	2	2

Weir drown-out (% years) **(WDO)**			OPTION A	OPTION B	OPTION C	OPTION D	OPTION E
	Natural	Current (56740)	57200	57150	57210	57220	57300
Lock 1, Sep-Mar	63	29	33	36	36	39	45
Weir 32, Aug-Nov	53.2	39.4	53.2	54.1	53.2	45.9	56
			OPTION A	OPTION B	OPTION C	OPTION D	OPTION E
Risk of algal bloom (% yrs Lock 3 < 4,000 ML/d, Nov-Apr) Moderate security **(ABM)**	Natural	Current (56740)	57200	57150	57210	57220	57300
	2.6	13.8	14.6	12.2	10.7	6.7	2.2
% Darling water of total at Lock 10 **(PDA)**			OPTION A	OPTION B	OPTION C	OPTION D	OPTION E
	Natural	Current (56740)	57200	57150	57210	57220	57300
Nov	8.5	21.4	21.8	22.1	21.8	18	13.2
Dec	10.6	32.4	28.9	28.2	29.1	27.1	20
Jan	15.6	39.2	35.6	33	34	33.3	26.6
Feb	22.1	28.8	25.6	23.4	24.2	22.9	19.4
Average (Nov-Feb)	14.2	30.5	28.0	26.7	27.3	25.3	19.8
Salinity (ave level in EC at Morgan) **(ECM)**			OPTION A	OPTION B	OPTION C	OPTION D	OPTION E
	Nat (not available)	Current (56740)	57200	57150	57210	57220	57300
EC		551	552.4	536.4	526.1	506.8	471.4

See Appendix 1 for description of nodes at which ERP indicator were assessed.
* Spell analysis indicator (see Appendix 2 for more detailed explanation of spell analysis). The sensitivity of some indicators is constrained by the use of the River Murray monthly simulation model.