An ecological assessment of benefits and risks associated with the proposed management actions for the Pike River and its floodplain

Prepared by Todd Wallace

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Cover Image: River red gum and lignum woodland at Pike Floodplain
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Executive Summary

Background

The Pike River District covers the River Murray floodplain and highland between Paringa and Lyrup along the River Murray in South Australia. The Pike River floodplain system comprises numerous ecological assets including a range of floodplain and aquatic habitats. These include river red gum and black box woodlands, lignum shrublands, chenopod shrublands, herblands and dunes. The aquatic habitats include permanent fast and slow flowing anabranches, permanent and temporary wetlands. The Pike River/Mundic Creek complex is currently experiencing a significant decline in health. However, the complex is considered to retain significant ecological character and attributes and continues to support a high diversity of both terrestrial and aquatic habitats, including populations of rare, endangered and nationally threatened species. The floodplain also contains many sites of European and Indigenous cultural heritage significance.

There are a number of processes that compromise the ecological integrity of the Pike floodplain. The key threats to the site are altered flow regimes, elevated highly saline groundwater, obstructions to fish passage, grazing pressure, and pest plants and animals. Flow regulation in particular has reduced flooding frequencies and duration, and has resulted in saline groundwater levels increasing by up to 3m higher than would have occurred under natural, or pre-regulation conditions.

A number of previous studies have investigated the condition of the Pike Floodplain. Wallace (2009) demonstrated that the condition of the majority of the existing tree community was either stressed or worse, and that the number of juvenile trees present is not sufficient to maintain the existing tree community at any of the sites. That report concluded that the floodplain will require direct management intervention to retain the ecological character and attributes for which it has historically been valued. Beyer et al (2010) concluded that the riparian habitat was generally in poor condition. However, the in-stream habitat was deemed to be relatively good. It was considered that the Pike Anabranch system may provide a good template for a habitat restoration approach involving increasing connectivity and flowing habitats to increase the diversity of micro- and meso-habitats. Marsland (2010) concluded that management actions that aim to increase floodplain inundation, in the absence of natural flooding, are essential for increasing and maintaining the diversity of the understorey vegetation community. Wallace and Rengasamy (2011) assessed the distribution and magnitude of salinised and sodic soils at the Pike Floodplain and concluded that saline and sodic soils where limiting to vegetation condition and that management actions to address the extent and magnitude of soil salinity and sodicity at the Pike Floodplain should be pursued.

Management objectives

The following management objectives have been previously defined for the Pike River floodplain:

- to improve the condition of existing vegetation
- to improve key aquatic riparian and terrestrial habitats required by native flora and fauna, including waterbirds, fish, reptiles, mammals and frogs
- to achieve a sustainable balance between the needs of the various users of the floodplain
- to recognise and, where possible, respond to the needs of the existing productive users of the floodplain

Management options

As part of a management strategy to address the threat of altered flow regimes and alleviate the effects of elevated saline groundwater and reduced frequency of flows that inundate the floodplain, three stages of an integrated infrastructure project have been proposed. These are:

1. Upgrade the existing inlet structures at Margaret Dowling and Deep Creek
2. Upgrade all existing floodplain structures (with the exception of Col Col bank)
3. Construction and operation of new environmental regulators to generate broadscale floodplain inundation

Stages 1 and 2 involve improving the existing structures in order to provide capacity to manage and increase inflows and provide passage for fish. Stage 3 involves the construction of a large environmental regulator at the site of the existing Col Col bank, combined with a smaller, structure at Tanyaca Ck, and associated blocking banks at low elevation sections of the floodplain. These works will provide a mechanism by which water levels can be raised within the anabranch system in order to inundate large areas of floodplain with some degree of independence from the magnitude of prevailing flows in the Murray River.

Objectives of this assessment

The primary objective of the current assessment is to the provide the Department for Water with an assessment of the potential benefits and risks associated with the two proposed management options:

1. Upgrade and manipulation of inlet structures and floodplain structures (Banks B, C, E, D, F, F1, G and Coomb's bridge) independent of the environmental regulators at Col Col bank and Tanyaca Creek (improved base-flows)

2. Manipulation of inlet structures and floodplain structures (Banks B, C, E, D, F, F1, G and Coomb's bridge) in combination the environmental regulators at Col Col bank and Tanyaca Creek (managed inundations)

Approach used

The approach utilised here comprised a desktop investigation underpinned by expert assessment to identify key ecological values, threats to these values and an estimation of the likelihood, frequency and consequences of these threats. This approach provides an explicit and transparent way to deal with the complexity of assessing and making management decisions for aquatic systems, which are often complex ecosystems that may not always be fully understood. The assessment provided here represents a preliminary evaluation of the benefits and risks anticipated to arise from the proposed management options. A semi-quantitative approach was used to achieve a broad and relatively comprehensive assessment, but it is recognised that the scope of assessment is not exhaustive. This approach was employed on a basis of maintaining a realistic budget and the relatively limited amount of existing data for this floodplain. The lack of data is acknowledged as a weakness of the approach as it precludes more intensive quantitative analysis (i.e. the use of Bayesian network modelling). Scores for likelihood, frequency, consequence were applied to a benefit/risk calculator to obtain benefit and risk scores respectively. Scores range from 1 (minimum) to 6 (maximum). Scores were also provided for certainty to

improve clarity regarding level of confidence at which the respective scores can be interpreted. Scores for this component ranged from 1 (very uncertain) to 4 (very certain).

A total of 23 types of potential benefits and 25 types of potential risks were assessed. For the majority of benefits and risks, multiple sources and potential impacts (models) of benefit/risk were considered. Results of the assessment are provided in two formats:

- A text base format providing a basis for the assessment (i.e. brief background information on the biota or abiotic process under consideration) followed by a description of the scores obtained for likelihood, frequency, consequence and benefit/risk rating
- Summarised in table format where issues are presented in functional groups with scores obtained for likelihood, frequency, consequence and benefit/risk rating colour coded. This format is included to enable rapid appraisal of the magnitude of benefit/risk associated with each component

Key findings

Potential benefits

Detail on specific results are not reproduced here in the interests of brevity. However, in brief, for the management option "improved base flows", the areas within which high (≥5) values for "Benefit Scores" were attained are:

- Connectivity
- Hydrology
- Freshening of saline groundwater
- Golden perch and silver perch
- Murray cod
- Freshwater catfish (due to Increased flows and structural habitat, improves mesoscale mosaic of hydrodynamics and improved connectivity)
- Wetland generalist fish species

For the management option "managed inundations", the areas within which high (≥5) values for "Benefit Scores" were attained are:

- Soil moisture availability
- Condition of established floodplain eucalypts
- Recruitment of floodplain eucalypts
- Abundance and distribution of flood dependent understorey vegetation
- Productivity and energy transfer
- Resilience

Potential risks

For the management option "improved base flows", the areas within which high (≥5) values for "Risk Scores" were attained are:

- Hydrology
- Extraction
- Expansion of invasive plants
- Carp population
- Weatherloach and gambusia

- Freshwater catfish (negative interactions with increased populations of introduced fish species)
- Threatened species that may be present but have not been detected

For the management option "managed inundations", the areas within which high (≥5) values for "Risk Scores" were attained are:

- In-stream salinity impacts
- Soil sodicity
- Fringe degradation
- Blackwater events
- Expansion of invasive plants
- Failure of native vegetation to improve
- Carp population
- Weatherloach and gambusia
- Threatened species that may be present but have not been detected

It is important to note that "Lack of data" and "Monitoring" were also identified as areas of high risk.

Conclusions:

It is clear from this assessment that there is a range of benefits that can be achieved via the changes to management being proposed. Conversely, there is a range of risks posed by the proposed management actions. These risks require careful management and a robust monitoring program to ensure (i) potential benefits are realised; (ii) risks are not converted to hazards; and (iii) managers are aware of, and respond promptly to emerging issues.

Key documents that need to be developed as a priority include:

1. A monitoring program

   This needs to incorporate the existing management objectives, a set of ecological objectives and a set of preliminary yet defensible ecological targets. The monitoring program also needs to identify the ecosystem components, variables and indicators that require monitoring and outline appropriate monitoring techniques. The approach to monitoring, analysis and interpretation of the data, and dissemination of knowledge needs to be consistent with other regionally relevant floodplain sites.

2. An operating strategy

   This needs to incorporate a set of operating principles for improved base-flows and managed inundations designed to maximise benefits and minimise risks. During the development of this operating strategy, it will be critical to recognise (i) the need for variability within and between operations; and (ii) that the prevailing ecological condition of the floodplain and therefore the ecological objectives and outcomes of each operation will be different. Furthermore, the prevailing hydrology of the river and the volumes of environmental water available will vary between and within operations. Hence the monitoring strategy needs to be highly flexible rather than prescriptive.

It is critical to recognise that using regulators to inundate large floodplains under low flow conditions has not been used as a restoration technique anywhere in the world. Consequently there is no precedent for this management activity and actual responses may differ from those expected. Frequent scrutiny of the

results of the monitoring program combined with a flexible approach to management of the structures will be required to ensure that the potential benefits of improved base flows and managed inundations are attained without severely compromising other components of the ecosystem.

1. Introduction

The Pike River floodplain system

The Pike River District covers the River Murray floodplain and highland between Paringa and Lyrup along the River Murray in South Australia. The floodplain is a complex system of creeks, backwaters and lagoons that receives water mainly from Lock and Weir No 5 upper pool. The Pike River/Mundic Creek complex extends over 4,000 hectares of River Murray floodplain generally ranging in width from 4 to 7 km. The floodplain is located within the river reach from 563.6 to 541.9 river km.

The Pike River floodplain system comprises numerous ecological assets including a range of floodplain and aquatic habitats. These include river red gum (*Eucalyptus camaldulensis*) and black box (*E. largiflorens*) woodlands, lignum (*Muehlenbeckia florulenta*) shrublands, chenopod (*Atriplex* spp.) shrublands, herblands and dunes (Commonweath of Australia, 2010). The aquatic habitats include permanent fast and slow flowing anabranches, permanent and temporary wetlands (Beyer et al., 2010).

The Pike River/Mundic Creek complex is currently experiencing a significant decline in health. However, the complex is considered to retain significant ecological character and attributes. The system is considered a high conservation value aquatic ecosystem (Commonweath of Australia, 2010) and continues to support a high diversity of both terrestrial and aquatic habitats, including populations of rare, endangered and nationally threatened species. The floodplain also contains many sites of European and Indigenous cultural heritage significance.

Basic description of Pike River hydrology

Flow enters the Upper Pike through Margaret Dowling Creek and Deep Creek. Lower Pike receives flow primarily over Col Col embankment. Flows may enter or leave via Rumpagunyah Creek depending on conditions in the Lock 4 weir pool. Lower Pike then discharges to the River Murray Lock 4 weir pool (see Figure 1). The levels and flows in Lower Pike respond to levels and flows in the River Murray between Lock 5 and Lock 4 (Burnell & Watkins, 2008). A map of the system showing the locations of banks is presented in Figure 1. The Upper Pike system has a reasonably constant flow from the Lock 5 weir pool of 300 ML day^{-1} when flows in the River Murray are less than 60,000 ML day^{-1}. Raising Lock 5 increases flow into the Upper Pike. Lowering of the Lock 5 will decrease inflows into the upper Pike. Lock 4 similarly influences flow into the Lower Pike via Rumpagunyah Creek, Swift Duck Creek and Wood Duck Creek.

Current condition of the Pike River floodplain

There are a number of processes that compromise the ecological integrity of the Pike floodplain. The key threats to the site are altered flow regimes, elevated highly saline groundwater, obstructions to fish passage, grazing pressure, and pest plants and animals. Flow regulation in particular has reduced flooding frequencies and duration, and has resulted in saline groundwater levels increasing by up to 3m higher than would have occurred under natural, or pre-regulation conditions.

An assessment of tree condition undertaken in 2009 (Wallace, 2009) demonstrated that although there were individual trees that scored in the “good” condition category, there are no transects with mean or median scores in this category. The most frequently occurring category was “stressed”, with 43% of transects in this category. 38% of transects were in “poor” condition, and 19% were in “very poor”

condition. It was concluded that: (i) it is extremely unlikely that tree condition will improve without above average rain fall or a return to a more frequent flooding regime, and (ii) that the decline in condition observed between the 2002 baseline assessment and the 2009 assessment is likely to continue. Furthermore, Wallace (2009) demonstrated that the number of juvenile trees present is not sufficient to maintain the existing tree community at any of the sites. Given that floodplain eucalypts are generally considered to require a flood for mass germination followed by repeat flooding or above average rainfall for successful recruitment, the existing distribution and density of trees is not sustainable under the current hydrological regime. That report concluded that the floodplain will require direct management intervention to retain the ecological character and attributes for which it has historically been valued.

An assessment of fish and fish habitats within the Pike Anabranch (Beyer et al., 2010) concluded that the riparian habitat was generally in poor condition. However, the in-stream habitat was deemed to be relatively good. Few habitat associations were revealed in some fish species, which may be related to low habitat heterogeneity present under the current regime. It was considered that the Pike Anabranch system could provide a good template for a habitat restoration approach involving increasing connectivity and flowing habitats to increase the diversity of micro- and meso-habitats.

Marsland (2010) reported that the recent drought, and the period since the last overbank flood has contributed to the Pike floodplain being characterised by a vegetation assemblage more typical of semi-arid areas than regularly inundated floodplains. In addition, soil salinisation due to shallow, saline ground water would tend to favour the more salt tolerant species over grasses and floodplain herbs. Based on observations from other sites (i.e. Chowilla floodplain), that author concluded that management actions that aim to increase floodplain inundation, in the absence of natural flooding, are essential for increasing and maintaining the diversity of the understorey vegetation community.

Wallace and Rengasamy (2011) assessed the distribution and magnitude of salinised and sodic soils at the Pike Floodplain. Only 2 out of 31 sites were considered to have a soil profile regarded as non-saline and non-sodic. In terms of interfering with key management and ecological objectives for the Pike Floodplain, the high levels of sodicity recorded may interfere with the ability to re-establish floodplain vegetation via surface crusting combined with high soil strength reducing seedling emergence and root penetration. A simple comparison of data collected prior to and post the 2010-11 flood indicates that there may have been substantial leaching of salt from the upper soil profile during the flood. Soil moisture availability is a function of soil salt content and soil moisture. In areas where depth to groundwater is very shallow, regular flooding may not substantially increase sub-soil moisture but may reduce salt content. Conversely, in areas where groundwater is relatively deep, flooding may not significantly reduce soil salt content but may substantially increase average soil moisture content. However, both of these scenarios will result in increased soil moisture availability and improved conditions for vegetation. Those authors concluded that management actions to address the extent and magnitude of soil salinity and sodicity at the Pike Floodplain should be pursued.

Management Objectives for the Pike River floodplain

The following objectives have been previously defined for the Pike River floodplain:

- to improve the condition of existing vegetation
- to improve key aquatic riparian and terrestrial habitats required by native flora and fauna, including waterbirds, fish, reptiles, mammals and frogs
- to achieve a sustainable balance between the needs of the various users of the floodplain

- to recognise and, where possible, respond to the needs of the existing productive users of the floodplain

In support of these objectives, the Pike Floodplain has previously been divided into eight ecological assets:

- Flowing watercourses;
- Permanent wetlands;
- Temporary wetlands;
- Red Gum woodlands;
- Lignum shrublands;
- Chenopod shrublands / Grasslands;
- Black box woodlands
- Dunes

Table 1: Flow frequency under natural (pre-regulation) and current (regulated) conditions at Pike.

River Murray flow (ML/d)	Return Period (number of times peak flows occur in 100 years)		Duration (number of months in which river flow shown in first column is exceeded)	
	Natural	Current	Natural	Current
5000	100	100	11.8	11.9
10000	100	94	10.1	4.6
20000	99	63	7.8	4.6
30000	96	51	6.4	3.9
40000	91	40	4.9	3.3
50000	79	30	3.9	2.7
60000	59	21	3.9	2.5
70000	49	15	3.6	2.9
80000	45	12	3.2	2.6
90000	37	11	3.1	2.1
100000	32	9	2.9	2.0
120000	23	5	2.2	2.8
150000	12	4	2.2	1.5

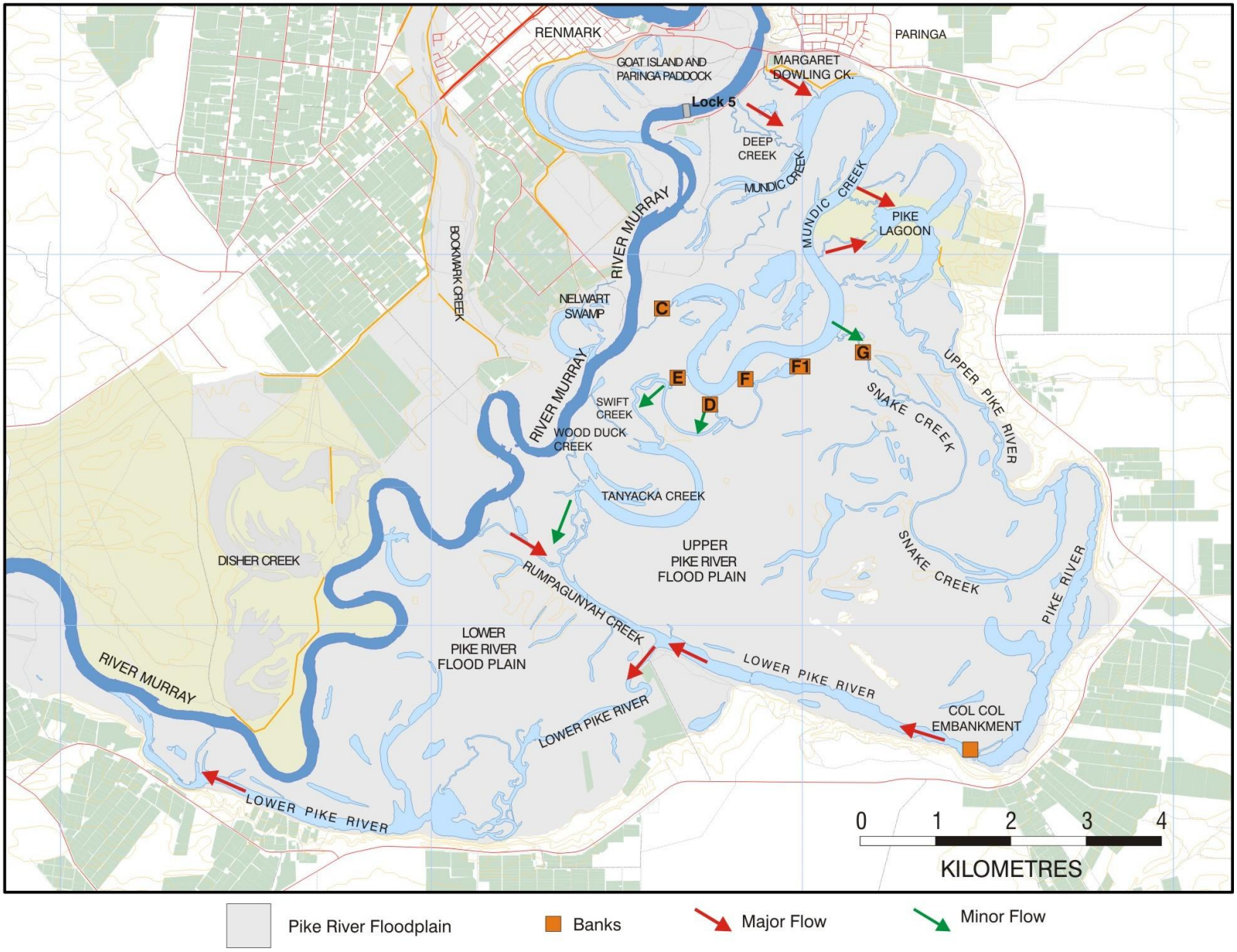

Figure 1. Map of floodplain showing locations of banks and major and minor flow paths (figure courtesy of Brad Hollis).

2. Management Options

As part of a management strategy to address the threat of altered flow regimes and alleviate the effects of elevated saline groundwater and reduced frequency of flows that inundate the floodplain, three stages of an integrated infrastructure project have been proposed. These are:

1. **Upgrade Margaret Dowling and Deep Creek inlets.**

   Inflows through Margaret Dowling and Deep Creek is currently constrained to a combined total of 300 $MLday^{-1}$. The proposed upgrades to the structures will provide capacity to control flow at rates between 0-600 ML day^{-1} at Deep Creek, and between 0-400 ML day^{-1} at Margaret Dowling Creek. The upgraded structures will be designed to provide passage for small, medium and large bodied fish over a range of flow and head and tail water level conditions.

2. **Upgrade all existing floodplain structures with the exception of Col Col bank.**

   This involves upgrading a number of the existing banks that control inflows and water levels (see Figure 1). The existing structures that control inflows into the Pike anabranch, and those within the anabranch system, have been designed solely for water management for irrigation purposes. Under existing conditions, most structures provide no fish passage and cannot be operated to manage flow (see Figures 2a-g). Installation of improved structures at the existing bank locations that incorporate ecological principles will allow for increased in-flows, increased connectivity and ability to re-instate variability to inflows and water levels.

   Water Technology (2010b) modelled water level, discharge, velocity, and shear stress at a range of locations to provide a comparison of (i) existing conditions, (ii) upgraded structures with the existing inlet conditions, (iii) upgraded structures with increased inflow at 600 $MLday^{-1}$ and (iv) upgraded structures with increased inflow at 1,000 $MLday^{-1}$. The results of that modelling are provided in Table 3 (section R8).

3. **Construction and operation of new environmental regulators to generate broadscale floodplain inundation**

   This stage involves the construction of a large environmental regulator at the site of the existing Col Col bank, combined with a smaller structure at Tanyaca Ck, and associated blocking banks at low elevation sections of the floodplain. These works will provide a mechanism by which water levels can be raised within the anabranch system in order to inundate large areas of floodplain with some degree of independence from the magnitude of prevailing flows in the Murray River (the primary factor controlling floodplain inundation). The anticipated inundation extent (based on hydrological modelling) with Lock 5 operating at 16.8 mAHD, 1000 ML day^{-1} flowing in at Deep Creek and Margaret Dowling Creek, and the Col Col regulator set at 16.4 mAHD is presented in Figure 3.

The infrastructure will be designed, constructed and operated exclusively for environmental benefit. Utilisation of large structures to inundate large sections of floodplain is likely to generate greater wetland connectivity, and potentially provide additional ecological outcomes than could be achieved by pumping water into discrete/individual sites (Veltheim et al., 2009). However, it is critical to recognise that using regulators to inundate large floodplains under low flow conditions has not been used as a restoration technique anywhere in the world (Nicol, 2007). Consequently there is no precedent for this management activity (Brookes et al., 2006) and actual responses may differ from those expected (Rogers & Paton, 2008).

Figure 2a: Coombs Bridge (photo: T. Wallace)

Figure 2b: Snake Creek Stock Crossing (photo: T. Wallace)

Figure 2c: Bank F1 (photo: T. Wallace)

Figure 2d: Bank F (photo: T. Wallace)

Figure 2e: Bank D (photo: T. Wallace)

Figure 2f: Bank E (photo: T. Wallace)

Figure 2g: Bank C (photo: T. Wallace)

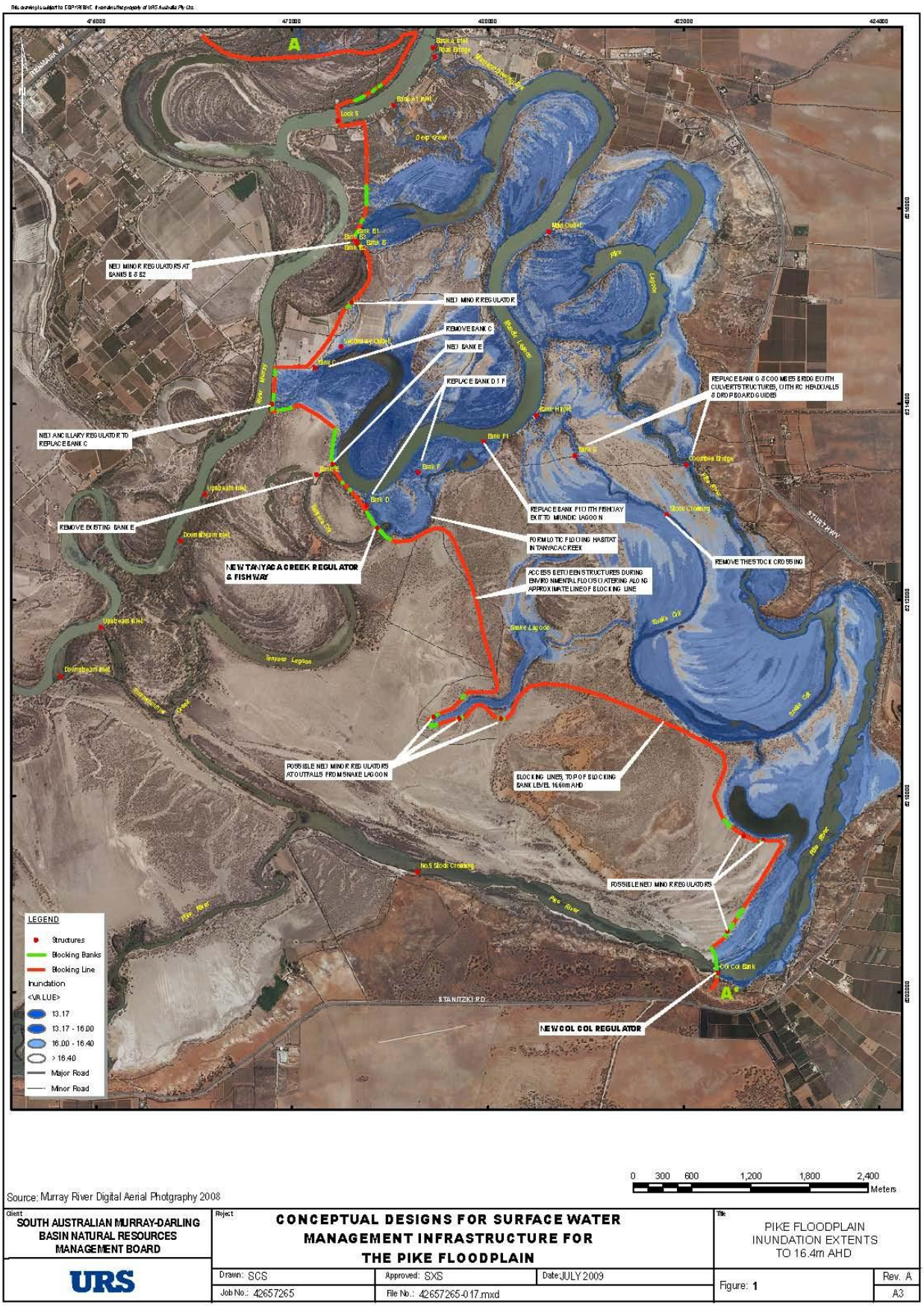

Figure 3. Map of predicted inundation extent with Lock 5 operating at 16.8 mAHD, 1000 ML day^{-1} flowing in at Deep Creek and Margaret Dowling Creek, and the Col Col regulator set at 16.4 mAHD

Potential operational regimes for consideration

Without the proposed package of works outlined above, the hydrological regime of the system will remain largely as it has been for the last 60 years; a very stable hydraulic regime (flows and water levels) controlled by poorly designed and maintained flow control structures. The majority of the structures are set higher than the bed of waterways resulting in increased commence to flow thresholds, there is substantial (e.g. up to 1.4 m) head loss across structures, and the structures are characterised by very poor or non-existent fish passage at the banks structure (see Figures 2a-g).

There are critical risks to the ecology and sustainability of the floodplain complex associated with taking no management action. However, the "do-nothing" scenario is not considered a realistic option, and therefore is not considered here, as (i) there is an existing commitment to change in the form of the *Pike Implementation Plan* (PIP) which is formally documented in a Memorandum of Understanding (MoU); and (ii) Funds (~$10 M) have been secured to undertake detailed design and replacement of all floodplain regulators (with the exception of Col Col). Proposals for the remaining works are being developed.

Once the three stages of the integrated infrastructure project have been completed, there will be a matrix of management operations that may be undertaken to influence the hydrology of the Pike Floodplain system. These will primarily involve two levels of management:

1. Manipulation of inlet structures independent of the environmental regulators at Col Col bank and Tanyaca Creek

2. Manipulation of inlet structures in combination the environmental regulators at Col Col bank and Tanyaca Creek

The overarching objective of the two levels of management are to improve the condition of the Pike River Floodplain. For the purposes of this document, these management options are referred to as "improved base-flow conditions" and "managed inundations" respectively. The potential operating frequency at which the structure(s) will be operated is coupled to water availability and the condition of the floodplain relative to a range of ecological objectives. For managed inundations, this is likely to manifest as an operating cycle of three months inundation during spring on a frequency of once every two to four years. However, it is critical to ensure that operation of the structures retains a high degree of variability and that corresponding base-flow periods with no managed inundations are an integral component of the long-term operating strategy.

Manipulation of inlet structures independent of the environmental regulators at Col Col bank and Tanyaca Creek (improved base-flow conditions)

For the purposes of this current assessment, it was anticipated that increased base-flows would be established and maintained at the maximum rate (i.e. 1,000 MLday^{-1}), as (i) this is the extreme case; and (ii) it is understood that there are no operational constraints precluding this as an option (once the structures are completed including the appropriate engineering at the structures, and in areas identified as requiring additional protection works (B.Hollis, pers com). However, there are some key factors that will need to be considered including:

1. Variability

a. Maintaining a consistently high flow (e.g. 1,000 MLday^{-1}) may not be a desirable outcome. Imparting some level of seasonal/frequent variation in flow may be more desirable

2. Impacts on geomorphology including potential for high bed shear to mobilise acid sulfate soils which are known to be widely distributed through the anabranch system (Shand et al., 2009) needs to be considered
3. Bank C needs to be upgraded before inflows of 1,000 MLday^{-1} can be used (Water Technology, 2010b)
4. The design of the pool and riffle at Tanyaca Creek needs to be optimised for flows in order to maintain appropriate velocities across this structure

Principles likely to guide management of improved base flows

Over the long-term, the manner in which the inlet structures will be operated is anticipated to be highly flexible. The proposed upgrades to the structures will provide capacity to control flow at rates between 0-1000 MLday^{-1}. Utilisation of this capacity for controlling inflows will provide a pathway to increase variability in flow velocity and water exchange, and may offer a pathway to reinstate some small-scale variability in inundation extent in the upper reaches of the inlet creeks . It is recommended that an operating strategy be developed incorporating variability in in-flows between 300-1,000 MLday^{-1}. Key features of the hydrograph such as spring freshes should be included. It is recommended that in-flows should not be reduced below existing rates (i.e. 300 MLday^{-1}) without extensive consideration of management and ecological objectives and potential risks to water quality, biota and abiotic processes.

Manipulation of inlet structures in combination with the environmental regulators at Col Col bank and Tanyaca Creek (managed inundations)

Short-term (e.g. first 5 years after completion of works)

The delivery of environmental water allocations via the environmental regulators should be used in the short-term to halt the decline in condition of the anabranch system and reinstate resilience (see section B15 for detail on the concept of resilience). This may require operation of the structures at a higher frequency than (i) natural flood return intervals and (ii) a higher frequency than that which would be used in the medium- and long-term.

Medium- and long-term

In order to attain a sustainable condition of the floodplain, the use of the environmental regulators should have two foci:

1. capitalise on outcomes from preceding floods
2. control against stressors such as highly saline groundwater by maintaining sufficient soil moisture availability for sustainable vegetation communities
3. reduce the persistence and severity of engineered droughts during dry periods

These concepts suggest a flexible approach to operation where the regulator may be used to re-inundate the floodplain in the year following an unregulated flood during relatively wet periods to (i) maximise improvement in condition of long-lived vegetation, (ii) ensure that germination/spawning/breeding leads to recruitment, and (iii) build resilience. Operations during dry periods may be targeted at maintaining

condition of biota and abiotic processes within responsive ranges such that (i) the floodplain can withstand extended periods of lower than average rainfall and engineered droughts; (ii) there is a large positive response to the next inundation (either managed or unregulated flood); and (iii) avoid long-term or irreversible damage.

The management approach to floodplains should focus on delivering a hydrological regime that allows for the achievement of ecological objectives, not simply returning a historical, long-term average flood return interval. Moving away from generic recommendations of reinstating more natural flood return frequencies (e.g. 1 flood every 2-3 years) towards an understanding of the relationships that underpin the long-term viability of ecological communities is critical to (i) build resilience and (ii) minimise the need for managed inundations over the long-term. This will require an understanding of relationships between vegetation condition, soil moisture availability, and groundwater conditions (Johns et al., 2009). In some cases, the flood return frequency required to achieve ecological objectives and targets may be substantially higher or lower than natural return frequencies.

Principles likely to guide initial managed inundations

- Lock 5 operating at 16.8mAHD for 120 days
- 1000 ML day^{-1} flowing in at Deep Creek and Margaret Dowling Creek
- Bank B and C completely open
- Stop-logs added progressively to the bays of the environmental regulators at Tanyaca and Col Col, raising water levels immediately upstream of the regulators by up to 10 cm day^{-1}
- 20 days will be required to increase water levels upstream of Col Col from 14.35mAHD to 16.4 mAHD (2 m operational range)
- Allow 500 ML day^{-1} to flow over the regulating structures during operation
- The additional water will be impounded on the floodplain until desired inundation extent is achieved. Full inundation extent (~16 GL and 1,500 ha) requires 4 $^{1}/_{2}$ weeks
- Impounded water levels would be fluctuated for 40 days (by increasing or decreasing anabranch inflows and/or removing and reinstating stop logs at downstream regulators) to induce variation in inundation extent
- Col Col regulator lowered by up 10cm per day at the regulator. Slower rates are likely to be required as water leaves the floodplain and water levels with channels begin to fall in order to prevent bank failure
- During draining phase and for approximately 3 weeks post inundation, high inflows combined with Banks B and C fully open will be maintained
- High discharge downstream of the Col Col and Tanyaca Creek regulators, coupled with moderate flows over Lock 5 will be utilised for dilution purposes and minimise adverse impacts to water quality

3. Conceptual model of the potential influence of the proposed regime

A generic conceptual model of the influence of the new disturbanceregime (altered flow and inundation extent) on the overarching management objective of maintaining the high biodiversity values of the Pike Floodplain is presented in Figure 2. Recognising that this conceptual model is simplistic and generic, this identifies (i) some of the key processes required in order to achieve outcomes at the higher trophic levels, and (ii) some of the flow-on benefits of achieving outcomes for floodplain trees and understorey vegetation in terms of habitat and food resources. It is clear from the conceptual model that the monitoring program that will need to be developed will need to have broad scope and include assessment of processes in order to understand the observed responses at higher trophic levels.

Variability is a critical factor

Variability in frequency, timing, magnitude and duration is potentially more important than biological factors in structuring aquatic communities (see Leigh et al., 2010). Constant variations in flow combined with geomorphology (e.g. elevation, wetland commence to flow levels) function as a controlling agent of longitudinal and lateral connectivity to generate a spatially and temporally dynamic habitat mosaic with adjacent and distant areas inundated and exposed for different lengths of time leading to increased biodiversity (see King et al., 2003b; Leigh et al., 2010). A dynamic, variable water regime maintains the biodiversity and ecological processes characteristic of every river and wetland ecosystem (see Arthington et al., 2010). Under any given flow scenario, a single river system will display a dynamically changing range of dry, drying, lotic, and lentic habitats. This spatio-temporal variability in habitats generates high biodiversity (Ward & Stanford, 1995; Ward et al., 1999) with the lateral expansion and connectivity of floodplain habitats during floods providing spawning, nursery and foraging areas for a variety of vertebrates (see Bunn & Arthington, 2002).

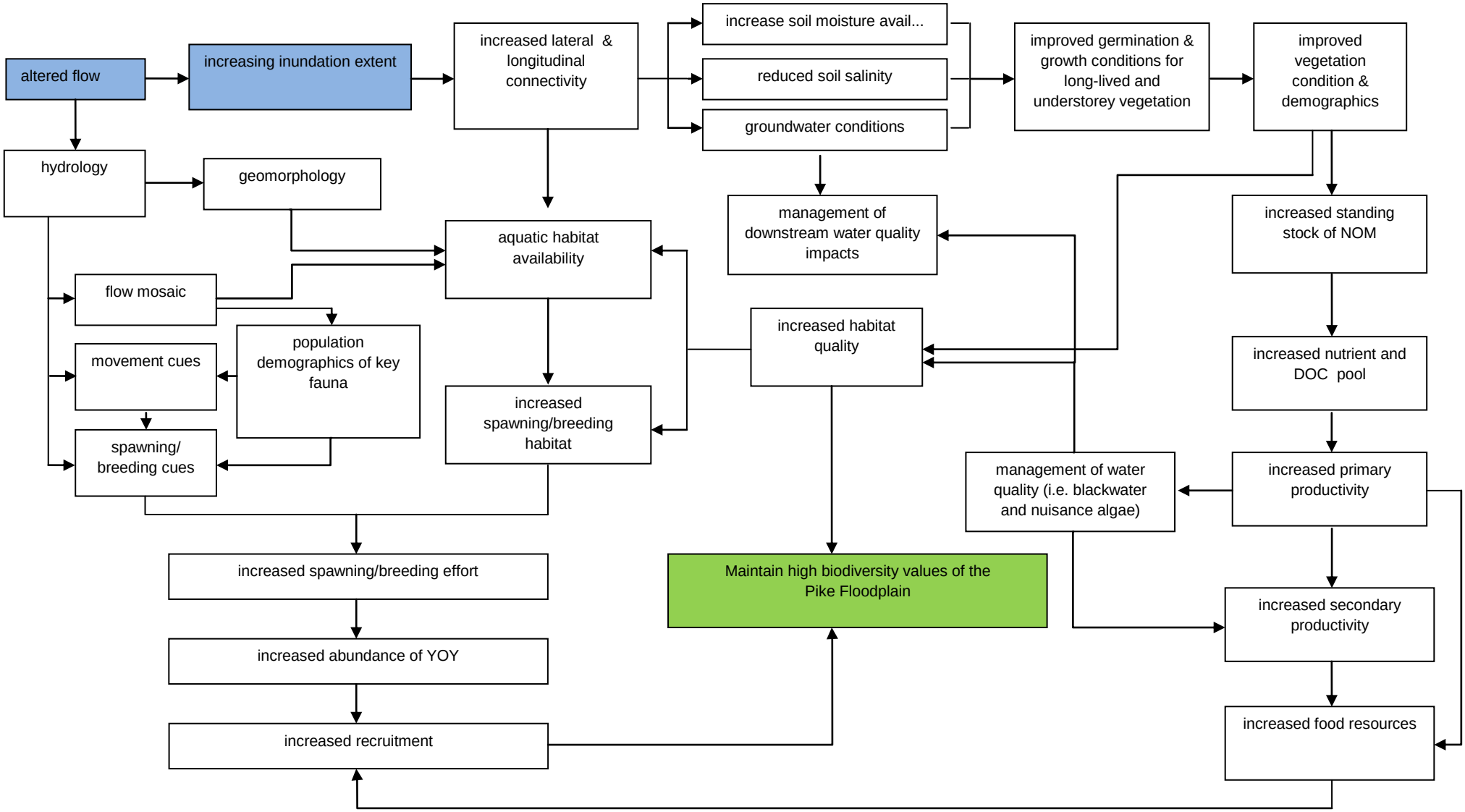

Figure 2. Simple, generic conceptual model of the influence of the new disturbance regime (altered flow and inundation extent, blue boxes) on the overarching management objective of maintaining the high biodiversity values of the Pike Floodplain (green box). Adapted from Wallace (2011)

4. Process applied in the Benefit and Risk Assessment

Objectives of this assessment:

The primary objective of the current assessment is to the provide the Department for Water with an assessment of the potential benefits and risks associated with the two proposed management actions outlined in the section 2 of this report:

3. Manipulation of inlet structures and upgrade of mid pool structures (Banks B, C, D, E, F, F1 G, Coomb's Bridge) independent of the environmental regulators at Col Col bank and Tanyaca Creek (improved base-flows)

4. Manipulation of inlet structures and upgrade of mid pool structures (Banks B, C, D, E, F, F1 G, Coomb's Bridge) in combination the environmental regulators at Col Col bank and Tanyaca Creek (managed inundations)

Approach used:

The concept of risk is defined as the likelihood of an undesirable effect (Victorian EPA 2004). An Ecological Risk Assessment (ERA) can involve various levels of investigation ranging from qualitative desktop investigations to intensive quantitative analysis relying on data collection and development of predictive models (EPA, 2004).

The approach utilised here comprised a desktop investigation underpinned by expert assessment to identify key ecological values, threats to these values and an estimation of the likelihood, frequency and consequences of these threats. This presents a sound basis for managing the risks posed by threats within the floodplain complex and is based on standard risk assessment protocol (EPA, 2004). This approach was recently utilised by Whiterod et al (2010) to undertake an ecological risk assessment of Mullaroo Creek on behalf of the Mallee Catchment Management Authority. This approach provides an explicit and transparent way to deal with the complexity of assessing and making management decisions for aquatic systems, which are often complex ecosystems that may not always be fully understood. There are three main phases involved in the approach used here. These are outlined in the following sections.

Phase 1: Problem formulation:

Identify values and threats, the relationships between these and developing a risk analysis plan. This phase was informed by (i) the workshop, attended by 11 participants including 2 managers and 9 scientists, (ii) ongoing discussions with managers and a review of literature/previous studies related to the site. A number of benefits and risks to the Pike River anabranch were identified. The list of participants in the workshop is presented in Table 2.

Table 2: Participants in the workshop (phase 1) and risk questionnaire (phase 2).

Name	Institution	Workshop	Questionnaire
Pichu Rengasamy	The University of Adelaide	✓	✓
Daniel Rogers	DENR	✓	✓
George Ganf	The University of Adelaide	✓	
Brenton Zampatti	SARDI	✓	✓
Jason Nicol	SARDI	✓	✓
Martin Mallen-Cooper	Fishway Consulting Services	✓	✓
Ivor Stuart	Kingfisher Research	✓	✓
Andrew Telfer	Australian Water Environments	✓	✓
Brad Hollis	Department for Water	✓	
Mike Harper	DENR	✓	
Todd Wallace	The University of Adelaide	✓	✓

Phase 2: Benefit and Risk analysis:

The benefit and risk analysis phase utilised a semi-quantitative approach to assess:

- the ***likelihood*** that the identified benefits and risks will impact an ecosystem,
- the ***frequency*** at which the benefits and risk will occur
- ***consequence*** if risk is converted to a hazard/ anticipated benefit is achieved
- ***certainty*** of understanding

A series of benefit and risk tables were developed following the workshop and were structured by guild/ecosystem component. For each question, the source of the benefit/risk and the impact of the benefit/risk were stated. The semi-quantitative assessment utilised the input of ecologists with recognised expertise in relevant fields. The respondents to the questionnaire are outlined in Table 2. Respondents were asked to direct their attention to those areas where they would be able to provide an informed and/or considered answer i.e. this is an area of expertise, research interest or something that they have given considerable thought to. A number of the tables were refined after the first iteration to add depth, transparency and rigour to the assessment.

Participants were requested to provide a response for likelihood, frequency and consequence of the benefit/risk occurring. The scale of response for each component of likelihood, frequency, and consequence is ranked on a range from 1-6. For certainty of understanding, the scale of response is 1-4. For anticipated benefits, a description of the scores for each category are provided in Tables 3 - 6 respectively. For anticipated risks, a description of the scores for each category are provided in Tables 7 - 10 respectively.

The scale of response for each component of likelihood, frequency, magnitude and consequence is ranked on a range from 1-6. For certainty of understanding, the scale of response is 1-4. A description of the scores for each category are provided in tables 3-7 respectively.

Table 3: Likelihood score and criteria for use in this assessment

Score	Criteria	Alternate descriptor
1	Practically Impossible	None
2	Conceivable but highly unlikely	Very unlikely
3	Remotely possible	Unlikely
4	Unusual but possible	Possible
5	Quite possible	Likely
6	Almost certain	Very Likely

Table 4: Frequency (exposure) score and criteria for use in this assessment

Score	Criteria
1	10 yearly
2	2-4 years
3	Annual
4	Monthly
5	Weekly
6	Daily

Table 5. Benefit score and benefit rating criteria for assessing the effects of flow delivery method on ecological outcomes. Adapted from Wallace et al., (2011) and Arthington et al (2003)

Score	Criteria	Consequence	Descriptor used in report
1	No natural ecological requirements/processes are met	No change will occur	No change predicted
2	Very few natural ecological requirements/processes are met	Change in condition unlikely to be detected	Very minor positive change
3	Few natural ecological requirements/processes are met	Change in condition likely to be small	Minor positive change
4	Some natural ecological requirements/processes are met	Moderate positive change in condition	Moderate positive change
5	Most natural ecological requirements/processes are met	Large, positive change in condition	Major positive change
6	All natural ecological requirements/processes are met	Significant positive change in condition	Very major positive change

Table 6. Consequence score and risk rating criteria for assessing the effects of flow delivery method on ecological outcomes. Modified from Whiterod et al (2010).

Score	Criteria	Consequence	Descriptor used in report
1	Risk posed is negligible	Insignificant	No change predicted
2	A tolerable level of risk that does not necessarily need to be addressed	Minor	Very minor negative change
3	Management action may reduce risk to more acceptable levels	Moderate	Minor negative change
4	Management action should be taken to reduce risk to more acceptable levels	Major	Moderate negative change
5	Risk must be addressed through management action.	Severe	Major negative change
6	Risk must be addressed through management action.	Catastrophic: If risk is converted to hazard, recovery may not be ensured	Very major negative change

Table 7. Certainty rating criteria for assessing the effects of flow delivery method on ecological outcomes. From Mallen-Cooper et al. (2011)

Score	Class	Description
1	Very Uncertain	No available data. Diverse views/conceptual understanding
2	Uncertain	No available data. Strong consensus on conceptual understanding
3	Moderately Certain	Supported by indirect, observational or limited scientific data
4	Very Certain	Supported by direct or abundant scientific data

Phase 3: Benefit and Risk characterisation:

Benefit/Risk rating calculator

A benefit/risk calculator was used to relate the scores for likelihood, frequency and consequence, and thereby produce a benefit/risk rating. Benefit/risk calculators provide a simple and readily interpretable visual/graphical assessment of benefit/risk to ecological values (Hart et al., 2005). For the current assessment, a modified version of the risk calculator developed by Hydro Environmental (2005) was utilised. The primary modifications were generated by Whiterod et al (2010).

The benefit/risk calculator relates likelihood and frequency via a tie line to possible consequence and then to a benefit/risk rating. Benefit risk ratings are ranked on a scale from 1-6. An example of the determination of a benefit rating is provided. In this example, a likelihood score of quite possible, a frequency score of monthly and a consequence score of minor impact has been applied. This generates a benefit rating of 3 (moderate). The description of benefit ratings and risk ratings are defined in Tables 5 and 9 respectively.

Influence of frequency on benefit and risk ratings

Benefit and risk ratings are a combination of the scores assigned to benefit (or risk), frequency, and consequence. Therefore, frequency of operation has a substantial impact on benefit and risk outcomes. With this in mind, it is critical to consider the scores for likelihood and consequence with an understanding

that the frequency of events will alter the benefit/risk that will be experienced i.e. improved outcomes may be achieved by operation of the proposed regulator at higher or lower frequencies respectively.

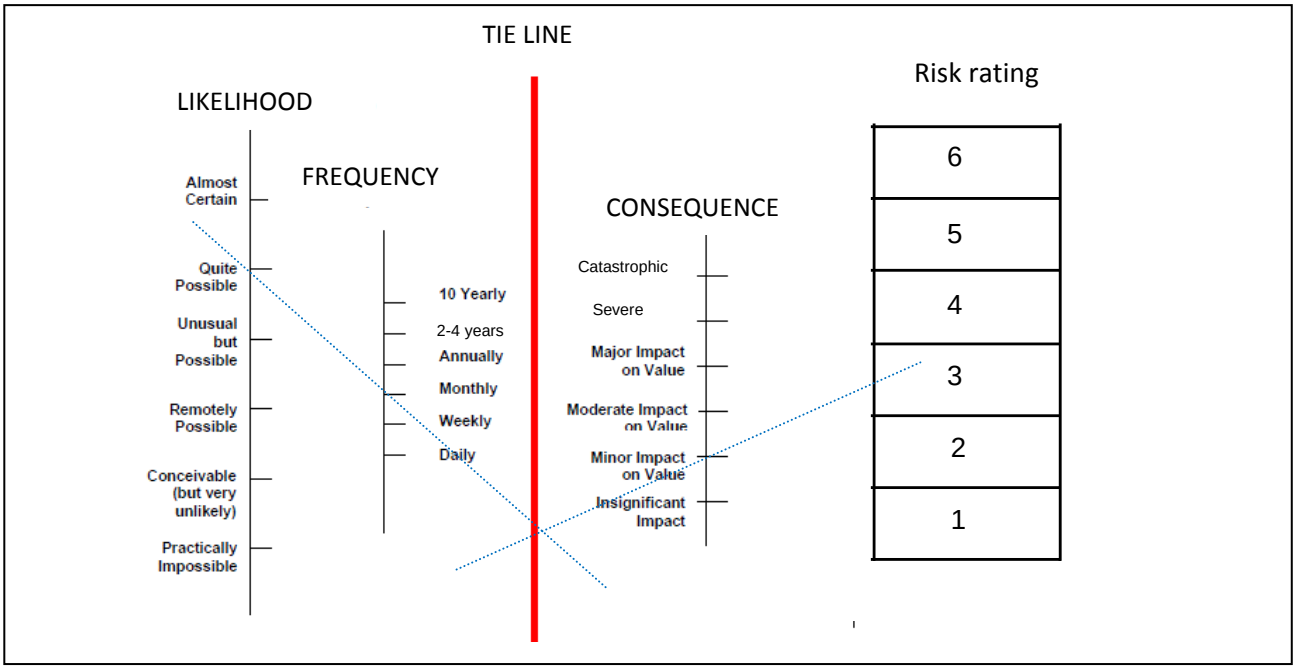

Figure 3: Risk calculator. Blue dotted line depicts calculation of risk rating as example described in text. Modified from Whiterod et al. (2010).

Reporting

The results for all completed questionnaires were compiled to provide mean scores for likelihood, frequency and consequence, and benefit/risk ratings for each question. The results are provided in tables at the end of the respective sections (section 4 and 5). To improve ability to visually interpret the results, a colour coding has been applied to the tables (see Figure 4).

The report (this document) incorporates the results of the semi-quantitative risk analysis taking into account key points raised during the problem formulation workshop. It is anticipated that the outputs will provide the information base to support decision-making to enable decisions on the validity of pursuing the proposed management action, and designing operation regimes that will maximise benefit and minimise risk.

Risk	Benefit	scale
1	1	minimum
2	2	
3	3	
4	4	
5	5	
6	6	maximum

Figure 4: Colour coding of risk and benefit ratings for easier visual interpretation of scores.

Limitations of the approach used in this assessment

Certainty

Ecosystems, such as freshwater environments, and the interactions within them are inherently complex (Suter, 2007). This complexity can lead to substantial uncertainties in our understanding and management of these systems. Due to a combination of (i) lack of data, (ii) incomplete understanding of ecological processes; and (iii) the management action(s) under consideration is unprecedented, there is a high degree of uncertainty in the assessments undertaken here.

Many of the models used in this assessment are untested conceptual models of ecosystem function based on expert opinion. A key issue here is that excessive reliance on theory rather than empirically verified interactions (science) misleads ecology (Karr, 1999) such that untested conceptual models become pseudo-fact. Furthermore, lack of knowledge can lead to language description and interpretation uncertainties. Therefore, risk assessment must contend with three types of uncertainty (Regan et al., 2002)

- variability: arises from the natural variation in ecosystems;
- incertitude: arises from incomplete knowledge of the ecosystem; and
- language: arises because of vague, ambiguous or confused definitions.

In order to account for these sources of uncertainty, all ERA assessments must rely on a range of assumptions and simplifications (Hart et al. 2005). It is important to (i) be aware of these limitations and where practicable identify uncertainty to ensure the transparency and creditability of the risk assessment (EPA, 2004). The certainty scores applied to the questionnaire by the respondents provides insight into the basis of the scores assigned and the validity of the overall scores (sensu Mallen-Cooper et al., 2011).

Divergence between anticipated and observed scores/ratings

In some cases there is/may be a divergence between the anticipated and observed scores/ratings. It is considered that this functions as both a strength and a weakness of the approach. The approach may identify issues that are, or are not, normally considered as potential benefits and risks of managed inundations. It may also reflect uncertainty and/or diverse views on the relative importance of specific processes/ecological functions in floodplain environments. Models with (i) low certainty scores (i.e. **uncertain** or **very uncertain**) or (ii) benefit/risk scores and ratings that diverge substantially from those anticipated, identify knowledge gaps requiring attention.

A semi-quantitative approach

The assessment provided here represents a preliminary evaluation of the benefits and risks anticipated to arise from the proposed management options. A semi-quantitative approach was used to achieve a broad and relatively comprehensive assessment, but it is recognised that the scope of assessment is not exhaustive. This approach was employed on a basis of maintaining a realistic budget and the relatively limited amount of existing data for this floodplain. The lack of data is acknowledged as a weakness of the approach as it precludes more intensive quantitative analysis (i.e. the use of Bayesian network modelling).

5. Assessment of potential benefits

B1: Connectivity during improved base-flows

Background

It is well recognised that longitudinal barriers (e.g. weirs, dams) and lateral barriers between rivers and floodplains (diversion and flood protection levees) sever connectivity and can lead to isolation of populations, failed recruitment, local extinction and loss of aquatic biodiversity (Bunn & Arthington, 2002; Arthington & Pusey, 2003). There is a hierarchical relationship between connectivity and movement of biotic and abiotic resources between the river channel and anabranch creeks and floodplain habitats (Wallace et al., 2011):

- 1D active movement
    - longitudinal movement undertaken by fish and macro-crustacea (shrimps, prawns, yabbies, crayfish)
- 2D active movement
    - lateral movement that is undertaken by fish and macro-crustacea (shrimps, prawns, yabbies, crayfish)
- 3D active movement
    - movements undertaken by birds and macro-invertebrates that can fly in/out in response to changing conditions
- Passive movement
    - Primarily 1D and 2D movements undertaken by carbon, nutrients, phytoplankton, micro-invertebrates, plant propagules and early life stages (egg, larval) of fish

The exchange of material between the river and the riparian zone is regarded as a key component of riverine function (Vannote et al., 1980). During the rising limb of the hydrograph, material is transported from the river to the floodplain. In the recession phase, carbon, nutrients, plankton, propagules and fish are transported from the floodplain to the river; a fundamental process of rivers and floodplains (Junk et al. 1989). The existing structures that control inflows into the Pike anabranch, and those within the anabranch system, have been designed solely to maintain stable water levels to support irrigation and domestic extraction. Installation of improved structures at the existing bank locations that incorporate ecological principles will allow for increased in-flows and water exchange and increased 1D and 2D movement.

Model tested:

Source of potential benefit:
Improved structures at the existing bank locations

Impact of potential benefit:

- Improved longitudinal connectivity for active movement for fish and macrocrustacea (shrimps, prawns, yabbies, crayfish)
- Improved lateral connectivity for active movement (fish and macrocrustacea)
- Improved passive connectivity - exchange of nutrients, carbon, phytoplankton, plant propagules, microinvertebrates and early life stages (egg, larvae) of fish

Mean values for scores and benefit ratings are presented in Table B1.

Frequency of impact:
Mean frequency scores were **monthly** to **weekly**.

Benefit rating:
The mean likelihood scores for these three models were all **possible** to **likely**. Mean consequence scores were **minor** to **moderate**. Mean Benefit ratings were all **moderate** to **major**.

Certainty:
Mean certainty scores were **uncertain** to **moderately certain**.

B2: Hydrology during improved base-flows

Background:

Flow is regarded as the key driver regulating processes and diversity in river systems and can be regarded as the master variable. Flow magnitude, frequency, timing, duration, variability, rate of change and sequence all hold major ecological significance. Many of the issues outlined in the preceding section (B1) regarding connectivity are directly applicable here. Improved water exchange may (i) improve water quality and reduce the likelihood of undesirable events such as harmful or nuisance algal blooms; and (ii) improve the diversity and quality of aquatic habitat.

A major characteristic of habitat that determines the fish community is water velocity, which can be grouped into fast-flowing (or high velocity), slow-flowing, main river channel and backwaters (Mallen-Cooper et al., 2011). It has been demonstrated that Murray cod prefer fast flowing habitats (Koehn, 2006; Zampatti et al., 2006a; Zampatti et al., 2006b). Increasing the diversity of flow habitats should be a key management priority.

Weir pools and low velocity environments may act as sediment sinks for sediments transported downstream from processes such as surface erosion within the catchment and bank erosion/collapse within the river channel (Neave & Rayurg, 2006; Gell et al., 2009). Shallow systems with sinuous course and low stream velocities and are often largely depositional environments but may retain sufficiently high velocity during flood events to produce and maintain scour holes. In systems such as the Darling Anabranch in South-western New South Wales, some of these scour holes were historically large and deep enough to function as near permanent water holes providing important habitat for the flora and fauna species (Wallace et al., 2007). Within the Pike River system, it is likely that a range of factors including construction of the existing flow control structures and lack of natural floods in recent years have resulted in increased deposition of sediments, and reduced rates of scour in the channel. It is likely that the greatest ability to reinstate scour is likely to occur on tight bends, within sites located immediately downstream of the main inlets (i.e. Margaret Dowling Creek and Deep Creek).

Model 1:

Source of potential benefit:
Improved inflow at Margaret Dowling and Deep Creek

Impact of potential benefit:

- Improved lateral connectivity
- Improved water exchange
- Improved ability to reinstate localised scour processes
- Increased outflow improves attractant flow for fish during base flows

Mean values for scores and benefit scores are presented in Table B2.

Frequency of impact:
The capacity for improved inflows will be effectively permanent once the improved structures are in place. Consequently the temporal frequency of impact of the management actions is daily. The mean frequency scores were **weekly** to **daily**.

Benefit rating:
The mean likelihood scores for this model were **possible** to **likely**. The mean consequence score was **minor** for ability to reinstate localised scour processes and **moderate** for the remaining models. The mean benefit score was **moderate** for ability to reinstate localised scour processes and **major** to **very major** for the remaining components.

Certainty:
The mean certainty scores ranged from **uncertain** to **moderately certain**.

Model 2:

Source of potential benefit:
Improved inflow at banks B and C during relatively high flows

Impact of potential benefit:

- Improved lateral connectivity
- Improved water exchange
- Improved ability to reinstate localised scour processes
- Increased outflow improves attractant flow for fish during higher flows

Frequency of impact:
Improved connectivity will be effectively permanent once the improved structures are in place. However, the magnitude of increases in flow is small until flows in the River Murray exceed approximately 40,000 $MLday^{-1}$. The mean frequency scores were **2-4 years** for ability to reinstate localised scour processes. This reflects the anticipated return interval (2-4 years) for flows >40,000 $MLday^{-1}$. The mean scores for lateral connectivity (**annual**), and water exchange and outflow (**monthly**) may reflect an expectation of improved outcomes being somewhat independent of prevailing river flows for the remaining models.

Benefit rating:
Mean values for scores and benefit ratings are presented in Table B8. The mean likelihood scores for this model were **possible** to **likely**. The mean consequence scores ranged from **minor** to **moderate**. The mean benefit score was **minor** for ability to reinstate localised scour processes and **moderate** to **major** for the remaining components.

Certainty:
The mean certainty scores were **uncertain**.

Model 3:

Source of potential benefit:
Environmental regulator at Col Col bank and Tanyaca Creek

Impact of potential benefit:

- Ability to inundate floodplain at near natural return intervals

Mean values for scores and benefit scores are presented in Table B2.

Frequency of impact:
The mean frequency score (**2-4 years**) reflects the anticipated operating frequency of the proposed regulator.

Benefit rating:
The mean likelihood score for this model was **likely**. The mean consequence score was **moderate**. The mean benefit rating was **possible**.

Certainty:
The mean certainty score was **moderately certain**.

Model 4:

Source of potential benefit:
Increased diversity of flow mosaic (no-, slow, moderate, fast flow)

Impact of potential benefit:

- Increased diversity of hydraulic habitat types for biotic and abiotic processes at the local scale
- Increased diversity of hydraulic habitat types for biotic and abiotic processes at the regional scale

Mean values for scores and benefit scores are presented in Table B2.

Frequency of impact:
It is anticipated that introducing variability in flow conditions within the anabranch will become part of an annual operating strategy. The mean frequency score recorded was **annual**.

Benefit rating:
The mean likelihood scores were **possible** and **likely** respectively. The mean consequence scores were **moderate** and **minor** respectively. The mean benefit ratings were **moderate** and **minor** respectively.

Certainty:
The mean certainty score was **moderately certain**

Model 5:

Source of potential benefit:
Increased diversity of wetland inundation regime (permanent, ephemeral, shallow, deep)

Impact of potential benefit:

- Increased diversity of habitat types for biotic and abiotic processes at the local scale
- Increased diversity of habitat types for biotic and abiotic processes at the regional scale
- Ability to manage the inundation regime of oxbow lakes

Mean values for scores and benefit scores are presented in Table B2.

Frequency of impact:
It is anticipated that introducing variability in flow conditions within the anabranch as part of an annual operating strategy will increase diversity of habitat types. The mean frequency score was **2-4 years** for the first two components and **annual** for the inundation regimes of oxbow lakes.

Benefit rating:
The mean likelihood scores were **possible** and **likely**. The mean consequence scores were **minor** at the regional scale and **moderate** at the local scale. The mean benefit score was **minor** for the impact on biotic and abiotic processes at the regional scale, **moderate** for ability to manage oxbow lakes and **major** for impact on biotic and abiotic processes at the local scale.

Certainty:
Mean certainty scores ranged from **uncertain** to **moderately certain**.

B3: Freshening of saline groundwater and/or generation of freshwater lenses associated with improved base-flows and managed inundations

Background:

Vegetation community health is dependent on a number of soil and groundwater processes. Previous studies have indicated that key indicator species; River Red Gum and Black Box are responsive to groundwater salinity (Overton and Jolly 2004). Where groundwater conductivity exceeds 30 000 μScm^{-1} for River Red Gum and 55 000 μScm^{-1} for Black Box the health of these species can decline.

Existing conceptual models of groundwater recharge during a flood suggest that inundation of large areas of floodplain will recharge areas of the shallow aquifer once a hydraulic gradient is established between the floodwaters and the underlying aquifer (SKM, 2011). Vertical recharge occurs through direct infiltration of floodwater, and horizontal recharge occurs in wetlands, backwaters, the river and its anabranches and tributaries when the surface water level exceeds the head at the groundwater interface (Holland et al., 2006). Recharge decreases groundwater salinity, as the hydraulic gradient is reversed and fresh water flows into the more saline floodplain aquifer (Jolly et al., 1998; Woessner, 2000; Hantush, 2005). These effects may extend up to 50 m from the stream edge (Holland et al., 2006).

Model tested:

Source of potential benefit:
Lateral and vertical infiltration of relatively low salinity surface water

Impact of potential benefit:

- improvement in soil moisture availability in unsaturated zone

Mean values for scores and benefit scores are presented in Table B3.

Frequency of impact:
It is anticipated that introducing variability in flow conditions within the anabranch as part of an annual operating strategy will increase variability in standing water levels. The mean frequency score recorded was **annual**. This reflects an expectation that some near bank lateral recharge will occur as a result of variations of in-stream water levels. Vertical infiltration at large spatial scales will be confined to periods of floodplain inundation. The frequency of this is likely to be **2-4 years**.

Benefit rating:
The mean likelihood score was **likely**. The mean consequence score was **moderate**. The mean benefit score was **major**.

Certainty:
The mean certainty score was **moderately certain**.

B4: Soil moisture availability associated with managed inundations

Background:

Soil moisture availability is a function of soil salt content and soil moisture. The accumulation of salt in soils is driven by evaporative discharge of groundwater (transpiration by plants and/or evaporation through the unsaturated zone). As water evaporates, salt is left behind and accumulates in soils. The amount of salt that accumulates depends on depth to groundwater, flooding regime (frequency and extent of inundation), groundwater salinity, soil type and vegetation type (Baldwin, 1996). Where dissolved salts are high in concentration, water uptake by plants can be restricted (SKM, 2010b). Soils may be defined as saline when the concentration of salts in the soil water is sufficient to cause reduced plant growth (Rengasamy et al., 2009). Conditions where the total soil moisture pressure exceeds the physiological capacity of the plants root membrane to extract water are referred to as “osmotic drought” (Overton and Doody 2006). The effect of high salt content in saline soils is similar to drought conditions in non-saline soils as the ability of plants to extract water is reduced. This effect is compounded as the soil dries between floods and rainfall events as the salinity of the soil increases even though the salt content may remain static (Rengasamy et al., 2009). High soil salinity and sodicity leads to a loss of soil structure, microbial diversity and abundance (Fitzpatrick et al., 1994), loss of soil egg banks of flood responsive understorey vegetation and micro-invertebrates (Nielsen et al., 2003a; Brock et al., 2005b; Porter et al., 2007).

Inundation has the potential to "wash" salt out of the upper layers of soil. This salt may be entrained into surface water flows or dispersed further down the soil profile (SKM, 2011). The amount of salt that can be leached from soils during flooding is influenced by flood frequency, duration and soil type. Salt is more likely to be leached from coarse-grained sediments, such as sands, than finer-grained sediments, such as clays (Ackeroyd *et al.* 1998). Surprisingly, there is little empirical data on the mechanisms of salt accumulation and dispersal in floodplain settings (SKM, 2011). In areas where depth to groundwater is very shallow, regular flooding may not substantially increase sub-soil moisture but may reduce salt content. Conversely, in areas where groundwater is relatively deep, flooding may not significantly reduce soil salt content but may substantially increase average soil moisture content. However, both of these scenarios will result in increased soil moisture availability (SKM, 2010b) and improved conditions for vegetation (Pichu Rengasamy, *pers comm*).

The potential response of shallow-rooted vegetation to rainfall events is complex and non-linear. Strong interactions between rainfall, antecedent soil moisture, plant functional type and the observed response to rain events were reported by Reynolds *et al.* (2004). If soil moisture is not already high (Golluscio et al., 1998), or rain events are not large enough to generate a substantial increase in moisture at depth (e.g. 0.3 m) there is likely to be little observable response (Baldwin et al., submitted). Consecutive closely spaced rain events that maintain soil moisture (Reynolds et al., 2004) and seasonality of rainfall is also likely to be important (Ogle & Reynolds, 2004).

Model 1:

Source of potential benefit:

Increased flooding frequency increases soil moisture content

Impact of potential benefit:

- Stimulation of soil microbial activity and shifts in soil microbial community structure
- Improved conditions for vegetation growth

- Increased soil carbon
- Increased ground cover and condition of long-lived vegetation
- Improved soil structure

Mean values for scores and benefit scores are presented in Table B4.

Frequency of impact:
Mean frequency scores were **2-4 years** for all components with the exception of "Stimulation of soil microbial activity...". The mean score for this component was **annual**.

Benefit rating:
The mean likelihood score for improved soil structure was **unlikely**. Mean likelihood score for the remaining models were **possible** and **likely**. The mean consequence scores for soil carbon and soil structure were **minor,** with **moderate** for the remaining components. A mean benefit rating of **minor** was recorded for soil carbon and soil structure. For ground cover and condition of long-lived vegetation the benefit rating was **moderate**. For the remaining components the benefit rating was **major**.

Certainty:
Mean certainty scores ranged from **uncertain** to **moderately certain**

Model 2:

Source of potential benefit:
Reduced soil salinity and/or sodicity increases soil moisture availability

Impact of potential benefit:
- Improved conditions for vegetation growth
- Increased soil carbon
- Increased ground cover and condition of long-lived vegetation
- Improved soil structure

Mean values for scores and benefit scores are presented in Table B4.

Frequency of impact:
Due to groundwater conditions on the floodplain, reductions in soil salinity and/or sodicity are likely to be tightly coupled to the frequency of flooding. The mean frequency score recorded was **2-4 years**.

Benefit rating:
Mean likelihood scores were **possible** to **likely**. The mean consequence score were **minor** for soil carbon to **moderate** for the remaining components. The mean benefit rating for soil carbon was **very minor**. Mean benefit scores for the remaining models were **minor** (soil structure) and **moderate** for the remaining components.

Certainty:
Mean certainty scores ranged from **uncertain** to **moderately certain**

B5: Improved condition of established floodplain eucalypts associated with managed inundations

There is anticipated to be some lateral freshening of near-bank groundwater driven by small scale changes in surface water levels associated with the ability to manipulate inflows. However, the spatial and temporal magnitude, and the extent of freshening achievable within the Pike Floodplain is currently unquantified, and will be (i) highly variable within and between reaches due to changes in soil type and connectivity with the aquifer; and (ii) dependent on the preceding and prevailing hydrology. Consequently, this section is focused on changes associated with managed inundations.

Background:

The following information is extracted from Wallace et al ., (2011).

Red Gum and Black Box vegetation existing in semi-arid climates can utilise low salinity groundwater (the upper tolerance limit is 30,000 μScm^{-1} for river red gum and 55,000 μScm^{-1} for black box (Overton and Jolly, 2004)). In areas characterised by low rainfall, high potential evaporation, and high salinity groundwater, trees extract water from the upper soil profile and become sensitive to salt accumulation (Jolly et al., 1993) during dry periods. These trees rely on periodic flooding to improve soil water availability and to leach salt from the soil profile. Responses to flooding (new growth) are typically due to increased soil moisture in the upper soil profile and not necessarily a change in salinity in the deeper profile (Overton & Doody, 2008).

The ability of trees to respond to the application of EWA's is tightly coupled to pre-existing condition. As part of an assessment of the efficacy of EWA's delivered specifically for improving the condition of river red gums, Wallace (unpublished data) demonstrated that 92% of trees with between 1-50% canopy cover responded to the application of environmental water. 68% of trees that had recently (i.e. within several weeks) lost all of their canopy, responded. However, less than 15% of trees that had lost their canopy and were showing signs of the inner bark cracking responded. At the site scale (independent of individual tree condition prior to delivery of the EWA) 80% of trees had responded by 8 weeks post watering, but by 32 weeks post watering only 70% of trees were still showing positive signs of improvement. It has become increasingly obvious that repeated watering over time is required to maintain the initial vegetation response and to ensure that the tree vegetation continues to improve (Overton & Doody, 2008; Souter et al., Submitted).

Assessments of tree condition (River red gum, black box and river cooba) at Pike Floodplain (Wallace, 2009) reveal that although there are individual trees that are in “good” condition, there are no transects (n = 30 trees per transect) with mean or median scores in this category. The most frequently occurring category was “stressed”, with nine of twenty one (21) transects in this category. Eight transects were in “poor” condition, and four were in “very poor” condition. Gehrig and Nicol (2010) suggested that at Pike Floodplain, improvements in black box woodland and understorey condition will be dependent on overbank flooding.

Model 1:

Source of potential benefit:

Increased soil moisture availability driven by increased soil moisture, reduced soil salinity and soil sodicity

Impact of potential benefit:

- Improved habitat for dependent species

- Improved source of carbon and nutrients
- Increased food resources for invertebrates
- Improved soil carbon/nutrient status of soil
- Increased food resources and/or foraging habitat for higher trophic levels (e.g. insectivorous birds)

Mean values for scores and benefit ratings are presented in Table B5.

Frequency of impact:
Mean frequency scores for the soil carbon/nutrient status model was 2-4 years for "Improved source of carbon and nutrients" and **monthly** and **weekly** for the remaining components.

Likelihood and Consequence:
The mean likelihood score for all components was **likely**. The mean consequence scores for the soil carbon/nutrient status component was **minor**. The mean consequence scores for the remaining components were **moderate**.

Benefit rating:
The mean benefit rating for "Improved source of carbon and nutrients" was **moderate**. The benefit ratings for the remaining components were **major** and **very major**.

Certainty:
Mean certainty scores ranged from **uncertain** to **moderately certain**.

Model 2:

Source of potential benefit:
Increased soil moisture availability driven by increased soil moisture, reduced soil salinity and soil sodicity

Impact of potential benefit:
- Ability to manage large proportion of tree community that is difficult to achieve at other regionally relevant sites

Mean values for scores and benefit ratings are presented in Table B5.

Frequency of impact:
The mean frequency score was **2-4 years**.

Likelihood and Consequence:
The mean likelihood score was **likely**. The mean consequence score was **very major**.

Benefit rating:
The mean benefit rating was **very major**.

Certainty:
The mean certainty scores was **moderately certain**.

B6: Improved recruitment of floodplain eucalypts associated with managed inundations

Background:

The age-class distribution of woodland trees is an indicator for recruitment and survival, and the growth of young trees must at least match the mortality of old trees if a stand is to remain viable (George et al., 2005). Assessments of tree size class-frequency distribution at the Pike Floodplain (Wallace, 2009) demonstrate that for the majority of sites, the distribution diverges from the smooth "inverse J-shaped distribution" described by Smith et al., (1997) which is considered to depict a sustainable community. George *et al*., (2005) suggested that skewed distribution indicates episodic recruitment or high mortality of small size classes.

The existing data (Wallace, 2009) demonstrates that the number of juvenile trees present at the Pike Floodplain is not sufficient to maintain either the existing (only live trees) or pre-existing (all standing trees) community structure at any of the sites. At all transects, at least double (x2) the number of existing juvenile trees is required. The large divergence between required numbers of juveniles for population maintenance and observed numbers of juvenile trees on the Pike Floodplain implies that the tree community is not currently sustainable in the long-term.

The germination and establishment of River red gums (*Eucalyptus camaldulensis* Dehnh. Myrtaceae) (RRG) is not completely dependent on flooding. However, regeneration (recruitment success) is greatly enhanced by appropriate flood regimes (i.e. follow-up flooding; Bacon *et al*. 1993, Roberts and Marston 2000, MDBC 2001). Jensen *et al*., (2008) reported germination of RRG following rainfall at an ephemeral creek site on Chowilla Floodplain, indicating that flooding may not be a necessary pre-requisite for germination to occur. However, George (2004, as cited by Jensen et al., (2008)) suggested that a flood followed by above average rain fall is a pre-requisite for successful recruitment. Reduction in seedling loss (death) through removal of pressures such as grazing by both domestic stock and native and feral animals is also likely to be required to ensure the sustainability of the tree community.

Model 1:

Source of potential benefit:

Increased soil moisture availability driven by increased soil moisture, reduced soil salinity and soil sodicity

Impact of potential benefit:

- Increased diversity of age classes leading to long-term sustainable population

Mean values for scores and benefit ratings are presented in Table B6.

Frequency of impact:

The mean frequency score was **2-4 years**.

Likelihood and Consequence:

The mean likelihood score was **likely**. The mean consequence score was **very major**.

Benefit rating:

The mean benefit rating was **very major**.

Certainty:
The mean certainty score was **moderately certain**.

Model 2:

Source of potential benefit:
Reduced grazing pressure

Impact of potential benefit:

- Increased diversity of age classes leading to long-term sustainable population

Mean values for scores and benefit ratings are presented in Table B6.

Frequency of impact:
The mean frequency score was **monthly**.

Likelihood and Consequence:
The mean likelihood score was **likely**. The mean consequence score was **major**.

Benefit rating:
The mean benefit rating was **very major**.

Certainty:
The mean certainty score was **moderately certain**

B7: Improved abundance and distribution of flood dependent understory vegetation associated with managed inundations

Background:

The following information is adapted from Wallace et al ., (2011).

The main factors that influence plant recruitment in wetland and floodplain habitats are presence or absence of standing water (van der Valk, 1981b) depth, duration, frequency and timing of flooding (Casanova & Brock, 2000), soil salinity (Nielsen et al., 2003b; Brock et al., 2005a) and soil moisture (Nicol 2004). Native flood-dependent plants are typically short-lived, with flooding required to remove drought tolerant species that become established during the drying phase (Nicol, 2004). Roberts *et al.* (2000) suggest that for modelling purposes plant water regime should be considered as a time series of three states: inundated and submerged; inundated but not submerged and not inundated. Key statistics for each are; mean duration; variability of duration; variability of the period between the occurrence of one state or another; seasonal occurrence of the three states.

The majority of flood-dependent understorey species are annuals that are able to complete their life cycle in a matter of weeks (Cunningham et al. 1981 as cited by (Nicol et al., 2010a). Nicol (2004) suggests that most native understorey plant species are opportunistic and do not have temperature requirements for germination. However, monitoring of outcomes from EWA's has demonstrated that autumn-winter flooding near Mildura (Victoria) does not produce as strong an ecological response as water delivered in spring-summer (Chatfield, 2007; D'Santos, 2007). Furthermore, Campbell et al. (unpublished data) have demonstrated a strong seasonal difference between the effects of spring and winter floods on understorey composition, using soil cores collected from a wetland at Lindsay Island (Victoria). In addition, seasonal differences in exotic species have been observed in wetlands where EWA's have been delivered (Nicol et al., 2010b).

Rates of rise are not generally important for the establishment of flood-dependent plant species as many will not germinate until water levels are drawn down and the soil is exposed to the atmosphere but retains a high moisture content (Nicol, 2004). Slow rates of drawdown in the range 10-30 mm day^{-1} (<50mm) have the greatest benefit for amphibious and floodplain plant communities (Nicol, 2004), providing time and moisture for a range of flood-dependent species to germinate and become established.

During a period of frequent flooding, the plant community is dominated by amphibious and flood-dependent species for approximately 12 months and is then progressively replaced by increasingly drought tolerant species until the next flood. In wetlands that are inundated on a near-annual basis, the shift towards terrestrial species is not likely to be observed. However, prolonged or permanent inundation can lead to low plant diversity (van der Valk, 1994; Nielsen & Chick, 1997; Barrett et al., 2010). In the extended absence of floods, drought tolerant species become increasingly dominant (see Nicol et al., 2010a). Nicol, Doody et al., (2010a) suggest that a return frequency of 3-5 years is likely to be sufficient to maintain seed banks and ensure the long term persistence of amphibious and floodplain species. This is supported by Brock (2011) who demonstrated that viable seed for more than 70% of the species originally present in wetland soil cores survived drought conditions for longer than 5 years. Furthermore, germination of almost half of the original species occurred in seven consecutive annual wetting events even though replenishment of the seed bank by development of new seed was deliberately prevented. This indicates that soil seed banks are highly resilient. However, the risk of loss of taxa during long droughts is real. Once the soil seed bank of flood-dependent and amphibious species has been depleted, a single flood event is likely to produce a suppressed response (sensu Nicol et al., 2010a). Re-establishment will be heavily

dependent on the distribution of propagules elsewhere in the landscape and factors (flow direction and connectivity, wind and biota) facilitating dispersal among wetlands (Green et al., 2008; Questad & Foster, 2008).

Under current conditions the littoral zone in the River Murray between Lock 10 (Wentworth, NSW) and Lock 1 (Blanchetown, South Australia) is a contracted strip approximately 1m wide (Nicol et al., 2010a). Water level fluctuations driven by flow spikes, weir pool manipulations or use of large infrastructure, will substantially increase the width of this littoral zone (Nicol et al., 2010a). On floodplains and in wetlands, repeatedly filling sites to the same inundation level at the same time of year will lead to the establishment of a "bath-tub ring" or very narrow zone of response (Brookes et al., 2006) and must be avoided.

Model tested:

Source of potential benefit:
Increased soil moisture availability driven by increased soil moisture, reduced soil salinity and soil sodicity

Impact of potential benefit:

- Improved habitat for dependent species
- Improved pathways for interception and processing and transfer of carbon and nutrients
- Increased food resources for native grazing animals
- Increased food/habitat resources for invertebrates
- Increased food resources and/or foraging habitat for higher trophic levels (e.g. insectivorous birds)
- Improved soil carbon/nutrient status of soil

Mean values for scores and benefit ratings are presented in Table B7.

Frequency of impact:
The mean frequency scores ranged from **annual** to **2-4 years**.

Likelihood and Consequence:
The mean likelihood scores for all components were **likely**. For "Improved soil carbon/nutrient status of soil", the mean consequence score was **minor**. For the remaining components, mean consequence scores were **moderate**.

Benefit rating:
The mean benefit ratings for "Improved soil carbon/nutrient status of soil" and "..pathways for interception and processing of carbon and nutrients" were **moderate**. For all other components the benefit rating was **major**.

Certainty:
The mean certainty scores ranged from **uncertain** to **moderately certain**.

B8: Improved abundance and distribution of aquatic plants (submerged and emergent vegetation) associated with managed inundations

There is anticipated to be some potential for improving the abundance and distribution of aquatic plants associated with the ability to manipulate inflows. However, the spatial and temporal magnitude, and the extent of this benefit is difficult to quantify without a detailed understanding of how the inlets will be operated and the extent of variation in inundation extent and habitat types that can be achieved by manipulating inflows. Consequently, this section is focused on changes associated with managed inundations.

Background:

The following information is adapted from Wallace et al ., (2011).

Aquatic macrophytes have propagules that allow them to establish while the substrate is flooded (van der Valk, 1981b) but the germination and establishment of most amphibious species occurs in shallow water or when water levels are declining (van der Valk, 1981a; Brock & Casanova, 1997; Casanova & Brock, 2000; Bell & Clarke, 2004). This is likely to be because in shallow water (0-20cm) availability of both water and atmospheric gases is optimal (Blanch et al., 2000). Duration and timing of flooding can affect the capacity of macrophytes to reproduce as (i) standing water needs to remain present long enough for life-cycles to be completed if new propagules are to be added; and (ii) rates of growth and reproduction vary according to seasonal cycles (Warwick & Brock, 2003).

In terms of survival, established stands of low-growing and emergent amphibious macrophytes are generally more vulnerable to rapid increases in water depth than submerged and free-floating aquatic species, as many of these species are unable to maintain sufficient rates of photosynthesis and gas exchange to survive extended periods of inundation (Siebentritt & Ganf, 2000b). Some emergent macrophytes can grow taller to maintain photosynthetic leaf or stem tissue above the water surface. However this can be detrimental to long term survival and future vegetative regeneration capacity if it occurs at the expense of below-ground storage biomass (e.g. rhizomes, tubers) (Rea & Ganf, 1994; Blanch et al., 1999; Siebentritt & Ganf, 2000a).

Model tested:

Source of potential benefit:
Increased aquatic habitat availability

Impact of potential benefit:

- Improved habitat for dependent species
- Improved pathways for interception and processing and transfer of carbon and nutrients
- Increased food/habitat resources for invertebrates
- Increased food resources and/or foraging habitat for higher trophic levels (e.g. herbivorous birds, fish)

Mean values for scores and benefit ratings are presented in Table B8.

Frequency of impact:
The mean frequency scores was **2-4 years**.

Likelihood and Consequence:
The mean likelihood scores for all components was **possible**. Mean consequence scores were **minor**.

Benefit rating:
The mean benefit rating for all components was **minor**.

Certainty:
The mean certainty score was **uncertain**.

B9: Decrease in relative abundance of salt tolerant species associated with managed inundations

Background:

Native flood-dependent plants are typically short-lived, with flooding required to remove drought tolerant species that become established during the drying phase (Nicol, 2004). In the extended absence of floods, drought tolerant species become increasingly dominant. Capon et al. (2009) report that the key issue for understorey and aquatic vegetation at Chowilla Floodplain is the replacement of flood tolerant species by drought tolerant species, e.g. chenopod shrubs, and the replacement, in turn, of these by salt tolerant species (Marsland *et al.*, 2009; Nicol *et al.*, 2009). Similar processes can be expected to be occurring at the Pike River floodplain. The switch from drought tolerant to salt tolerant understorey vegetation occurs when soil salinities exceed 20,000 μScm^{-1} (Hassam 2007, Bailer et al., 2002 as cited by (Nicol et al., 2010a).

Model tested:

Source of potential benefit:
Increased soil moisture availability driven by increased soil moisture, reduced soil salinity and soil sodicity

Impact of potential benefit:

- Improved abundance and distribution of flood dependent/drought tolerant understory vegetation

Mean values for scores and benefit ratings are presented in Table B9.

Frequency of impact:
The mean frequency scores was **2-4 years**.

Likelihood and Consequence:
The mean likelihood scores for all components was **likely**. Mean consequence score was **moderate**.

Benefit rating:
The mean benefit rating for all components was **moderate**.

Certainty:
The mean certainty scores was **moderately certain**.

B10: Recruitment ecology of waterbirds associated with managed inundations

Background:

The following is extracted from Wallace et al ., (2011).

Birds are typically found at the top of food webs (Rogers & Paton, 2008) and are able to use 3D active movement to fly in/out in response to changing conditions. Consequently their responses to environmental change tend to be indirect, manifesting through the responses of the trophic levels below them. Benefits to bird communities from the delivery of EWA's will therefore be dependent on benefits being provided to the aquatic and terrestrial organisms on which the food web relies, such as aquatic and terrestrial vegetation, macroinvertebrates and fish (Rogers & Paton, 2008). For example, waterbirds dependent on invertebrates will respond to flooding prior to those dependent on large macro-crustacea or macrophytes (see Kingsford et al., 2010). This lag phase provides the opportunity for differences between natural and managed floods to cascade across multiple levels and manifest into large differences in the quality of outcomes.

Regional and continental cues used by waterbirds to select nest sites and initiate breeding are complex and poorly understood; travelling flood pulses may be one of a number of cues used to initiate breeding in Australian waterbirds (Kingsford and Norman 2002 as cited by (Rogers & Paton, 2008)). Consequently, delivery of EWA's into sites that provide good habitat may not result in breeding as the landscape scale cues are not being provided. However, prior to river regulation, wetlands within the Murray–Darling Basin may have been highly reliable habitats for waterbirds because they are predominantly filled by flows travelling from distant catchments and are not dependent on local rainfall (Kingsford et al., 2010). Furthermore, the observation of breeding events on artificially watered wetlands throughout the MDB suggests that the lack of natural cues may not be a critical issue for waterbirds (Rogers & Paton, 2008). The effects of this may only become clear over the long-term (i.e. cumulative impacts).

The extent of floods are an important consideration as it will determine the total area of habitat potentially available to groups/species dependent on inundated or recently inundated areas for colonisation and breeding. For example, the extent of wetland inundation and the size of a waterbird breeding event are linked (Briggs et al. 2997, Crome, 1988, Scott 1997 as cited by (Rogers & Paton, 2008)) as large areas of productive wetland are able to support more nesting (Rogers & Paton, 2008). The duration of flooding is the primary determinant of the success of an individual nesting attempt. Minimum inundation times for a range of waterbirds are typically around 100 days, but for some species (i.e. Black Swan) are as high as 180 days. It is important to note that the duration required varies between species based on intrinsic (physiological preparation, egg development and incubation, nestling development) and extrinsic (development of food/prey communities) factors that are influenced by spatio-temporal variability in wetland productivity (Rogers & Paton, 2008). A minimum of 120 days (4 months) is generally suggested as the minimum duration (Young et al. 2003 as cited by Rogers & Paton, 2008).

For waterbirds, nest sites need to be in close proximity to foraging habitat as breeding waterbirds will typically only travel short distances from an active nest to acquire food; if the wetland where nesting occurs does not provide the food resources required, those resources must be provided via an adjacent site. For waterbirds that utilise submerged aquatic macrophytes as a key food source their response will be linked to the availability of those plants (Rogers & Paton, 2008). During managed delivery of water to discrete sites, the ability to produce a functional mosaic of habitats in order to provide the requirements of ecological communities must be taken into account. The distribution of flood responsive species will differ between a natural flood and one generated by large infrastructure. This is attributable to the effects of natural floods

being evenly distributed with regard to elevation across the floodplain. In comparison, the use of large infrastructure and the backwater curve generated leads to the maximum area inundated being located adjacent to the regulator at relatively high elevations (mAHD) compared to the area inundated at the tail end of the inundation zone where the water level will not rise as high (Nicol et al., 2010a). Rogers and Paton (2008) suggest drawdown rates should not exceed 50mm day^{-1} in order to avoid nest abandonment by breeding waterbirds.

Water depth has a significant influence on waterbird diversity as particular species occupy specific habitat types defined by water depth. Wetland management that provides the greatest diversity of habitat types including variable water depths, mud flats, inundated vegetation and deeper water areas results in the greatest abundance and diversity of waterbirds (see Brandis et al., 2009). The extent of wetland inundation and the size of a waterbird breeding event are linked (Briggs et al. 2997, Crome, 1988, Scott 1997 as cited by Rogers & Paton, 2008) as large areas of productive wetland are able to support more nesting (Rogers & Paton, 2008). The duration of flooding is the primary determinant of the success of an individual nesting attempt.

Very large water bird breeding events may not occur on a regular basis at Pike River floodplain. However, regular small breeding events may be critical to ensure enough recruitment events within the lifespan of individuals to maintain sustainable populations over the long-term.

Model tested:

Source of potential benefit:
Changes to hydrology

Impact of potential benefit:
Increased opportunities for small-scale breeding events for waterbirds via:

- Appropriate landscape mosaic including increased nesting/breeding habitat is created
- Increased foraging habitat combined with improved food resources is provided
- Recruitment (fledging) is increased
- Improved carrying capacity for local population
- Increased recruitment from young-of-year to adults improves local population demographics
- Increased recruitment from young-of-year to adults improves regional population demographics

Mean values for scores and benefit ratings are presented in Table B10.

Frequency of impact:
The mean frequency scores was **2-4 years**.

Likelihood and Consequence:
The mean likelihood scores for habitat and carrying capacity were **likely**. The mean likelihood scores for recruitment components were **possible**. The mean consequence scores for all components was **moderate**.

Benefit rating:
The mean benefit ratings for habitat and carrying capacity components were **moderate**. The mean benefit ratings for recruitment components were **minor**.

Certainty:
The mean certainty score for "increased foraging habitat...." was **moderately certain**. The mean certainty scores for the remaining components was **uncertain.**

B11: Recruitment ecology of frogs associated with managed inundations

Background:

The majority of frog species that occur at the southern end of the MDB (including Pike River floodplain) have wide breeding seasons, but few species breed during June and July; hence water delivered during this period is likely to have reduced positive outcomes compared to flooding commencing in August-September (Veltheim et al., 2009). For frogs, water needs to persist in wetlands at suitable depths for a minimum of 3-5 months to allow sufficient time for successful tadpole metamorphosis (Veltheim et al., 2009). Providing quality habitat at multiple sites reduces the likelihood of pressures such as disease, poor habitat or predation having a catastrophic impact on the local population.

Model tested:

Source of potential benefit:
Changes to hydrology

Impact of potential benefit:
Increased opportunities for breeding via:

- Appropriate landscape mosaic including increased nesting/breeding habitat is created during managed inundations
- Increased foraging habitat combined with improved food resources is provided during managed inundations
- Recruitment to young-of-year is increased during managed inundations
- Improved carrying capacity for local population
- Increased recruitment from young-of-year to adults improves local population demographics in the long-term
- Increased recruitment from young-of-year to adults improves regional population demographics

Mean values for scores and benefit ratings are presented in Table B11.

Frequency of impact:
The mean frequency scores for improved carrying capacity, and improving local and regional population demographics were **10 years**. Mean frequency scores for the remaining components were **2-3 years**.

Likelihood and Consequence:
The mean likelihood scores for improved carrying capacity, and improving local population demographics were **unlikely**. The mean score for improving regional population demographics was **very unlikely**. The mean likelihood scores for the remaining components were **likely**. The mean consequence scores for improving local population demographics was **major**. The mean consequence score for all other components was **moderate**.

Benefit rating:
The mean benefit ratings for improving regional population demographics and improved carrying capacity were **no change predicted**. The mean benefit rating for local population demographics was **very minor**. The mean benefit ratings for the remaining components were **moderate**.

Certainty:
The mean certainty scores ranged from **very uncertain to moderately certain**.

B12: Productivity and energy transfer associated with managed inundations

Background:

Under low flow conditions, autotrophic sources of carbon are believed to dominate foodwebs (Bunn et al., 2003; Hadwen et al., 2009). For example, Oliver and Merrick (2006) and Oliver and Lorenz (2007) demonstrated that the River Murray is energy constrained with net production close to zero. Studies in the Logan, Gwydir and Ovens Rivers (Hadwen et al., 2009) and Lachlan River (Moran, 2011; Wallace & Bindokas, 2011b) have demonstrated that respiration of the heterotrophic bacterial community and DOC consumption is limited by the quality of DOC present. This is considered to be the case for the majority of Australian rivers during low flow conditions when allochthonous DOC supply is limited (Robertson et al., 1999). In contrast, during periods of high flow and floods, inputs of allochthonous DOC are likely to provide a short-lived but significant productivity boom.

Sherr and Sherr (1988) propose that the microbial food web is capable of transporting a significant proportion of carbon to zooplankton The assimilated carbon and nutrients are subsequently cycled though the food web to higher trophic level organisms (e.g. birds and fish) via multiple pathways, including via micro- and macro-invertebrates. This process is referred to as 'trophic upsurge' (Furch & Junk, 1997; Kern & Darwich, 1997; Geraldes & Boavida, 1999; Scharf, 2002; Talbot et al., 2006; Lourantou et al., 2007). Returning water that contains a high biomass of prey items and increased nutrient loads to river channels is likely to improve the recruitment success of fish inhabiting those river channels (Balcombe et al., 2007; King et al., 2009; Meredith & Beesley, 2009).

Factors that will influence the success (survival and recruitment) or failure of breeding events of key groups such as frog, fish and birds include the availability of appropriate food resources at the correct times via the productivity boom (Bunn et al., 2006) that occurs during floods. The productivity boom provides abundant food resources for a range of higher order animals and is therefore regarded as an ecosystem service. Invertebrates are a key food resource for breeding waterfowl as they provide the protein source required for egg and nestling development. The responses of guilds that are piscivorous, herbivorous, reliant on aquatic macro-invertebrates and terrestrial invertebrate/ insects, or utilise aquatic plants (e.g. sedges and rushes) for nesting material will depend on the provision of appropriate habitat and response/development of food resources (Rogers & Paton, 2008).

Model 1:

Source of potential benefit:
Increased frequency of allochthonous inputs from floodplain

Impact of potential benefit:

- Improved mass of carbon and nutrients available for trophic upsurge
- Improved abundance of food resources for multiple trophic levels
- Improved nutritional value of food resources for multiple trophic levels

Mean values for scores and benefit ratings are presented in Table B12.

Frequency of impact:
The mean frequency scores were **2-4 years**.

Likelihood and Consequence:
The mean likelihood scores were **likely**. The mean consequence scores were **moderate** for mass of carbon and nutrients, and abundance of food resources. The mean consequence score was **major** for nutritional value of food resources.

Benefit rating:
The mean benefit ratings were **major**.

Certainty:
The mean certainty score for the model ranged from **very uncertain** to **moderately certain**.

Model 2:

Source of potential benefit:
Productivity benefits from upstream flooding transferred into anabranch

Impact of potential benefit:

- Increased abundance of abiotic resources (e.g. nutrients, carbon) to drive productivity
- Increased abundance of biotic resources (e.g. invertebrates, plant propagules, larval fish)

Mean values for scores and benefit ratings are presented in Table B12.

Frequency of impact:
The mean frequency scores were **2-4 years**.

Likelihood and Consequence:
The mean likelihood scores were **possible**. The mean consequence scores were **moderate.**

Benefit rating:
The mean benefit ratings were **major**.

Certainty:
The mean certainty score for the model ranged from **very uncertain** to **uncertain.**

B13: Carbon Sequestration associated with managed inundations

There is anticipated to be some improvement in vegetation and soil condition driven by lateral freshening of near-bank groundwater associated with the ability to manipulate inflows. However, the spatial and temporal magnitude, and the potential magnitude of those improvements, and hence carbon sequestration is likely to be relatively small compared to the improvement potentially achievable via managed inundations. Consequently, this section is focused on changes associated with managed inundations.

Background:

Increased growth rates of floodplain trees and increased biomass of understorey vegetation should lead to an increase in carbon sequestration on the floodplain. The magnitude of increase that can be expected is largely unquantified. However, Colloff and Baldwin (2010) point out there is likely to be inter-dependence between the wet and dry phases in the form of reciprocal provisioning of bioavailable carbon. Carbon that is fixed during the dry phase could be important for functioning during the wet phase and carbon fixed during the wet phase could be important for functioning during the dry phase. This process is typically referred to as a pulse-reserve model. The flux of material from the floodplain to the water column following inundation (Baldwin & Mitchell, 2000), which is considered to be important for the functioning of the aquatic ecosystem (Junk et al., 1989), offers an example of this process.

The growth of aquatic macrophytes during the wet phase (during or following flooding) has been shown to contribute at least an order of magnitude more organic material to the soil than any rain induced pulse reserve response. In a study undertaken at Yanga floodplain (New South Wales) Baldwin et al (submitted) demonstrated that the amount of root material and total organic matter content was substantially greater in soils that had recently been flooded compared to soils that had not been flooded for some time. The organic matter fixed during the wet phase is slowly mineralized during the dry phase and hence serves as an energy source for years after flood recession (Baldwin et al., submitted). In that study, large (i.e. 3000 g m^{-2}) differences in total organic matter between sites that had recently (months) been flooded compared to sites that had been dry for more than eight years were attributed to the loss of above and below ground (e.g. root mass) plant material in the long-dry sites.

The organic carbon content of soils directly influences the provision of nutrients to plants via decomposition and mineralization processes releasing nutrients essential for plant growth. Indirect roles are associated with soil physiochemical properties including aggregation, pH buffering, cation exchange capacity and water retention (Wilson et al., 2011). Soil organic carbon dynamics is in turn influenced by microbial community structure and activity. Baldwin et al (submitted) propose that the carbon reserve generated in the soil following flooding supports terrestrial processes for a number of years. Those authors propose that small rainfall events that do not substantially increase soil moisture at depth (e.g. 0.3m) and thereby support a positive vegetation response, may actually lead to depletion of soil carbon reserves as wetting of soil can increase microbial activity and associated carbon mineralization within minutes to hours.

Model 1:

Source of potential benefit:

Improved soil condition

Impact of potential benefit:

- increased carbon uptake and storage.

Mean values for scores and benefit scores are presented in Table B13.

Frequency of impact:
Mean frequency score was **2-4 years**

Likelihood and Consequence:
The mean likelihood score was **likely**. The mean consequence score was **minor.**

Benefit rating:
The mean benefit score was **minor**.

Certainty:
The mean certainty scores was **uncertain**.

Model 2:

Source of potential benefit:
Improved long-lived plant biomass

Impact of potential benefit:

- increased carbon uptake and storage

Mean values for scores and benefit scores are presented in Table B13.

Frequency of impact:
Mean frequency score was **10 years**.

Likelihood and Consequence:
The mean likelihood scores for these two models were **likely**. Mean consequence scores were **minor.**

Benefit rating:
Mean benefit scores were **minor**.

Certainty:
The mean certainty scores was **moderately certain**.

B14: Ability to test hypotheses with BACI design associated with (i) improved base-flows and (ii) managed inundations

Background:

One of the unique aspects of the proposed intervention and management regime for the Pike Anabranch is that if constructed, the regulators will only influence the inundation regime of the upper Pike Floodplain. Managed inundations will not be able to be undertaken on the lower Pike Floodplain. This offers the ability to have the impact site (upper floodplain) and control site (lower floodplain) adjacent to each other reducing confounding effects typically associated with spatially separated impact and control sites. This attribute allows for the design and implementation of robust BACI (before, after, control, impact) experiment designs, an aspect that is not available at most floodplains that are likely to undergo managed inundation regimes.

Model tested:

Source of potential benefit:
Changes to hydrology

Impact of potential benefit:

- Unique ability to test hypotheses with robust design significantly improves ability to address knowledge gaps and improve confidence in establishing cause and effect relationships

Mean values for scores and benefit scores are presented in Table B14.

Frequency of impact:
The ability to apply BACI experimental designs is available at all times. However, operation of the structure is predicted to occur once every 2-4 years. The mean frequency score was **2-4 years**.

Benefit rating:
The mean likelihood scores for this model was **possible**. The mean consequence score was **moderate**. The mean benefit score was **minor.**

Certainty:
Mean certainty scores was **moderately certain**.

B15: Reinstatement of resilience associated with managed inundations

Background:

There is an urgently growing need to move away from maintaining stabilised conditions, where management interventions are focused on preventing irreversible damage once the system is already in an extreme level of precariousness (Scheffer et al., 2001; Scheffer & Carpenter, 2003). Instead, management needs to focus on reinstating resilience as the most pragmatic and effective way of managing ecosystems in order to withstand future droughts and provide ecosystem services (Scheffer et al., 2001; Scheffer & Carpenter, 2003; Folke et al., 2004; Bond et al., 2008).

Holling (1973) defined resilience as "a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables....". Resilience has multiple attributes, but four aspects are critical (Walker et al. 2004 as cited by (Folke et al., 2004)):

- *Latitude*; the maximum amount the system can be changed and still reorganize within the same state.
- *Resistance*; how large a disturbance is required to change the current state of the system.
- *Precariousness*; how close the system is to a threshold that, if breached, makes reorganization difficult.
- *Cross-scale relations*; how the three attributes above are influenced by the states and dynamics of the system, at scales above and below the scale of interest.

Unregulated river systems are likely to have a very large degree of resilience, latitude and resistance, displaying a transient, dynamic regime (Holling, 1973) with two distinct extremes (Scheffer et al., 2001; Scheffer & Carpenter, 2003) in which wetlands are always drying or flooding (Kingsford et al., 2010). Rather than the wet and dry phase being two states with characteristic dominant biota, there is only a single state with two alternative phases interspersed by floods and droughts (Colloff & Baldwin, 2010); the system will progressively revert towards the preceding condition once the disturbance (flooding or drying) is removed. Once a driver (i.e. permanent inundation or very long drying) exerts sufficient pressure to exceed the threshold for change a catastrophic (rather than smooth) transition to an alternate state can occur (Scheffer et al., 2001; Scheffer & Carpenter, 2003).

River management has skewed river channels towards an anti-drought scenario. Conversely, it has skewed floodplains such as Pike River floodplain toward a strong, persistent engineered drought significantly compounding the effects of climate drought. As a result, the floodplain is in a highly altered state and an extreme state of precariousness. It must be recognised that applications of environmental water are unlikely to return the floodplain to the condition that would have been observed pre-river regulation. It is not currently possible to predict how similar the conditions that can be achieved will be to pre-regulation conditions. This is largely because we lack sufficient ecological knowledge to predict how floodplains in different conditions will respond. This represents a major hurdle for managers as volumes of environmental water are limited and resilience is an ecosystem property that can be either created or destroyed (Colloff & Baldwin, 2010). Reinstating flows and reoperation of existing infrastructure should be actively used during wet and median conditions to build resilience, as reinstating resilience is the most pragmatic and effective way of managing ecosystems (Wallace et al., 2011).

Model tested:

Source of potential benefit:
Ability to inundate floodplain components independent of river conditions

Impact of potential benefit:

- Maintain floodplain in responsive condition
- Prime floodplain for coming, natural high flow events
- Capitalise on outcomes from preceding inundations to ensure recruitment

Mean values for scores and benefit ratings are presented in Table B15.

Frequency of impact:
The mean frequency scores for all components were **2-4 years**.

Likelihood and Consequence:
The mean likelihood scores were **likely**. The mean consequence scores were **major**.

Benefit rating:
The mean benefit ratings were **very major.**

Certainty:
The mean certainty score for each model was **uncertain.**

B16: Golden perch and silver perch during improved base-flow conditions

General comments on fish communities

The following is extracted from Wallace et al ., (2011).

Life history stages of many riverine fish (pre-spawning condition and maturation, movement cues, spawning cues and behaviour, larval and juvenile survival, generation of food, availability of suitable habitats) are linked to the flow regime. Throughout the MDB the decline in abundance and distribution of native fish has been attributed to construction of barriers to movement, altered temperature regimes, reductions in aquatic vegetation and deeper pool habitats, removal of reproductive cues, and reduced access to the floodplain (see King et al., 2010). Balcombe et al (2011) concluded that the largely unregulated rivers of the upper Murray-Darling Basin are in better ecological condition and able to support recruiting populations, than regulated rivers with upstream impoundments where reduced flood frequency, intensity and duration may have suppressed recruitment due to successive years without strong flood pulses. Gehrke et al. (1995) concluded that river regulation may alter the relative abundance of native fishes and introduced fishes by desynchronising environmental and reproductive cycles.

Flood-induced changes in spawning and recruitment on floodplains is partially understood for several species of fish (King et al., 2003a). Throughout the MDB it is generally recognised that some species (i.e. Murray cod, freshwater catfish) spawn completely independently of the prevailing hydrograph and that others (i.e. golden perch) may spawn in response to flooding. Low-flow recruitment has been hypothesized as an important life history strategy for many Murray-Darling fishes (Humphries et al., 1999), and is likely to be a critical strategy as many of these fish are short-lived (e.g. < 3 yrs) and need to spawn and recruit in long droughts (Mallen-Cooper & Stuart, 2006). Species that recruit under low flow conditions (i.e. are not flood-dependent) may be able to do so as their larvae are not dependent on flood-responsive food resources (Puckridge & Walker, 1990). However, in all species, it is considered that flooding may enhance survival of larval and young of year fish by providing increased habitat, food resources and dispersal of fish between otherwise isolated habitats and populations (Balcombe et al., 2007; King et al., 2009; King et al., 2010).

King et al. (King et al., 2003a) propose that in order for an EWA to provide for successful spawning and recruitment of fish, the hydrograph would need to (i) couple high flows and temperatures, (ii) be within a predictable time phase for that system (iii) have slow rates of rise and fall (iv) have a duration of several weeks (v) inundate a large proportion of floodplain. Periods of increased flow or flooding, linked with seasonal high water temperatures, drive pulses of fish production in dryland and other floodplain rivers (Balcombe & Arthington, 2009). Flooding outside of the normal spring– summer spawning period would be unlikely to trigger any spawning response from fish, but would provide water into wetlands for maintenance of fish habitat along with other potential benefits to the river ecosystem (King et al., 2010). Mallen-Cooper et al. (2008) conclude that it is more beneficial for native fish to deliver more flow infrequently than less flow frequently.

A major characteristic of habitat that determines the fish community is water velocity, which can be grouped into fast-flowing (or high velocity), slow-flowing, main river channel and backwaters (Mallen-Cooper et al., 2008). It has been demonstrated that Murray cod prefer fast flowing habitats (Koehn, 2006; Zampatti et al., 2006a; Zampatti et al., 2006b). The adjacent relatively slow flowing edge habitats are considered to be important spawning and nursery areas for a number of Murray-Darling Basin fish species (King 2004a as cited by (Mallen-Cooper et al., 2008)). The direct contribution of edge habitats in enhancing

recruitment is unknown, but high diversity of water velocity is a significant habitat feature that needs to be actively managed during managed floods (Mallen-Cooper et al., 2008). During large, unregulated floods there is a significant increase in velocity above that occurring during base flows. In direct contrast, compared to both base-flow and unmanaged floods, velocity will be substantially reduced when using large infrastructure to generate floods. Temporary reductions in velocity associated with managed flooding interfere with the availability of these high flow habitats and could have cumulative impacts on regional fish populations. Furthermore, the water impounded by large constructed infrastructure, particularly if operated without maximum possible flow through, will have low velocities and is likely to act as a larval sink, preventing dispersal into the river system (Mallen-Cooper et al., 2008). In order to avoid minimise the risk of stranding fish in connected wetlands, Mallen-Cooper et al. (2008) recommend a drawdown rate of 20-50 mm day^{-1}.

Golden perch and Silver perch

Golden perch (*Macquaria ambigua ambigua*), are flow-cued spawners with generally variable recruitment in floodplain habitats (Humphries *et al*., 1999; Mallen-Cooper & Stuart, 2003). Relatively low numbers of golden perch were captured within the Pike system during the baseline survey (Beyer et al., 2010). However, there was a diverse size range of individuals (280–600mm total length (TL)). Silver perch (*Bidyanus bidyanus*), a protected species under the South Australian *Fisheries Management Act 2007*, were in low numbers. This demonstrates (i) the importance of protecting, restoring and maintaining habitat for fish in the Pike system (Beyer et al., 2010).

The anticipated benefit of the proposed actions are for improved populations of golden perch and silver perch, which are native species that:

i. have declined in regional abundance and are considered at risk, and
ii. spawn in response to changes in flow over a landscape scale

Model 1:

Source of potential benefit:
Spawning due to changes in mesoscale flow regime

Impact of potential benefit:

- Increase in larval population

Mean values for scores and benefit ratings are presented in Table B16.

Frequency of impact:
For improved base flow all components are scored as **daily**

Likelihood and Consequence:
The mean likelihood score was **none**. The mean consequence scores was **major**

Benefit rating:
The mean benefit rating was **moderate.**

Certainty:
The mean certainty score was **very certain** for likelihood and **very certain** for consequence.

Model 2:

Source of potential benefit:
Increased food and habitat for larvae and young-of-year (YOY)

Impact of potential benefit:

- Increased survival of larvae and YOY

Mean values for scores and benefit ratings are presented in Table B16.

Frequency of impact:
For improved base flow all components are scored as **daily**

Likelihood and Consequence:
The mean likelihood score was **none**. The mean consequence score was **major**.

Benefit rating:
The mean benefit rating was **moderate.**

Certainty:
The mean certainty score was **very certain** for likelihood and **very certain** for consequence.

Model 3:

Source of potential benefit:
Increased flows and structural habitat, improves mesoscale mosaic of hydrodynamics. Combined with improved connectivity, provides increased food, habitat and access for sub-adults and adults

Impact of potential benefit:

- Local population increases through immigration into anabranch habitats (regional population remains unchanged by improvements in Pike River)

Mean values for scores and benefit ratings are presented in Table B16.

Frequency of impact:

For improved base flow all components are scored as **daily**

Likelihood and Consequence:
The mean likelihood score was **likely**. The mean consequence score was **minor**.

Benefit rating:
The mean benefit rating was **very major.**

Certainty:
The mean certainty score was **moderately certain** for likelihood and **very certain** for consequence.

B17: Golden perch and silver perch associated with managed inundations

Background:

The anticipated benefit of the proposed actions are for improved populations of golden perch and silver perch, which are native species that:

iii. have declined in regional abundance and are considered at risk, and
iv. spawn in response to changes in flow over a landscape scale

Model 1:

Source of potential benefit:
Spawning due to changes in mesoscale flow regime

Impact of potential benefit:

- Increase in larval population

Mean values for scores and benefit ratings are presented in Table B17.

Frequency of impact:
For managed inundations all components are scored as **2-4 years**

Likelihood and Consequence:
The mean likelihood scores was **none**. The mean consequence scores was **major**

Benefit rating:
The mean benefit ratings was **no change.**

Certainty:
The mean certainty score was **very certain** for likelihood and **very certain** for consequence.

Model 2:

Source of potential benefit:
Increased food and habitat for larvae and young-of-year (YOY)

Impact of potential benefit:

- Increased survival of larvae and YOY

Mean values for scores and benefit ratings are presented in Table B17.

Frequency of impact:
For managed inundations all components are scored as **2-4 years**

Likelihood and Consequence:
The mean likelihood score was **none**. The mean consequence score was **major**

Benefit rating:
The mean benefit ratings was **no change.**

Certainty:
The mean certainty score for each model was **very certain** for likelihood and **very certain** for consequence.

Model 3:

Source of potential benefit:
Increased flows and structural habitat, improves mesoscale mosaic of hydrodynamics. Combined with improved connectivity, provides increased food, habitat and access for sub-adults and adults

Impact of potential benefit:

- Local population increases through immigration into anabranch habitats (regional population remains unchanged by improvements in Pike River)

Mean values for scores and benefit ratings are presented in Table B17.

Frequency of impact:
For managed inundations all components are scored as **2-4 years**

Likelihood and Consequence:
The mean likelihood score was **likely**. The mean consequence score was **minor**.

Benefit rating:
The mean benefit rating was **minor.**

Certainty:
The mean certainty score was **moderately certain** for likelihood and **very certain** for consequence.

B18: Murray cod during improved base-flow conditions

Background:

Murray cod is Australia's and one of the world's largest wholly freshwater fish species (Rowland 1989). It is an iconic species, with significant economic, cultural, recreational and environmental value (Rowland, 2005). Prior to European settlement, Murray cod was a major component of the diet of Aboriginal people, and also provided a food source to early European colonists (Humphries, 2007). Murray cod were an important component for a commercial fishery in New South Wales, Victoria and South Australia at various stages between the 1860s and 2003, but decades of declining catch rates led to the closure of the last state fishery (South Australia) in 2004 (Rowland, 2005; PIRSA, 2009). Murray cod is listed as 'Critically endangered' under the International Union for the Conservation of Nature (IUCN, 2010) *2010 Red List of Threatened Species* (IUCN 2010) and is listed nationally as 'Vulnerable' under the Australian *Environment Protection and Biodiversity Conservation Act 1999*.

The anticipated benefit of the proposed actions is for improved populations of Murray cod, which is a native species that:

i. has declined in regional abundance and is considered at risk,
ii. spawns in response to increasing water temperature, independently of flow, and
iii. recruits over a mesoscale or landscape scale, in channel habitats with sufficient flow, habitat and hydrodynamic diversity.

Model 1:

Source of potential benefit:

Improved mesoscale mosaic of hydrodynamics leads to increase in resident adults and increased spawning of adults

Impact of potential benefit:

- Increase in larval population in Pike habitats

Mean values for scores and benefit ratings are presented in Table B18.

Frequency of impact:
For improved base flow all components are scored as **daily**

Likelihood and Consequence:
The mean likelihood score was **none**. The mean consequence score was **major**

Benefit rating:
The mean benefit rating was **moderate.**

Certainty:
The mean certainty score was **moderately certain** for likelihood and **moderately certain** for consequence.

Model 2:

Source of potential benefit:
Improved downstream passage at inlets increases survival of larvae from the River Murray

Impact of potential benefit:

- Increase in larval population in Pike habitats

Mean values for scores and benefit ratings are presented in Table B18.

Frequency of impact:
For improved base flow all components are scored as **daily**

Likelihood and Consequence:
The mean likelihood score was **unlikely**. The mean consequence score was **major**

Benefit rating:
The mean benefit rating was **very major.**

Certainty:
The mean certainty score for each model was **moderately certain** for likelihood and **moderately certain** for consequence.

Model 3:

Source of potential benefit:
Improved mesoscale mosaic of hydrodynamics leads to increase in larval and YOY habitats.

Impact of potential benefit:

- Increased survival of larvae and YOY

Mean values for scores and benefit ratings are presented in Table B18.

Frequency of impact:
For improved base flow all components are scored as **daily**

Likelihood and Consequence:
The mean likelihood score was **unlikely**. The mean consequence score was **major**

Benefit rating:
The mean benefit rating was **very major.**

Certainty:
The mean certainty score was **very uncertain** for likelihood and **moderately certain** for consequence.

Model 4:

Source of potential benefit:
Increased flows and structural habitat, improves mesoscale mosaic of hydrodynamics. Combined with improved connectivity, provides increased food, habitat and access for juveniles and sub-adults

Impact of potential benefit:

- Local population increases through immigration into anabranch habitats (note: regional population remains unchanged by improvements in Pike River)

Mean values for scores and benefit ratings are presented in Table B18.

Frequency of impact:
For improved base flow all components are scored as **daily**

Likelihood and Consequence:
The mean likelihood score was **possible**. The mean consequence score was **major**

Benefit rating:
The mean benefit rating was **very major.**

Certainty:
The mean certainty score for each model was **very uncertain** for likelihood and **moderately certain** for consequence.

Model 5:

Source of potential benefit:
Increased flows and structural habitat, improves mesoscale mosaic of hydrodynamics. Combined with improved connectivity, provides increased food, habitat and access for adults

Impact of potential benefit:

- Local population increases through immigration into anabranch habitats (note: regional population remains unchanged by improvements in Pike River)

Mean values for scores and benefit ratings are presented in Table B18.

Frequency of impact:
For improved base flow all components are scored as **daily**

Likelihood and Consequence:
The mean likelihood score was **none**. The mean consequence scores was **major**

Benefit rating:
The mean benefit rating was **moderate.**

Certainty:
The mean certainty score was **moderately certain** for likelihood and **moderately certain** for consequence.

B19: Murray cod associated with managed inundations

Background:

The anticipated benefit of the proposed actions is for improved populations of Murray cod, which is a native species that:

iv. has declined in regional abundance and is considered at risk,
v. spawns in response to increasing water temperature, independently of flow, and
vi. recruits over a mesoscale or landscape scale, in channel habitats with sufficient flow, habitat and hydrodynamic diversity.

Model 1:

Source of potential benefit:

Improved mesoscale mosaic of hydrodynamics leads to increase in resident adults and increased spawning of adults

Impact of potential benefit:

- Increase in larval population in Pike habitats

Mean values for scores and benefit ratings are presented in Table B19.

Frequency of impact:
For managed inundations all components are scored as **2-4 years**

Likelihood and Consequence:
The mean likelihood scores was **none**. The mean consequence scores was **major**

Benefit rating:
The mean benefit rating was **no change**

Certainty:
The mean certainty score for each model was **moderately certain** for likelihood and **moderately certain** for consequence.

Model 2:

Source of potential benefit:
Improved downstream passage at inlets increases survival of larvae from the River Murray

Impact of potential benefit:

- Increase in larval population in Pike habitats

Mean values for scores and benefit ratings are presented in Table B19.

Frequency of impact:
For managed inundations all components are scored as **2-4 years**

Likelihood and Consequence:
The mean likelihood scores was **unlikely**. The mean consequence score was **major**

Benefit rating:
The mean benefit rating was **minor.**

Certainty:
The mean certainty score for each model was **moderately certain** for likelihood and **moderately certain** for consequence.

Model 3:

Source of potential benefit:
Improved mesoscale mosaic of hydrodynamics leads to increase in larval and YOY habitats.

Impact of potential benefit:

- Increased survival of larvae and YOY

Mean values for scores and benefit ratings are presented in Table B19.

Frequency of impact:
For managed inundations all components are scored as **2-4 years**

Likelihood and Consequence:
The mean likelihood score was **very unlikely**. The mean consequence scores was **major**

Benefit rating:
The mean benefit ratings was **very minor.**

Certainty:
The mean certainty score for each model was **uncertain** for likelihood and **moderately certain** for consequence.

Model 4:

Source of potential benefit:
Increased flows and structural habitat, improves mesoscale mosaic of hydrodynamics. Combined with improved connectivity, provides increased food, habitat and access for juveniles and sub-adults.

Impact of potential benefit:

- Local population increases through immigration into anabranch habitats (note: regional population remains unchanged by improvements in Pike River)

Mean values for scores and benefit ratings are presented in Table B19.

Frequency of impact:
For managed inundations all components are scored as **2-4 years**

Likelihood and Consequence:
The mean likelihood score was **very unlikely**. The mean consequence score was **major**

Benefit rating:
The mean benefit rating was **very minor.**

Certainty:
The mean certainty score was **uncertain** for likelihood and **moderately certain** for consequence.

Model 5:

Source of potential benefit:
Increased flows and structural habitat, improves mesoscale mosaic of hydrodynamics. Combined with improved connectivity, provides increased food, habitat and access for adults

Impact of potential benefit:

- Local population increases through immigration into anabranch habitats (note: regional population remains unchanged by improvements in Pike River)

Mean values for scores and benefit ratings are presented in Table B19.

Frequency of impact:
For managed inundations all components are scored as **2-4 years**

Likelihood and Consequence:
The mean likelihood score was **none**. The mean consequence score was **major**

Benefit rating:
The mean benefit rating was **no change**

Certainty:
The mean certainty score was **uncertain** for likelihood and **moderately certain** for consequence.

B20: Freshwater catfish during improved base-flow conditions

Background:

Catfish (*Tandanus tandanus*) were once widespread in the Murray–Darling Basin, but their distribution and abundance have severely declined, with populations now fragmented throughout the MDB. The species is listed as a threatened species in Victoria (Vic), New South Wales (NSW) and South Australia, where it is protected. Riverine populations of freshwater catfish are now considered rare (Clunie and Koehn 2000 as cited by Mallen-Cooper et al., 2008). Catfish are believed to prefer slow-flowing habitats and build nests of gravel or sticks in which eggs are guarded by the male fish. Spawning is independent of flooding and occurs in rising water temperatures in spring and summer.

Catfish are regarded as a relatively immobile species; tagging studies generally report limited movement (Reynolds, 1983) and only small numbers are collected in fishways (Mallen-Cooper, 1999; Mallen-Cooper & Brand, 2007) indicating that only a very small proportion of the population disperse (as cited by Mallen-Cooper et al., 2008). This aspect of their life history makes their presently fragmented populations particularly sensitive to local disturbance. Recolonisation is very slow and is exacerbated by barriers to movement (Mallen-Cooper et al., 2008). The population of freshwater catfish that has been detected in Pike River (Beyer et al., 2010) is likely to have a high conservation value; if the population is reproductively successful it may contribute to the broader population.

The anticipated benefit of the proposed actions is improved populations of freshwater catfish, which is a native species that:

i. has declined in regional abundance and is considered at risk,
ii. spawns in response to increasing water temperature, independently of flow, and
iii. recruits over a mesoscale, in channel and large off-channel habitats which have sufficient habitat and low densities of carp.

Background:

Model 1:

Source of potential benefit:

Improved mesoscale mosaic of hydrodynamics leads to increase in resident adults and increased spawning of adults

Impact of potential benefit:

- Increase in larval population in Pike habitats

Mean values for scores and benefit ratings are presented in Table B20.

Frequency of impact:
For improved base flow all components are scored as **daily**

Likelihood and Consequence:
The mean likelihood scores was **unlikely**. The mean consequence scores was **major**

Benefit rating:
The mean benefit ratings was **very major.**

Certainty:
The mean certainty score for each model was **moderately certain** for likelihood and **moderately certain** for consequence.

Model 2:

Source of potential benefit:
Improved downstream passage at inlets increases survival of larvae from the River Murray

Impact of potential benefit:

- Increase in larval population in Pike habitats

Mean values for scores and benefit ratings are presented in Table B20.

Frequency of impact:
For improved base flow all components are scored as **daily**

Likelihood and Consequence:
The mean likelihood score was **very unlikely**. The mean consequence score was **major**

Benefit rating:
The mean benefit ratings was **major.**

Certainty:
The mean certainty score was **very uncertain** for likelihood and **moderately certain** for consequence.

Model 3:

Source of potential benefit:
Improved mesoscale mosaic of hydrodynamics leads to increase in larval and YOY habitats.

Impact of potential benefit:

- Increased survival of larvae and YOY; local population increases and with emigration, the regional population increases

Mean values for scores and benefit ratings are presented in Table B20.

Frequency of impact:
For improved base flow all components are scored as **daily**

Likelihood and Consequence:
The mean likelihood score was **unlikely**. The mean consequence score was **major**

Benefit rating:
The mean benefit rating was **very major.**

Certainty:
The mean certainty score was **very uncertain** for likelihood and **moderately certain** for consequence.

Model 4:

Source of potential benefit:
Increased flows and structural habitat, improves mesoscale mosaic of hydrodynamics. Combined with improved connectivity, provides increased food, habitat and access for juveniles, sub-adults and adults

Impact of potential benefit:

- Local population increases through immigration into anabranch habitats (note: regional population remains unchanged by improvements in Pike River)

Mean values for scores and benefit ratings are presented in Table B20.

Frequency of impact:
For improved base flow all components are scored as **daily**

Likelihood and Consequence:
The mean likelihood score was **possible**. The mean consequence score was **major**

Benefit rating:
The mean benefit rating was **very major.**

Certainty:
The mean certainty score for each model was **very uncertain** for likelihood and **moderately certain** for consequence.

B21: Freshwater catfish associated with managed inundations

Background:

The anticipated benefit of the proposed actions is improved populations of freshwater catfish, which is a native species that:

iv. has declined in regional abundance and is considered at risk,
v. spawns in response to increasing water temperature, independently of flow, and
vi. recruits over a mesoscale, in channel and large off-channel habitats which have sufficient habitat and low densities of carp.

Background:

Model 1:

Source of potential benefit:

Improved mesoscale mosaic of hydrodynamics leads to increase in resident adults and increased spawning of adults

Impact of potential benefit:

- Increase in larval population in Pike habitats

Mean values for scores and benefit ratings are presented in Table B21.

Frequency of impact:
For managed inundations all components are scored as **2-4 years**

Likelihood and Consequence:
The mean likelihood score was **unlikely**. The mean consequence score was **major**

Benefit rating:
The mean benefit rating was **minor**

Certainty:
The mean certainty score was **moderately certain** for likelihood and **moderately certain** for consequence.

Model 2:

Source of potential benefit:
Improved downstream passage at inlets increases survival of larvae from the River Murray

Impact of potential benefit:

- Increase in larval population in Pike habitats

Mean values for scores and benefit ratings are presented in Table B21.

Frequency of impact:
For managed inundations all components are scored as **2-4 years**

Likelihood and Consequence:
The mean likelihood score was **very unlikely**. The mean consequence score was **major**

Benefit rating:
The mean benefit rating was **very minor.**

Certainty:
The mean certainty score for each model was **very uncertain** for likelihood and **moderately certain** for consequence.

Model 3:

Source of potential benefit:
Improved mesoscale mosaic of hydrodynamics leads to increase in larval and YOY habitats.

Impact of potential benefit:

- Increased survival of larvae and YOY; local population increases and with emigration, the regional population increases

Mean values for scores and benefit ratings are presented in Table B21.

Frequency of impact:
For managed inundations all components are scored as **2-4 years**

Likelihood and Consequence:
The mean likelihood score was **unlikely**. The mean consequence score was **major**

Benefit rating:
The mean benefit rating was **minor.**

Certainty:
The mean certainty score was **very uncertain** for likelihood and **moderately certain** for consequence.

Model 4:

Source of potential benefit:
Increased flows and structural habitat, improves mesoscale mosaic of hydrodynamics. Combined with improved connectivity, provides increased food, habitat and access for juveniles, sub-adults and adults

Impact of potential benefit:

- Local population increases through immigration into anabranch habitats (note: regional population remains unchanged by improvements in Pike River)

Mean values for scores and benefit ratings are presented in Table B21.

Frequency of impact:
For managed inundations all components are scored as **2-4 years**

Likelihood and Consequence:
The mean likelihood score was **very unlikely**. The mean consequence score was **major**

Benefit rating:
The mean benefit rating was **very minor.**

Certainty:
The mean certainty score was **uncertain** for likelihood and **moderately certain** for consequence.

B22: Wetland generalist fish species during improved base-flow conditions

Background

The anticipated benefit of the proposed actions is improved populations of wetland generalist fish species e.g. carp gudgeons, Australian smelt, flyspecked hardyhead, bony herring. These species are common throughout the lower River Murray. It must be noted that populations of wetland specialist fish species (e.g. purplespotted gudgeon, pygmy perch, Murray hardyhead, flathead galaxias) that are (i) uncommon throughout the lower River Murray; and (ii) are threatened species, are very unlikely to benefit from the proposed activities.

Model 1:

Source of potential benefit:
Improved mesoscale mosaic of hydrodynamics (including wetland diversity) leads to increase in resident adults

Impact of potential benefit:

- Increase in adult population in Pike habitats

Mean values for scores and benefit ratings are presented in Table B22.

Frequency of impact:
For improved base flow all components are scored as **daily**.

Likelihood and Consequence:
The mean likelihood score was **possible**. The mean consequence score was **minor.**

Benefit rating:
The mean benefit rating was **major.**

Certainty:
The mean certainty score was **moderately certain** for likelihood and **very certain** for consequence.

Model 2:

Source of potential benefit:
Improved mesoscale mosaic of hydrodynamics (including wetland diversity) leads to increase in spawning habitat for adults

Impact of potential benefit:

- Increase in larval population in Pike habitats

Mean values for scores and benefit ratings are presented in Table B22.

Frequency of impact:
For improved base flow all components are scored as **daily**.

Likelihood and Consequence:
The mean likelihood score was **possible**. The mean consequence score was **minor.**

Benefit rating:
The mean benefit rating was **major.**

Certainty:
The mean certainty score for each model was **moderately certain** for likelihood and **very certain** for consequence.

Model 3:

Source of potential benefit:
Improved mesoscale mosaic of hydrodynamics (including wetland diversity) leads to increase in larval and YOY habitats.

Impact of potential benefit:

- Increased survival of larvae and YOY; local population increases and, with emigration, the regional population increases

Mean values for scores and benefit ratings are presented in Table B22.

Frequency of impact:
For improved base flow all components are scored as **daily**.

Likelihood and Consequence:
The mean likelihood score was **possible**. The mean consequence score was **minor.**

Benefit rating:
The mean benefit rating was **major.**

Certainty:
The mean certainty score was **moderately certain** for likelihood and **moderately certain** for consequence.

B23: Wetland generalist fish species associated with managed inundations

Background

The anticipated benefit of the proposed actions is improved populations of wetland generalist fish species e.g. carp gudgeons, Australian smelt, flyspecked hardyhead, bony herring. These species are common throughout the lower River Murray. It must be noted that populations of wetland specialist fish species (e.g. purplespotted gudgeon, pygmy perch, Murray hardyhead, flathead galaxias) that are (i) uncommon throughout the lower River Murray; and (ii) are threatened species, are very unlikely to benefit from the proposed activities.

Model 1:

Source of potential benefit:
Improved mesoscale mosaic of hydrodynamics (including wetland diversity) leads to increase in resident adults

Impact of potential benefit:

- Increase in adult population in Pike habitats

Mean values for scores and benefit ratings are presented in Table B23.

Frequency of impact:
For managed inundations all components are scored as **2-4 years**

Likelihood and Consequence:
The mean likelihood score was **likely**. The mean consequence score was **minor.**

Benefit rating:
The mean benefit rating was **minor.**

Certainty:
The mean certainty score was **moderately certain** for likelihood and **very certain** for consequence.

Model 2:

Source of potential benefit:
Improved mesoscale mosaic of hydrodynamics (including wetland diversity) leads to increase in spawning habitat for adults

Impact of potential benefit:

- Increase in larval population in Pike habitats

Mean values for scores and benefit ratings are presented in Table B23.

Frequency of impact:
For managed inundations all components are scored as **2-4 years**

Likelihood and Consequence:
The mean likelihood score was **very likely**. The mean consequence score was **minor.**

Benefit rating:
The mean benefit rating was **moderate.**

Certainty:
The mean certainty score was **moderately certain** for likelihood and **very certain** for consequence.

Model 3:

Source of potential benefit:
Improved mesoscale mosaic of hydrodynamics (including wetland diversity) leads to increase in larval and YOY habitats.

Impact of potential benefit:

- Increased survival of larvae and YOY; local population increases and, with emigration, the regional population increases

Mean values for scores and benefit ratings are presented in Table B23.

Frequency of impact:
For managed inundations all components are scored as **2-4 years**

Likelihood and Consequence:
The mean likelihood score was **likely**. The mean consequence score was **minor.**

Benefit rating:
The mean benefit rating was **minor.**

Certainty:
The mean certainty score was **moderately certain** for likelihood and **moderately certain** for consequence.

6. Benefit matrix tables

Table B1. Connectivity during improved base flows

Benefit type	Source of potential benefit	Impact of potential benefit	Likelihood	Frequency	Consequence	Benefit Score	Certainty
Connectivity	Improved structures at existing bank locations	Improved longitudinal connectivity for active movement for fish and macrocrustacea (shrimps, prawns, yabbies, crayfish)	4.8	5.3	3.8	4.5	3.3
		Improved lateral connectivity for active movement (fish and macrocrustacea)	5.0	4.0	3.8	4.3	2.8
		Improved passive connectivity - exchange of nutrients, carbon, phytoplankton, plant propagules, microinvertebrates and early life stages (egg, larvae) of fish	5.5	4.0	4.0	5.3	3.3

Table B2. Hydrology during improved base flows

Benefit type	Source of potential benefit	Impact of potential benefit	Likelihood	Frequency	Consequence	Benefit Score	Certainty
Hydrology	Improved inflow at Margaret Dowling and Deep Creek	Improved lateral connectivity	4.6	5.3	4.0	5.8	3.6
		Improved water exchange	4.8	6.0	4.0	6.0	3.5
		Improved ability to reinstate localised scour processes	4.0	5.3	3.0	4.7	3.0
		Increased outflow improves attractant flow for fish during base flows	5.0	5.3	4.3	5.5	2.8
	Improved inflow at banks B and C during relatively high flows	Improved lateral connectivity	5.4	3.3	4.0	4.8	2.6
		Improved water exchange	5.5	4.0	3.8	5.0	2.3
		Improved ability to reinstate scour processes	4.3	2.5	3.3	3.3	2.7
		Increased outflow improves attractant flow for fish during higher flow	4.8	4.5	3.8	4.0	2.8
	Environmental regulator at Col Col bank and Tanyaca Creek	Ability to inundate floodplain at near natural return intervals	5.0	2.0	4.7	4.7	3.0
	Increased diversity of flow mosaic (no-, slow, moderate, fast flow)	Increased diversity of hydraulic habitat types for biotic and abiotic processes at the local scale	5.0	3.3	4.0	4.3	3.0
		Increased diversity of hydraulic habitat types for biotic and abiotic processes at the regional scale	4.3	3.3	3.3	3.3	3.0
	Increased diversity of wetland inundation regime (permanent, ephemeral, shallow, deep)	Increased diversity of habitat types for biotic and abiotic processes at the local scale	5.3	2.7	4.3	5.0	3.0
		Increased diversity of habitat types for biotic and abiotic processes at the regional scale	4.3	2.7	3.3	3.3	2.7
		Ability to manage the inundation regime of oxbow lakes	5.0	3.0	4.0	4.5	2.5

Table B3. Freshening of saline groundwater during both improved base flows and managed inundations

Benefit type	Source of potential benefit	Impact of potential benefit	Likelihood	Frequency	Consequence	Benefit Score	Certainty
Freshening of saline groundwater and or generation of freshwater lenses	Lateral and vertical infiltration of relatively low salinity surface water	Improvement in soil moisture availability in unsaturated zone	5.5	3.3	4.5	5.5	3.0

Table B4. Soil moisture availability associated with managed inundations

Benefit type	Source of potential benefit	Impact of potential benefit	Likelihood	Frequency	Consequence	Benefit Score	Certainty
Soil moisture availability	Increased flooding frequency increases soil moisture content	Stimulation of soil microbial activity and shifts in soil microbial community structure	5.3	3.0	4.3	5.3	2.7
		Improved conditions for vegetation growth	5.5	2.8	4.5	5.3	3.3
		Increased soil carbon	4.7	2.0	3.7	3.3	2.3
		Increased ground cover and condition of long-lived vegetation	5.5	2.5	4.3	4.8	3.3
		Improved soil structure	3.7	2.7	3.7	3.7	2.3
	Reduced soil salinity and/or sodicity increases soil moisture availability	Improved conditions for vegetation growth	5.3	2.5	4.0	4.3	3.0
		Increased soil carbon	4.7	2.0	3.3	2.7	2.3
		Increased ground cover and condition of long-lived vegetation	5.3	2.5	4.0	4.3	3.0
		Improved soil structure	4.7	2.3	4.0	3.7	2.3

Table B5.Condition of established floodplain eucalypts associated with managed inundations

Benefit type	Source of potential benefit	Impact of potential benefit	Likelihood	Frequency	Consequence	Benefit Score	Certainty
Improved condition of established floodplain eucalypts	Increased soil moisture availability driven by increased soil moisture, reduced soil salinity and soil sodicity	Improved habitat for dependent species	5.0	4.5	4.5	6.0	3.0
		Improved source of carbon and nutrients	5.5	2.5	4.5	4.5	3.0
		Increased food resources for invertebrates	5.0	5.0	4.5	6.0	2.5
		Improved soil carbon/nutrient status of soil	5.0	4.0	3.5	5.0	2.0
		Increased food resources and/or foraging habitat for higher trophic levels (e.g. insectivorous birds)	5.0	5.0	4.5	6.0	2.0
	Ability to inundate large proportion of black box community	Ability to manage large proportion of tree community that is difficult to achieve at other regionally relevant sites	5.5	2.0	6.0	6.0	3.5

Table B6. Recruitment of floodplain eucalypts associated with managed inundations

Benefit type	Source of potential benefit	Impact of potential benefit	Likelihood	Frequency	Consequence	Benefit Score	Certainty
Improved recruitment of floodplain eucalypts	Increased soil moisture availability driven by increased soil moisture, reduced soil salinity and soil sodicity	Increased diversity of age classes leading to long-term sustainable population	5.0	2.0	6.0	6.0	3.0
	Reduced grazing pressure on seedlings	Increased diversity of age classes leading to long-term sustainable population	5.5	4.0	5.5	6.0	3.5

Table B7 Improved abundance and distribution of understorey vegetation associated with managed inundations

Benefit type	Source of potential benefit	Impact of potential benefit	Likelihood	Frequency	Consequence	Benefit Score	Certainty
Improved abundance and distribution of flood dependent understory vegetation	Increased soil moisture availability driven by increased soil moisture, reduced soil salinity and soil sodicity	Improved habitat for dependent species	5.0	2.7	4.7	5.0	3.0
		Improved pathways for interception and processing and transfer of carbon and nutrients	5.0	2.3	4.0	4.3	2.3
		Increased food resources for native grazing animals	5.7	2.7	4.7	5.3	3.3
		Increased food/habitat resources for invertebrates	5.0	3.0	4.5	5.0	2.0
		Increased food resources and/or foraging habitat for higher trophic levels (e.g. insectivorous birds)	5.0	3.0	4.5	5.0	2.5
		Improved soil carbon/nutrient status of soil	5.0	2.3	3.7	4.0	2.7

Table B8 Improved abundance and distribution of aquatic plants associated with managed inundations

Benefit type	Source of potential benefit	Impact of potential benefit	Likelihood	Frequency	Consequence	Benefit Score	Certainty
Improved abundance and distribution of aquatic plants (submerged and emergent vegetation)	Increased aquatic habitat availability	Improved habitat for dependent species	4.7	2.7	3.3	3.3	3.0
		Improved pathways for interception and processing and transfer of carbon and nutrients	4.7	2.7	3.0	3.0	2.3
		Increased food/habitat resources for invertebrates	4.7	2.7	3.3	3.3	2.3
		Increased food resources for higher trophic levels (e.g. herbivorous birds, fish birds)	4.7	2.7	3.7	3.7	2.7

Table B9 Decrease in relative abundance of salt tolerant species associated with managed inundations

Benefit type	Source of potential benefit	Impact of potential benefit	Likelihood	Frequency	Consequence	Benefit Score	Certainty
Decrease in relative abundance of salt tolerant species	Increased soil moisture availability driven by increased soil moisture, reduced soil salinity and soil sodicity	Improved abundance and distribution of flood dependent/drought tolerant understory vegetation	5.3	2.5	4.5	4.8	3.0

Table B10 Recruitment ecology of waterbirds associated with managed inundations

Benefit type	Source of potential benefit	Impact of potential benefit	Likelihood	Frequency	Consequence	Benefit Score	Certainty
Recruitment ecology of waterbirds	Changes to hydrology leads to increased opportunities for small-scale breeding events for waterbirds	Appropriate landscape mosaic including increased nesting/breeding habitat is created	5.0	2.0	4.0	4.0	2.0
		Increased foraging habitat combined with improved food resources is provided	5.0	2.0	4.0	4.0	3.0
		Recruitment (fledging) is increased	4.0	2.0	4.0	3.0	2.0
		Improved carrying capacity for local population	5.0	2.0	4.0	4.0	2.0
		Increased recruitment from young-of-year to adults improves local population demographics	4.0	2.0	4.0	3.0	2.0
		Increased recruitment from young-of-year to adults improves regional population demographics	4.0	2.0	4.0	3.0	2.0

Table B11 Recruitment ecology of frogs associated with managed inundations

Benefit type	Source of potential benefit	Impact of potential benefit	Likelihood	Frequency	Consequence	Benefit Score	Certainty
Recruitment ecology of frogs	Changes to hydrology increases opportunities for breeding events	Appropriate landscape mosaic including increased breeding habitat is created	5.0	2.0	4.0	4.0	2.0
		Increased foraging habitat combined with improved food resources is provided	5.0	2.0	4.0	4.0	3.0
		Recruitment to young-of-year is increased	5.0	2.0	4.0	4.0	3.0
		Improved carrying capacity for local population	3.0	1.0	4.5	1.0	2.5
		Increased recruitment from young-of-year to adults improves local population demographics	3.0	1.0	5.0	2.0	2.5
		Increased recruitment from young-of-year to adults improves regional population demographics	2.5	1.0	4.5	1.0	1.5

Table B12 Productivity and energy transfer associated with managed inundations

Benefit type	Source of potential benefit	Impact of potential benefit	Likelihood	Frequency	Consequence	Benefit Score	Certainty
Productivity and energy transfer	Increased frequency of allochthonous inputs from floodplain	Improved mass of carbon and nutrients available for trophic upsurge	5.3	2.3	4.7	5.0	3.0
		Improved abundance of food resources for multiple trophic levels	5.3	2.3	4.7	5.0	2.7
		Improved nutritional value of food resources for multiple trophic levels	5.0	2.5	5.0	5.5	1.5
	Productivity benefits from upstream flooding transferred into anabranch	Increased abundance of abiotic resources (e.g. nutrients, carbon) to drive productivity	4.0	2.5	4.0	5.0	1.7
		Increased abundance of biotic resources (e.g. invertebrates, plant propagules, larval fish)	4.0	2.5	4.0	5.0	2.0

Table B13 Carbon sequestration associated with managed inundations

Benefit type	Source of potential benefit	Impact of potential benefit	Likelihood	Frequency	Consequence	Benefit Score	Certainty
Carbon sequestration	Improved soil condition	Increased carbon uptake and storage	5.0	2.0	3.3	3.0	2.7
	Improved long-lived plant biomass	Increased carbon uptake and storage	5.0	1.7	3.7	3.3	3.0

Table B14 Experimental design

Benefit type	Source of potential benefit	Impact of potential benefit	Likelihood	Frequency	Consequence	Benefit Score	Certainty
Ability to test hypotheses with BACI design	Impact (upper Pike) and control site (lower Pike) are immediately adjacent	Unique ability to test hypotheses with robust design significantly improves ability to address knowledge gaps and improve confidence in establishing cause and effect relationships	4.5	2.3	4.3	3.8	3.0

Table B15 Reinstatement of resilience associated with managed inundations

Benefit type	Source of potential benefit	Impact of potential benefit	Likelihood	Frequency	Consequence	Benefit Score	Certainty
Resilience	Ability to inundate floodplain components independent of river conditions	Maintain floodplain in responsive condition	5.0	2.5	5.0	6.0	2.7
		Prime floodplain for coming, natural high flow events	5.0	2.5	5.0	6.0	2.7
		Capitalise on outcomes from preceding inundations to ensure recruitment	5.5	2.5	5.0	6.0	2.5

Table B16. Golden perch and silver perch during improved base flows (L) = likelihood (C) = consequence

Benefit type	Source of potential benefit	Impact of potential benefit	Likelihood	Frequency	Consequence	Benefit Score	Certainty
Improved populations of **golden perch** and **silver perch**, which are native species that: i) have declined in regional abundance and are considered at risk, and ii) spawn in response to changes in flow over a landscape scale	**Spawning** due to changes in mesoscale flow regime	Increase in larval population	1	6	5	4	4 (L) 4 (C)
	Increased food and habitat for **larvae and YOY**	Increased survival of larvae and YOY	1	6	5	4	4 (L) 4 (C)
	Increased flows and structural habitat, improves mesoscale mosaic of hydrodynamics. Combined with improved connectivity, provides increased food, habitat and access for **sub-adults and adults**	Local population increases through immigration into anabranch habitats (note: regional popn. unchanged by improvements in Pike)	5	6	3	6	3 (L) 4 (C)

Table B17. Golden perch and silver perch during managed inundations (L) = likelihood (C) = consequence

Benefit type	Source of potential benefit	Impact of potential benefit	Likelihood	Frequency	Consequence	Benefit Score	Certainty
Improved populations of **golden perch** and **silver perch**, which are native species that: i) have declined in regional abundance and are considered at risk, and ii) spawn in response to changes in flow over a landscape scale	**Spawning** due to changes in mesoscale flow regime	Increase in larval population	1	2	5	1	4 (L) 4 (C)
	Increased food and habitat for **larvae and YOY**	Increased survival of larvae and YOY	1	2	5	1	4 (L) 4 (C)
	Increased flows and structural habitat, improves mesoscale mosaic of hydrodynamics. Combined with improved connectivity, provides increased food, habitat and access for **sub-adults and adults**	Local population increases through immigration into anabranch habitats (note: regional popn. unchanged by improvements in Pike)	5	2	3	3	3 (L) 3 (C)

Table B18. Murray cod during improved base flow conditions (L) = likelihood (C) = consequence

Benefit type	Source of potential benefit	Impact of potential benefit	Likelihood	Frequency	Consequence	Benefit Score	Certainty
Improved populations of **Murray cod**, which is a native species that: i) has declined in regional abundance and is considered at risk, ii) spawns in response to increasing water temperature, independently of flow, and iii) recruits over a mesoscale or landscape scale, in channel habitats with sufficient flow, habitat and hydrodynamic diversity.	Improved mesoscale mosaic of hydrodynamics leads to increase in resident adults and increased **spawning of adults**	Increase in larval population in Pike habitats	1	6	5	4	3 (L) 3 (C)
	Improved **downstream passage** at inlets increases **survival of larvae** from the River Murray	Increase in larval population in Pike habitats	3	6	5	6	3 (L) 3 (C)
	Improved mesoscale mosaic of hydrodynamics leads to **increase in larval and YOY habitats.**	Increased survival of larvae and YOY	3	6	5	6	1 (L) 3 (C)
	Increased flows and structural habitat, improves mesoscale mosaic of hydrodynamics. Combined with improved connectivity, provides increased food, habitat and access for: (i) **juveniles and sub-adults**	Local population increases through immigration into anabranch habitats (note: regional popn. unchanged by improvements in Pike)	4	6	5	6	1 (L) 3 (C)
	(ii) **adults**	Local population increases through immigration into anabranch habitats (note: regional popn. unchanged by improvements in Pike)	1	6	5	4	3 (L) 3 (C)

Table B19. Murray cod during managed inundations (L) = likelihood (C) = consequence

Benefit type	Source of potential benefit	Impact of potential benefit	Likelihood	Frequency	Consequence	Benefit Score	Certainty
Improved populations of **Murray cod**, which is a native species that: i) has declined in regional abundance and is considered at risk, ii) spawns in response to increasing water temperature, independently of flow, and iii) recruits over a mesoscale or landscape scale, in channel habitats with sufficient flow, habitat and hydrodynamic diversity.	Improved mesoscale mosaic of hydrodynamics leads to increase in resident adults and increased **spawning of adults**	Increase in larval population in Pike habitats	1	2	5	1	3 (L) 3 (C)
	Improved **downstream passage** at inlets increases **survival of larvae** from the River Murray	Increase in larval population in Pike habitats	3	2	5	3	3 (L) 3 (C)
	Improved mesoscale mosaic of hydrodynamics leads to **increase in larval and YOY habitats.**	Increased survival of larvae and YOY	2	2	5	2	2 (L) 3 (C)
	Increased flows and structural habitat, improves mesoscale mosaic of hydrodynamics. Combined with improved connectivity, provides increased food, habitat and access for: (i) **juveniles and sub-adults**	Local population increases through immigration into anabranch habitats (note: regional popn. unchanged by improvements in Pike)	2	2	5	2	2 (L) 3 (C)
	(ii) **adults**	Local population increases through immigration into anabranch habitats (note: regional popn. unchanged by improvements in Pike)	1	2	5	1	2 (L) 3 (C)

Table B20. Freshwater catfish during improved base flows (L) = likelihood (C) = consequence

Benefit type	Source of potential benefit	Impact of potential benefit	Likelihood	Frequency	Consequence	Benefit Score	Certainty
Improved populations of **freshwater catfish**, which is a native species that: i) has declined in regional abundance and is considered at risk, ii) spawns in response to increasing water temperature, independently of flow, and iii) recruits over a mesoscale, in channel and large off-channel habitats which have sufficient habitat and low densities of carp.	Improved mesoscale mosaic of hydrodynamics leads to increase in resident adults and increased **spawning of adults**	Increase in larval population in Pike habitats	3	6	5	6	3 (L) 3 (C)
	Improved **downstream passage** at inlets increases **survival of larvae** from the River Murray	Increase in larval population in Pike habitats	2	6	5	5	1 (L) 3 (C)
	Improved mesoscale mosaic of hydrodynamics leads to **increase in larval and YOY habitats.**	Increased survival of larvae and YOY; local population increases and with emigration, the regional population increases	3	6	5	6	1 (L) 3 (C)
	Increased flows and structural habitat, improves mesoscale mosaic of hydrodynamics. Combined with improved connectivity, provides increased food, habitat and access for **juveniles, sub-adults and adults**	Local population increases through immigration into anabranch habitats (note: regional popn. unchanged by improvements in Pike)	4	6	5	6	1 (L) 3 (C)

Table B21. Freshwater catfish during managed inundations (L) = likelihood (C) = consequence

Benefit type	Source of potential benefit	Impact of potential benefit	Likelihood	Frequency	Consequence	Benefit Score	Certainty
Improved populations of **freshwater catfish**, which is a native species that: i) has declined in regional abundance and is considered at risk, ii) spawns in response to increasing water temperature, independently of flow, and iii) recruits over a mesoscale, in channel and large off-channel habitats which have sufficient habitat and low densities of carp.	Improved mesoscale mosaic of hydrodynamics leads to increase in resident adults and increased **spawning of adults**	Increase in larval population in Pike habitats	3	2	5	3	3 (L) 3 (C)
	Improved **downstream passage** at inlets increases **survival of larvae** from the River Murray	Increase in larval population in Pike habitats	2	2	5	2	1 (L) 3 (C)
	Improved mesoscale mosaic of hydrodynamics leads to **increase in larval and YOY habitats.**	Increased survival of larvae and YOY; local population increases and with emigration, the regional population increases	3	2	5	3	1 (L) 3 (C)
	Increased flows and structural habitat, improves mesoscale mosaic of hydrodynamics. Combined with improved connectivity, provides increased food, habitat and access for **juveniles, sub-adults and adults**	Local population increases through immigration into anabranch habitats (note: regional popn. unchanged by improvements in Pike)	2	2	5	2	2 (L) 3 (C)

Table B22. Wetland generalist fish species during improved base flows (L) = likelihood (C) = consequence

Benefit type	Source of potential benefit	Impact of potential benefit	Likelihood	Frequency	Consequence	Benefit Score	Certainty
Improved populations of **wetland generalist fish species** e.g. gudgeons, smelt, hardyhead, bonies). (Note: these species are common throughout the lower River Murray	Improved mesoscale mosaic of hydrodynamics (including wetland diversity) leads to increase in resident **adults**	Increase in adult population in Pike habitats	4	6	3	5	3 (L) 4 (C)
	Improved mesoscale mosaic of hydrodynamics (including wetland diversity) leads to increase in **spawning habitat for adults**	Increase in larval population in Pike habitats	4	6	3	5	3 (L) 4 (C)
	Improved mesoscale mosaic of hydrodynamics leads to **increase in larval and YOY habitats.**	Increased survival of larvae and YOY; local population increases and, with emigration, the regional population increases	4	6	3	5	3 (L) 3 (C)

Table B23. Wetland generalist fish species during managed inundations (L) = likelihood (C) = consequence

Benefit type	Source of potential benefit	Impact of potential benefit	Likelihood	Frequency	Consequence	Benefit Score	Certainty
Improved populations of **wetland generalist fish species** e.g. gudgeons, smelt, hardyhead, bonies). (Note: these species are common throughout the lower River Murray	Improved mesoscale mosaic of hydrodynamics (including wetland diversity) leads to increase in resident **adults**	Increase in adult population in Pike habitats	5	2	3	3	3 (L) 4 (C)
	Improved mesoscale mosaic of hydrodynamics (including wetland diversity) leads to increase in **spawning habitat for adults**	Increase in larval population in Pike habitats	6	2	3	4	3 (L) 4 (C)
	Improved mesoscale mosaic of hydrodynamics leads to **increase in larval and YOY habitats.**	Increased survival of larvae and YOY; local population increases and, with emigration, the regional population increases	5	2	3	3	3 (L) 3 (C)

7. Assessment of potential risks

R1: Lack of data

Background

The Pike Floodplain has recently (i.e. since 2007) begun to receive considerable scientific attention. However, the quantity of research/assessments undertaken, and the breadth of those assessments is relatively narrow compared to other, regionally relevant floodplain sites. For example, annual surveys of the condition of the fish community at Chowilla have been undertaken since 2005. In comparison, only one robust assessment of the fish community has been undertaken at the Pike Anabranch system. That survey was undertaken following an extended drought and was completed in 2009. Due to the paucity of data, it is possible that some key characteristics (i.e. isolated populations of threatened or endangered species) of the floodplain have not identified.

Model tested:

Source of potential risk:
The distinct lack of data compared to other regionally relevant sites (i.e. Chowilla)

Impact of potential risk:

- Key habitats for threatened species not identified and managed appropriately
- Presence of threatened and/or rare species not identified
- Role of aquatic habitats as regional recruitment zone for pest species not known

Mean values for scores and risk ratings are presented in Table R1.

Frequency of impact:
The mean frequency scores ranged from **annual** to **monthly**.

Likelihood and Consequence:
The mean likelihood scores ranged from **possible** for "presence of threatened and/or rare species not identified", to **likely** for the remaining components. The mean consequence scores were **moderate** for all components.

Risk rating:
Mean risk ratings ranged from **moderate** for "role of aquatic habitats as regional recruitment zones..." to **major** for the remaining components.

Certainty:
The mean certainty scores for the model were **uncertain**.

R2: Operations; improved base-flows and managed inundations

Background

A key concern that is often raised by scientists regarding the construction and use of new engineering structures to deliver environmental water allocations, is the ability of management agencies to appropriately resource the operational team required for the structures both during individual operations, and provide resources for maintenance of the structures over the long-term.

Model tested:

Source of potential risk:
Financial constraints (i.e. insufficient resourcing)

Source of potential risk:

- Failure to maintain engineering integrity of structures over the long-term
- Operations team not resourced sufficiently to respond to required changes in a timely manner

Mean values for scores and risk ratings are presented in Table R2.

Frequency of impact:
The mean frequency score was **10 years** for "failure to maintain engineering integrity of structures over the long-term" and **annual** for "operations team not resourced sufficiently to respond to required changes in a timely manner".

Likelihood and Consequence:
The mean likelihood scores was **unlikely** for "failure to maintain engineering integrity of structures over the long-term" and **likely** for "operations team not resourced sufficiently to respond to required changes in a timely manner". The mean consequence scores were **moderate** for both components.

Risk rating:
The mean risk ratings were **very minor** for "failure to maintain engineering integrity of structures over the long-term" and **moderate** for "operations team not resourced sufficiently to respond to required changes in a timely manner".

Certainty:
The mean certainty scores for the model were **uncertain**

R3: In-stream salinity impacts associated with managed inundations

Background

Management of surface water-groundwater interactions and associated salinity impacts is a major issue for management of hydrology within systems such as Pike Floodplain. Due to surface water-groundwater interactions, large amounts of salt are likely to be exported from the Pike River floodplain during and following floods. The influence of operation of the proposed regulator on salt loads to the river must be monitored in order to manage and therefore minimise the downstream salinity impacts (Barber et al., 2011).

Elevated in-stream salinity will affect the quality of the water for downstream users (i.e. irrigators and potable use) but may also alter the aquatic invertebrate community (Kay et al., 2001) and nutrient processing. In this context, mean increases in in-stream salinity may be relatively low (e.g. surface water salinity may only increase from 400 to 600 μScm^{-1} following floodplain inundation). However, the salinity of the groundwater may be up to two orders of magnitude higher than that recorded in surface water. Salinities in the boundary layer where groundwater discharges into gaining streams may be higher than seawater and could have a significant impact on in-stream flora, fauna and biogeochemical processes.

Stratification can occur as a result of salinity driven density gradients, particularly where the river channel intercepts saline groundwater (see section R13 and R14 for more detail on the effects of stratification). Periods with high flow velocity may provide sufficient energy to disrupt the halocline and distribute toxic compounds that had accumulated in the bottom section of the water column. Wallace and Lenon (2010) recorded persistent thermal stratification in the outer creeks at Chowilla floodplain and suggested that this may be attributable to a thin layer of saline groundwater at the sediment-water interface in those creeks. Similar conditions may exist, particularly in the outer reaches of the Pike River system.

AWE have constructed a salt and water balance model for the Pike Floodplain. Meeting prior commitments at existing flow conditions is expected to result in an increase in salinity equivalent to 16 EC at Col Col bank and 8 EC at the Pike River outlet. It is of note that increased extraction is anticipated to reduce salt export to the river as salt load entering the lower pike from the upper pike is reduced via extraction (Burnell & Watkins, 2008)

Model 1:

Source of potential risk:
Managed flooding produces a large salinity spike in the anabranch system

Impact of potential risk:

- The salinity spike temporarily decreases crop water use efficiency
- Salinity temporarily precludes ability to use water for irrigation

Mean values for scores and risk ratings are presented in Table R3.

Frequency of impact:
The mean frequency scores were **2-4 years**

Likelihood and Consequence:
The mean likelihood scores were **likely**. The mean consequence scores were **minor** and **moderate** respectively.

Risk rating:
The mean risk ratings were **minor** and **moderate** respectively.

Certainty:
The mean certainty scores were **moderately certain.**

Model 2:

Source of potential risk:
Managed flooding produces a large salinity spike in the river downstream

Impact of potential risk:

- The salinity spike temporarily decreases crop water use efficiency
- Salinity temporarily precludes ability to use water for irrigation

Mean values for scores and risk ratings are presented in Table R3.

Frequency of impact:
The mean frequency scores were **2-4 years.**

Likelihood and Consequence:
The mean likelihood scores were **possible** for reducing water use efficiency and **unlikely** for precluding ability to use water for irrigation. The mean consequence scores were **minor** and **moderate** respectively.

Risk rating:
The mean risk ratings were **minor.**

Certainty:
The mean certainty was **moderately certain.**

Model 3:

Source of potential risk:
A significant salinity gradient at interface between groundwater and surface water in gaining streams is established

Impact of potential risk:

- Localised impact on aquatic macrophytes
- Localised density driven stratification

Mean values for scores and risk ratings are presented in Table R3.

Frequency of impact:
The mean frequency scores were **2-4 years** for impact on macrophytes and **daily** for localised density driven stratification.

Likelihood and Consequence:
The mean likelihood scores were **unlikely** for impact on macrophytes and **very likely** for localised density driven stratification. The mean consequence scores were **minor** for both components.

Risk rating:
The mean risk ratings were **no change** for impact on macrophytes and **very major** for density driven stratification.

Certainty:
The mean certainty scores were **very uncertain** for impact on macrophytes and **moderately certain** for localised density driven stratification.

R4: Soil salinity (changes in soil salinity associated with managed inundations)

Background

Where dissolved salts are high in concentration, water uptake by plants can be restricted (SKM, 2010b). Soils may be defined as saline when the concentration of salts in the soil water is sufficient to cause reduced plant growth (Rengasamy et al., 2009). Conditions where the total soil moisture pressure exceeds the physiological capacity of the plants root membrane to extract water are referred to as "osmotic drought" (Overton and Doody 2006). The effect of high salt content in saline soils is similar to drought conditions in non-saline soils as the ability of plants to extract water is reduced. This effect is compounded as the soil dries between floods and rainfall events as the salinity of the soil increases even though the salt content may remain static (Rengasamy et al., 2009). In areas where depth to groundwater is very shallow, regular flooding may not substantially increase sub-soil moisture but may reduce salt content. Conversely, in areas where groundwater is relatively deep, flooding may not significantly reduce soil salt content but may substantially increase average soil moisture content. However, both of these scenarios will result in increased soil moisture availability (SKM, 2010b) and improved conditions for vegetation (Pichu Rengasamy, *pers comm*).

Model tested:

Source of potential risk:
Flooding does not reduce soil salinity

Impact of potential risk:

- soil moisture availability is not increased

Mean values for scores and risk ratings are presented in Table R4.

Frequency of impact:
The mean frequency score was **2-4 years.**

Likelihood and Consequence:
The mean likelihood score was **possible**. The mean consequence score was **moderate**.

Risk rating:
The mean risk rating was **moderate.**

Certainty:
The mean certainty was **very uncertain.**

R5: Sodicity (changes in sodicity associated with managed inundations)

Background

Sodic soils contain a high proportion of sodium cations relative to other cations (e.g. magnesium, calcium, potassium). Sodic soils form when magnesium and calcium cations are displaced from clay particles by sodium cations. The displaced cations are leached from the soil profile and the sodium cations accumulate in the soil. Sodic soils contain sufficient sodium cations to affect soil structural stability, reduce infiltration and soil moisture holding capacity and increase soil strength. High soil strength restricts root elongation and survival of plants. Sodicity can substantially reduce infiltration and lead to an increase in salts and elements toxic to plants. It is important to recognise that sodicity is a separate issue from salinity. A soil may be sodic without being saline, saline without being sodic, or both sodic and saline (Rengasamy et al., 2009). High soil salinity and sodicity leads to a loss of soil structure, microbial diversity and abundance (Fitzpatrick et al., 1994), loss of soil egg banks of flood responsive understorey vegetation and micro-invertebrates (Nielsen et al., 2003a; Brock et al., 2005b; Porter et al., 2007).

Model 1:

Source of potential risk:
Flooding does not improve soil sodicity

Impact of potential risk:

- soil moisture availability is not increased

Mean values for scores and risk ratings are presented in Table R5.

Frequency of impact:
The mean frequency score was **annual.**

Likelihood and Consequence:
The mean likelihood score was **possible**. The mean consequence score was **moderate**.

Risk rating:
The mean risk rating was **major.**

Certainty:
The mean certainty was **uncertain.**

Model 2:

Source of potential risk:
Flooding exacerbates soil sodicity

Impact of potential risk:

- water infiltration decreases, soil moisture availability decreases

Mean values for scores and risk ratings are presented in Table R5.

Frequency of impact:
The mean frequency score was **monthly.**

Likelihood and Consequence:
The mean likelihood scores was **possible**. The mean consequence scores was **major**.

Risk rating:
The mean risk rating was **major.**

Certainty:
The mean certainty was **uncertain.**

R6: Sulfidic material (disturbance of sulfidic material)

Background

The build up of substantial pools of reduced inorganic sulfur and the subsequent occurrence of sulfidic sediments (also referred to as acid sulfate soils) throughout inland creeks and wetland systems (Baldwin & Fraser, 2009) has, until recently been considered an unusual occurrence. However, recent studies (Lamontagne et al., 2004; Hall et al., 2006; McCarthy et al., 2006) have demonstrated that sulfidic sediments are relatively widely distributed throughout wetlands in the Murray-Darling Basin (Hall et al., 2006). In brief, sulfidic sediments form when compounds containing sulfur are reduced to sulfide by bacteria under anoxic conditions. Primary sources of the sulfur compounds are saline groundwater, agricultural chemicals such as fertilisers containing sulfur, and soil amendments such as gypsum (Baldwin & Fraser, 2009). When exposed to oxygen, a series of chemical reactions within sulfidic materials results in the liberation of acid and a decrease in pH in the water column.

The oxygen demand generated by the oxidation of pyritic materials contained in reduced sulfidic sediments can produce anoxic (zero dissolved oxygen) conditions. Furthermore, heavy metals including aluminium and dissolved sulfides released into the water column as a result of oxidation of sulfidic sediments are toxic to aquatic organisms (for more information see Hall et al., 2006; Baldwin & Fraser, 2009). Hall et al., (2006) concluded that many of the wetlands surveyed contained sulfidic sediments and were at risk of net acidification if oxidised. Inappropriate management of these sites and the sediments within them has the potential to cause serious long-term or irreversible damage (Baldwin & Fraser, 2009). Disturbance of sulfidic sediments, as would happen during mechanical dredging of river pools or very high velocity resulting in scour and mobilisation of sediments in creeks, has potential to generate a number of water quality problems including rapid de-oxygenation of the water column, a decrease in pH and release of toxic compounds.

There have been previous recommendations on channel desilting and clearing to ensure the sustainability of the supply of irrigation water from the Pike Anabranch (Burnell & Watkins, 2008). However, it is considered that disturbance of sulfidic material that is known to be present and widely distributed in channels (Shand et al., 2009) needs to be considered. For example, acid sulfate material is distributed throughout Snake Creek (Shand et al., 2009). Drying of this Snake Creek via isolating it from the permanent channels in order to improve flow through other creeks is not recommended as a large flood is highly likley to reconnect the creek to the rest of the system. Previous studies in other lowland rivers within the Murray-Darling Basin (i.e. the Lachlan River) have suggested that dredging activities need to be undertaken with extreme caution when sulfidic material is present (Wallace & Bindokas, 2011a). Ad-hoc management in the form of dredging would not be recommended; a thorough examination of the risks at each respective site and a robust management plan to manage sediment removed from the site(s) would be essential if this option was to be pursued. The scope of such a review would need to include direct costs and management liabilities associated with the construction and maintenance of treatment pits for storage of dredged sediments and an comparison of the ecological benefits of increased water column depth v's risks associated with disturbance of sulfidic material.

It is worth noting that physical removal of sulfidic material by dredging will only provide a temporary benefit in alleviating the issue, as the source of the sulfur compounds (e.g. saline groundwater and/or agricultural chemicals such as fertilisers containing sulfur and soil amendments such as gypsum) and the processes driving the formation of sulfidic sediments will not have been addressed (Baldwin & Fraser, 2009). Indeed, Whitworth and Baldwin (2011) demonstrated that: (i) visual evidence of the formation of

sulfidic materials can be observed in less than one month; and (ii) all of the sulfate in solution can be converted into reduced forms in the sediment within a few months.

Model tested:

Source of potential risk:
Acid sulfate soils

Impact of potential risk:

- Areas containing acid sulfate soils are dried and re-wetted causing localised acidification events
- Mobilisation of sulfidic material due to increased scour causes rapid deoxygenation
- Mobilisation of sulfidic material due to dredging to increase flow rates

Mean values for scores and risk ratings are presented in Table R6.

Frequency of impact:
The mean frequency score for mobilisation of sulfidic material due to increased scour, and mobilisation due to dredging was **2-4 years**. For drying and rewetting, the mean frequency score was **annual**.

Likelihood and Consequence:
The mean likelihood score for mobilisation due to dredging was **unlikely**. For the remaining components, the mean likelihood scores were **very unlikely**. Mean consequence scores were **moderate** for all components.

Risk rating:
The mean risk rating was **very minor** for mobilisation due to dredging and **minor** for the remaining components**.**

Certainty:
The mean certainty was **uncertain** for mobilisation due to dredging and **moderately certain** for the remaining components**.**

R7: Fringe degradation associated with managed inundations

Background

Groundwater level is a critical factor affecting vegetation health. The critical depth to groundwater is related to flooding frequency such that as flooding frequency increases the critical depth decreases (SKM, 2010a). If tree roots are exposed to saturated conditions for prolonged periods, tree death will ensue. Furthermore, if groundwater levels rise above the extinction depth of evapotranspiration, salt from the groundwater may become concentrated within the unsaturated zone and exacerbate the current decline in vegetation health (SKM, 2010a). In areas where the groundwater is in close proximity to the soil surface, either direct seepage or evapoconcentration leads to the development of saline and sodic soils and the plant community becomes dominated by salt tolerant species. Multiple floods may be required to reduce soil salinities sufficiently to generate a desired response, meaning that larger volumes of water will be required to reinstate resilience (Nicol et al., 2010a).

In areas affected by shallow, saline groundwater, managed flooding will raise groundwater levels. There is a risk that in areas where groundwater levels fluctuate in the absence of inundation "fringe degradation" will occur as a result of increasing soil salinity. The potential for this risk to become a hazard needs to be monitored and managed (SKM, 2010b). Altering the extent of inundation in subsequent floods will aid in reducing the development of a fringe of degradation at the outer extent of the flood extent (Overton & Doody, 2008).

Model 4:

Source of potential risk:
Managed flooding leads to fringe degradation in areas where depth to groundwater decreases in the absence of flooding

Impact of potential risk:

- Saline groundwater intrudes into root zone
- Soil sodicity increases
- Soil salinity increases

Mean values for scores and risk ratings are presented in Table R7.

Frequency of impact:
The mean frequency score for soil sodicity was **monthly.** Mean frequency scores for the remaining components was **annual**.

Likelihood and Consequence:
The mean likelihood score for soil sodicity was **likely**. Mean likelihood scores for the remaining components was **possible**. The mean consequence scores were **moderate**.

Risk rating:
The mean risk rating was **major** for soil sodicity and **moderate** for the remaining components**.**

Certainty:
The mean certainty was **uncertain.**

R8: Geomorphology impacts associated with (i) improved base-flows and (ii) managed inundations

Background:

Channel geomorphology plays a large part in determining in-stream habitat complexity (Marsh et al., 2001) and therefore is an important indicator of habitat diversity and quality. Channel erosion can occur in response to river regulation, sudden fluctuations in depth, drying of channel banks and loss of a drying cycle on formerly ephemeral streams. Erosion increases channel cross-sectional area and channel capacity such that higher flows are required in order to generate lateral connectivity and achieve floodplain inundation. The sediments of lowland rivers and wetlands are typically rich in reactive reduced metals such as ferrous iron ($Fe2^{+}$) and anoxic with a few millimetres of the sediment-water interface. When exposed to oxygen as may occur as a result of resuspension/scour during high flow periods, oxidisation of the reduced compounds can result in a substantial oxygen debt. In slow flowing areas, there is an increased risk of sedimentation resulting from decreased velocity (Balcombe et al., 2011).

In the context of geomorphic impacts (i.e. bank failure), Gippel et al. (2011) recommended that a rate of 50 mm day^{-1} could be applied initially to drain water from the floodplain, and then this could be slowed to 30 mm day^{-1} as water levels within river/creek channels begin to fall. The high end of this range is possible early in the recession when there is sufficient water in the channel to support the weight of the saturated banks.

Water Technology (2010b) investigated (i) the influence on upgrading the structures at Banks D, E, F, F1, G, Coombes Bridge and Snake Creek Stock Crossing and (ii) the upgrading of Margaret Dowiling Creek and Deep Creek on water levels and flow velocity with flow to SA of 3,000 $MLday^{-1}$. The investigation included four scenarios. Locations and outputs are summarised in Table 3.

Scenarios modelled to date.

1. Scenario A

Existing conditions. There is a very small flow from Mundic Lagoon to Tanyaca Creek, but it is largely blocked by banks F1 and D. Bank C has a small flow back to the River Murray via the 0.22m diameter pipe. The major outflow from the Mundic Lagoon is to Pike River via the three outlets.

2. Scenario B1 Structure changes with existing inlet conditions

Existing inlet conditions with the structural changes at Banks D, E, F, F1, G, Coombes Bridge and Snake Creek Stock Crossing. The Tanyaca Creek pool and riffle is comprised of a series of riffles with approximately a 0.1 m water level drop at each 'step'. Increasing the flow down Tanyaca Creek, increasing the capacity of Coombes Bridge and Snake Creek will result in the water level in Mundic Lagoon. This needs to be managed. The flow through Tanyaca Creek is throttled to 4 $MLday^{-1}$ by reducing the riffle cross-sectional area, ensuring Mundic Lagoon water level was only reduced by 0.1 m. Modelled velocities in the riffles are approximately 1.2 ms^{-1}.

3. Scenario B2 Structure changes with upgraded inlets passing combined 600 ML day^{-1}

Inflows through Deep Creek and Margaret Dowling are increased by approximately 65% to a total of 600 ML day^{-1}. This counteracts the impact of the increased capacity of the upgraded ancillary structures on water levels in Mundic Lagoon. Water level in the Lagoon are raised by approximately 0.06 m from existing conditions. The Tanyaca Creek pool and riffle has a modelled flow of approximately 24 $MLday^{-1}$ with very high velocities (1.5-4.5 ms^{-1}) across the riffles. It was recommended that the riffles be widened to allow a more appropriate velocity for the given flow.

4. Scenario B3 Structure changes with upgraded inlets passing combined 1,000 ML day^{-1}

As per Scenario B1 and B2 but with increased 1,000 MLday-1 inflows through Deep Creek (600 $MLday^{-1}$)and Margaret Dowling (400 ML day^{-1}) Increased inflow raises Mundic Lagoon water level to above the existing Bank C crest level. The new blocking bank and access tracks need to be built before this scenario can be implemented. Modelled flow in the Tanyaca Creek pool and riffle is approximately 95 ML day^{-1} with very high velocity (1.5-4.5 ms^{-1}). The riffles would need to be widened to allow this flow with an appropriate velocity. Changes to the pool and riffle design will influence water levels in Mundic Lagoon. This will require attention.

Bed Shear Stress Mapping

Bed shear stress results were extracted for days corresponding to the velocity mapping presented above. Only 1D bed shear stresses were presented by Water Technology (2010). From the results of that study, it is evident that bed shear stress is closely correlated with average stream velocity.

Summary

The maximum deliverable in-flow with upgraded inlet structures is 1,000 $MLday^{-1}$. This is comprised of 400 $MLday^{-1}$ into Margaret Dowling and 600 $MLday^{-1}$ into Deep Creek (Water Technology, 2010a). There appears to be no operational barrier to sustaining flows of this magnitude in the long-term once the structures are completed including the appropriate engineering at the structures to prevent scour associated with the increased velocity (B.Hollis, pers com). However, there are some key factors that need to be considered:

5. Variability
    a. Maintaining a consistently high flow (e.g. 1,000 $MLday^{-1}$) may not be a desirable outcome. Imparting some level of seasonal/frequent variation in flow (e.g. 600-1,000 $MLday^{-1}$) may be more desirable
6. Impacts on geomorphology including potential for high bed shear to mobilise acid sulfate soils which are known to be widely distributed through the anabranch system (Shand et al., 2009) needs to be considered
7. Bank C needs to be upgraded before inflows of 1,000 $MLday^{-1}$ can be used
8. The design of the pool and riffle at Tanyaca Creek needs to be optimised for flows in order to maintain appropriate velocities across this structure

Model 1:

Source of potential risk:
High velocity flows

Impact of potential risk:

- Banks being eroded
- Excessive bed scour leads to channel incision

Mean values for scores and risk ratings are presented in Table R8.

Frequency of impact:
Mean frequency scores were **2-4 years**.

Likelihood and Consequence:
The mean likelihood scores were **unlikely** and **very unlikely** respectively. Mean consequence scores were **moderate** and **minor** respectively.

Risk rating:
The mean risk rating was **minor** for bank erosion and **no change** for bed scour**.**

Certainty:
The mean certainty scores were **uncertain.**

Model 2:

Source of potential risk:
Fast drawdown rates upon recession following managed inundations

Impact of potential risk:

- Mass bank failure

Mean values for scores and risk ratings are presented in Table R8.

Frequency of impact:
Mean frequency scores were **2-4 years**.

Likelihood and Consequence:
The mean likelihood scores was **unlikely**. The mean consequence scores was **moderate**.

Risk rating:
The mean risk rating was **moderate.**

Certainty:
The mean certainty scores were **uncertain.**

Model 3:

Source of potential risk:
Low flow velocities within the anabranch system during managed inundations

Impact of potential risk:

- depositional zone and high rates of sedimentation on floodplain

Mean values for scores and risk ratings are presented in Table R8.

Frequency of impact:
Mean frequency scores were **2-4 years**.

Likelihood and Consequence:
The mean likelihood scores was **very unlikely**. The mean consequence scores was **very minor**.

Risk rating:
The mean risk rating was **no change.**

Certainty:
The mean certainty scores were **uncertain.**

Table 3. Water levels, discharges, velocities and shear stress at selected locations for scenarios A, B1, B2 and B3 (from Water Technology, 2010b)

		A				B1				B2				B3			
		Existing conditions				Structure changes with existing inlets				Structure changes with upgraded inlets at combined 600 ML/d				Structure changes with upgraded inlets at combined 1,000 ML/d			
		h	q	v	τ	h	q	v	τ	h	Q	v	τ	h	q	v	τ
		m AHD	ML/d	m/s	N/m²	m AHD	ML/d	m/s	N/m²	m AHD	ML/d	m/s	N/m²	m AHD	ML/d	m/s	N/m²
1	Deep Creek	15.34	182	0.18	0.88	15.34	182	0.18	0.88	15.59	300	0.23	1.30	16.03	600	0.31	2.19
2	Margaret Dowling	14.88	181	0.16	0.90	14.85	181	0.16	0.96	15.09	300	0.22	1.60	15.28	400	0.25	2.04
3	Mundic Lagoon	14.64	363	0.02	0.00	14.54	363	0.02	0.00	14.70	599	0.03	0.01	14.88	999	0.05	0.02
4	Mundic Lagoon – Bank B	14.64	0	0.00	0.00	14.54	0	0.00	0.00	14.70	0	0.00	0.00	14.88	0	0.00	0.00
5	Mundic Lagoon Outlet 1	14.64	26	0.04	0.02	14.54	19	0.04	0.02	14.70	40	0.05	0.03	14.88	59	0.04	0.02
6	Mundic Lagoon Outlet 2	14.63	175	0.17	0.25	14.53	172	0.19	0.32	14.69	262	0.24	0.47	14.87	408	0.31	0.73
7	Mundic Lagoon Outlet 3	14.63	156	0.08	0.06	14.53	156	0.09	0.07	14.69	247	0.13	0.12	14.87	371	0.16	0.19
8	Upper Pike River	14.63	201	0.01	0.00	14.53	190	0.01	0.00	14.69	302	0.02	0.00	14.87	467	0.02	0.00
9	Snake Creek – Bank G	14.64	0	0.00	0.00	14.54	9	0.02	0.01	14.70	20	0.03	0.02	14.88	41	0.04	0.04
10	Tanyaca Creek – Bank F1	14.64	1	0.00	0.00	14.54	4	0.01	0.00	14.70	24	0.03	0.04	14.88	95	0.09	0.31
11	Tanyaca Ck u/s of Tanyaca Lagoon	13.21	1	0.00	0.00	13.22	4	0.02	0.00	13.23	24	0.10	0.16	13.30	95	0.35	2.01
12	Mundic Lagoon – Bank C	14.64	5	0.00	0.00	14.54	4	0.00	0.00	14.70	6	0.00	0.00	14.88	25	0.02	0.00
13	Pike River	14.47	356	0.05	0.02	14.47	353	0.05	0.02	14.59	568	0.07	0.04	14.70	878	0.10	0.07
14	Pike River	14.47	356	0.02	0.00	14.47	353	0.02	0.00	14.59	568	0.03	0.01	14.70	878	0.04	0.01
15	Lower Pike River	13.21	489	0.05	0.02	13.21	489	0.05	0.02	13.21	550	0.06	0.02	13.22	708	0.08	0.04

R9: Hydrology during improved base-flows

Background:

Water Technology (2010b) investigated (i) the influence on upgrading the structures at Banks D, E, F, F1, G, Coombes Bridge and Snake Creek Stock Crossing and (ii) the upgrading of Margaret Dowling Creek and Deep Creek on water levels and flow velocity with flow to SA of 3,000 $MLday^{-1}$. The investigation included four scenarios. A description of the scenarios modelled and the outputs are presented in section R5.

For managed inundations, the hydrodynamic modelling that has been undertaken by Water Technology (Technology, 2010a) is for a 120 day scenario using a MIKE FLOOD 1D-2D hydrodynamic model operating with an inflow at Deep Creek of 600 ML/d and at Margaret Dowling Creek of 400 ML/d. Velocities are highest at the start and end of the scenario when the gradient between Lock 5 upper pool and the outlet regulators at Tanyaca and Col Col is largest. When water levels are raised to 16.4 m AHD, high velocities will be produced immediately downstream of the outlet regulators as the water level downstream is between 13.3 and 13.8 m AHD at Col Col and Tanyaca respectively.

Model tested:

Source of potential risk:
Improved inflows

Impact of potential risk:

- High velocity flows at structures during relatively high flows may not support fish passage
- Increased outflow improves attractant flow for fish during base flows but insufficient fish passage results in accumulation of fish downstream of structures
- Increased inflow is not combined with increased structural habitat diversity
- Increased inflow is not combined with increased hydraulic diversity
- Inflow/discharge rates not optimised

Mean values for scores and risk ratings are presented in Table R9.

Frequency of impact:
The mean frequency scores for accumulation of fish downstream of structures was **annual**. Mean frequency scores for the remaining components were **monthly** and **weekly**.

Likelihood and Consequence:
The mean likelihood scores for inflow/discharge rates not optimised and accumulation of fish downstream of structures were **unlikely**. Mean likelihood scores for the remaining components ranged from **possible** to **likely**. The mean consequence score for inflow/discharge rates not optimised, and accumulation of fish downstream of structures, were **moderate**. Mean consequence scores for the remaining components were **minor**.

Risk rating:
The mean risk rating for high velocities flows may not support fish passage was **moderate**. For all other components the risk ratings were **major.**

Certainty:
The mean certainty scores were **uncertain.**

R10: Extraction for consumptive use during improved base-flows

Background:

Current irrigation allocation from Pike is 22.5 GL year^{-1} and there are also five approved "Prior Commitment" (PC) allocations of 14.8 GL giving a total intermediate term extraction of 37.3 GL year^{-1}. The PC allocations are distributed in the Upper Pike (42%) and lower Pike (58%). The impact of uptake of the full volume of PC on flow and salinity conditions is described by Burnell and Watkins (2008). Water levels in the Pike system will remain virtually unchanged by extraction up to twice PC. Inflow in the Upper Pike remains unchanged. As extraction increases, the flow into Lower Pike via Rumpagunyah increases to offset reduced flow over Col Col. Flows in mid Pike (between Col Col embankment and Rumpagunyah Creek confluence) and flow out of Lower Pike decrease (Burnell & Watkins, 2008).

Burnell and Watkins (2008) calculated that for an allocation of 1 GL, the average daily requirements during the January peak is 6.85 MLday^{-1} per GL allocation. Using a very simplistic approach, the additional 14.8 GL of prior commitment (that could theoretically be called upon), would require 101.4 ML day^{-1}. If inflows are increased from the current inflow of 300 ML day^{-1} to 600 ML day^{-1}, meeting PC would result in an effective increase in flow of 198.6 ML day^{-1}. For an increase in inflow to 1,000 ML day^{-1}, meeting PC would result in an effective increase in flow of 598.6 ML day^{-1}.

Model tested:

Source of potential risk:
Uptake of prior commitment entitlements

Impact of potential risk:

- Reduction in scale of benefit achievable from increased inlet capacity due to increased extraction

Mean values for scores and risk ratings are presented in Table R10.

Frequency of impact:
The mean frequency score was **daily**.

Likelihood and Consequence:
The mean likelihood scores was **very unlikely**. The mean consequence score was **moderate**.

Risk rating:
The mean risk rating was **major.**

Certainty:
The mean certainty scores were **uncertain.**

R11: Biogeochemical characteristics of Environmental Water Allocation during managed inundations

Background:

The source of water from which environmental water allocations (EWA) are comprised may influence outcomes. Water released from an upstream storage and transferred as an EWA into an individual site (i.e. wetland) during periods of in-channel flow, particularly very-low flow periods may restrict the ecological outcomes as the productivity gains from upstream flooding are not available to be transported into the managed site. The "missing pieces" are likely to include food resources, plant and invertebrate propagules dispersed from upstream sites, increased carbon and nutrient concentrations and other chemical cues resulting from inundation of floodplain soils and plant material, eggs and larvae of fish and other organisms spawned at upstream sites.

Conditions within upstream storages can range from functioning as a sink or source of nutrients, with associated changes in speciation of chemicals leading to changes in phytoplankton community structure at downstream sites (Baldwin et al., 2010). This can lead to flow-on effects on primary productivity and food webs downstream (see Burford et al., 2011). The river that water is being sourced from may also have an influence on materials transported into the site and the ecological outcomes realised. For example, the microfauna of water from the Darling and Murray Rivers are markedly different and the composition of microfauna varies between storages with short (e.g. Lake Mulwala) and long (e.g. Hume Dam) retention times (see Brookes et al., 2009). Furthermore, under very low flow conditions turbidity in the Darling River can be as low 16 NTU (Wallace, unpublished data) but Sherman et al., (1998) report that turbidity is usually very high (>100 NTU). When the Darling is in flood, increased turbidity can cause the euphotic depth in the lower River Murray to be less than 0.2 m (Mackay et al., 1988). If EWA are comprised of high turbidity water the potential for the growth of aquatic plants is greatly reduced (Brookes et al., 2009). Consequently, information on the source of water and the delivery mechanism (i.e. in-channel controlled delivery of water that has been in extended storage versus a rain driven flow peak that has included lateral connectivity with upstream floodplains) is likely to be important in understanding observations at the site scale.

Model tested:

Source of potential risk:
The source of water used for managed inundations

Impact of potential risk:

- Operations at low river flow (water derived from storages) limit productivity gains as benefits from upstream flooding are not available
- Operations during periods with high turbidity limit aquatic macrophyte and other primary productivity response

Mean values for scores and risk ratings are presented in Table R11.

Frequency of impact:
The mean frequency scores were **annual**.

Likelihood and Consequence:
The mean likelihood scores were **unlikely** and **possible** respectively. The mean consequence scores were **minor**.

Risk rating:
The mean risk rating for both components was **moderate**.

Certainty:
The mean certainty scores were **uncertain.**

R12: Inundation regime during managed inundations

Background:

Recognising the critical importance of maximising ecological outcomes by delivery of water in the most ecologically sensitive manner, it is important to acknowledge that over the long-term, delivery of water at times that are sub-optimal will sometimes be required in order to prevent the collapse of communities. The most appropriate method for delivery of an environmental water allocation will vary accordingly with a range of factors including but not limited to; availability of water, management targets and prevailing condition. Reinstating flows and reoperation of existing infrastructure should be actively used during wet and median conditions to build resilience at the site and system scale, as reinstating resilience is the most pragmatic and effective way of managing ecosystems (Wallace et al., 2011).

Model 1:

Source of potential risk:
Inundation regime disconnected from river hydrology and meteorological cues

Impact of potential risk:

- Disconnect between behavioural adaptations to hydrology and/or meteorological cues limits responses from higher trophic levels

Mean values for scores and risk ratings are presented in Table R12.

Frequency of impact:
The mean frequency score was **annual**

Likelihood and Consequence:
The mean likelihood score was **likely**. The mean consequence score was **minor**.

Risk rating:
The mean risk rating was **moderate**.

Certainty:
The mean certainty score was **moderately certain.**

Model 2:

Source of potential risk:
Aseasonal (winter) flooding

Impact of potential risk:

- Potential benefits not realised due to mismatch between prevailing thermal regime and day-length and behavioural adaptations of biota

Mean values for scores and risk ratings are presented in Table R12.

Frequency of impact:
The mean frequency scores was **2-4 years.**

Likelihood and Consequence:
The mean likelihood score was **possible**. The mean consequence score was **minor**.

Risk rating:
The mean risk rating was **very minor**.

Certainty:
The mean certainty scores was **uncertain.**

Model 3:

Source of potential risk:
Short floods (<10 days)

Impact of potential risk:

- Chemically mediated (e.g. nutrient release) and biogeochemically mediated process (e.g. blackwater events) occur but biotic responses are very limited

Mean values for scores and risk ratings are presented in Table R12.

Frequency of impact:
The mean frequency score was **annual**.

Likelihood and Consequence:
The mean likelihood score was **possible**. The mean consequence score was **minor**.

Risk rating:
The mean risk rating was **minor**.

Certainty:
The mean certainty score was **uncertain.**

R13: Harmful or nuisance algal blooms associated with managed inundations

Background

Thermal stratification is likely to have direct impacts on dissolved oxygen (DO), plankton and solutes (Becker et al., 2010). Thermal stratification is the differential heating of surface water which absorbs heat and so becomes less dense and floats on the cooler bottom waters. Stratification can also occur as a result of salinity driven density gradients, particularly where the river channel intercepts saline groundwater. The onset of thermal stratification is a function of river flow, solar radiation and wind speed (Maier et al., 2001). The extent of thermal stratification is primarily determined by the relative input of thermal energy (causes stratification) and turbulent kinetic energy (destroys stratification) (Bormans et al., 1997). Stratification can be disrupted from the air-water interface by wind energy and from the sediment-water interface by turbulence generated by water flow over the stream bed. Vertical velocity is low in stratified systems and as a consequence, the lower section of the water column (hypolimnion) is effectively isolated from the atmosphere during periods of stratification. Although persistent thermal stratification in rivers is not a typical occurrence because discharge normally provides sufficient kinetic energy to prevent its establishment, it can occur within deep pools during low and no-flow periods, particularly in summer (e.g. Turner & Erskine, 2005).

Riverine stratification can contribute to the establishment of cyanobacteria blooms (Webster et al. 1997) particularly if the water column remains stratified for more than 7 days (Maier et al., 2001). Under low- and no- flow conditions, the lack of water column mixing to entrain non-motile (or species that cannot control their buoyancy) phytoplankton in the water column will lead to a succession shift in the composition of the phytoplankton community. For example, Sherman et al. (1998) demonstrated that in the Murrumbidgee River, the median euphotic depth during the 1993–94 summer was 1.45 m, and that the establishment of persistent stratification at approximately 2 m caused a transition between the two dominant phytoplankton species; under low-flow conditions, the negatively buoyant diatom *Aulacoseira* spp rapidly sinks out of the euphotic zone, and the slightly buoyant cyanobacteria *Anabaena* spp accumulates in the euphotic zone.

Algal blooms within isolated wetlands may be locally significant but will have little impact on the main river channel. However, if the wetlands drain into the main channel this may be a significant source of toxins or taste and odour compounds. Consequently, such blooms may preclude the ability to return water from the floodplain to the river unless high flows are available to ensure the river is well-mixed (i.e. no stratification) and that “wash-out” exceeds phytoplankton growth rates (Brookes et al., 2007).

The hazards associated with cyanobacteria range from public health related toxicity issue to aesthetic water taste and odour issues. The toxins produced by cyanobacteria include both hepatotoxins (liver damaging) and neurotoxins (nerve damaging). The taste and odour compounds produced by cyanobacteria are geosmin and MIB. These compounds are difficult to remove with conventional water treatment and require expensive activated carbon for adequate removal. Consequently it is important to minimise cyanobacterial biomass in the River to reduce the risk from toxins and the taste and odour compounds.

Model 1:

Source of potential risk:
Insufficient water exchange and/or poor timing (i.e. summer inundation) leads to conditions conducive to bloom formation within the anabranch

Impact of potential risk:

- High phytoplankton biomass in isolated water bodies that do not drain back to river
- High phytoplankton biomass in connected water bodies that drain back to river
- Socio- amenity values are temporarily decreased

Mean values for scores and risk ratings are presented in Table R13.

Frequency of impact:
The mean frequency scores for all components were **2-4 years**.

Likelihood and Consequence:
The mean likelihood score for all components was **likely**. The mean consequence score for isolated water bodies that do not drain back to the river was **very minor**. Mean consequence scores for the remaining components were **moderate**.

Risk rating:
The mean risk rating for isolated water bodies that do not drain back to the river was **no change.** The mean risk rating for the remaining components was **moderate**.

Certainty:
The mean certainty score was **moderately certain.**

Model 2:

Source of potential risk:
Inundation coincides with high temperature and low flows in river. Dilution/mixing and turbulence is insufficient to "wash-out" phytoplankton biomass derived from the anabranch

Impact of potential risk:

- Phytoplankton bloom develops in river
- Toxin issues in river need to be managed for public safety (socio- amenity values are temporarily decreased)
- Toxins and taste and odour issues need to be managed in water treatment plants

Mean values for scores and risk ratings are presented in Table R13.

Frequency of impact:
The mean frequency scores for all components were **2-4 years**.

Likelihood and Consequence:
The mean likelihood scores for all components was **likely**. The mean consequence scores for all components were **moderate**.

Risk rating:
The mean risk rating for all components was **moderate**.

Certainty:
The mean certainty score was **moderately certain.**

R14: De-oxygenation and blackwater events associated with managed inundations

Background

Primary controls for the concentration of dissolved oxygen in rivers are (i) the physico-chemical processes of gas-exchange (oxygen diffusion into the water column across the air-water interface and water-gas saturation relationships); (ii) oxygen production from photosynthesis; (iii) sediment and pelagic oxygen demand (e.g. heterotrophic and autotrophic respiration, nitrification); and (iv) chemical oxygen demand (Odum, 1956; Burns et al., 1996; Kelly, 1997; Matlock et al., 2003).The onset of persistent stratification isolates the hypolimnion and precludes resupply of oxygen across the air-water interface. When oxygen demand becomes the dominant process, DO concentrations are depleted and hypoxic (<2 mg O_2 L^{-1}) and or anoxic conditions will become established.

There is a range of processes that may drive de-oxygenation events including: (i) increased flow velocity and turbulence that disrupts water column stratification and displaces oxygen demanding material (and accumulated toxins) that were confined in the lower section of the water column (hypolimnion) into the upper section of the water column (epilimnion); (ii) chemical oxygen demand resulting from the rapid oxidation of reduced sulphur compounds associated with re-suspension of sulfidic sediments (e.g. Sullivan et al., 2002; Johnston et al., 2003; Baldwin & Whitworth, 2009); (iii) the downstream passage of a discrete body of hypoxic/anoxic water resulting from the mobilization of organic debris (i.e. leaf litter, bark) that had accumulated in dry river channels during no-flow periods (Gilligan *et al*. (2009); and (iv) high flows that engage the floodplain and import bioavailable carbon (e.g. leaf litter and other floodplain plant material).

Blackwater events are generally defined as floodplain inundation events or periods of high flow where the concentration of dissolved organic carbon (DOC) is high enough to generate a dark colour in the water column similar to black tea (Howitt et al. 2007). When this discoloured water is associated with reduced concentrations of dissolved oxygen (DO) it is known as hypoxic blackwater (Baldwin & Whitworth, 2009; Watkins et al., 2010; Hladyz et al., 2011). Such events occur naturally in the lowland reaches of the Murray-Darling River system and were reported even prior to river regulation (Anon 1866). Blackwater events in the Murray-Darling Basin are invariably associated with inundation of forested floodplains (Whitworth et al., 2011).

Oxygen concentrations can be categorised on a range of scales. "Normal" conditions typically are described by DO >6 mgL^{-1}; and "low" concentrations are in the range 4-6 mgL^{-1} (Whitworth et al., 2011). Hypoxia is often described by DO concentrations <2 mgL^{-1} (Sabo et al., 1999) and anoxia when DO concentrations are at or very near zero. Hypoxia (and anoxia) is a major concern for the ecology of wetlands and receiving waters, as tolerance to hypoxia is species and life-stage specific, therefore changes in DO concentration can have significant impacts on biodiversity (Ekau et al., 2010). Hypoxia is associated with fish kills (Erskine et al., 2005), disruption of endocrine systems (Wu et al., 2003) embryonic development (Shang & Wu, 2004) and survival and hatch rates (Hassell et al., 2008) of fish and degradation of aquatic macroinvertebrate communities in streams (Walsh et al., 2001; Walsh, 2002; Feminella et al., 2003) and wetlands (Spieles & Mitsch, 2003). Anoxia may lead to the release of sediment bound material such as manganese, iron (Davison, 1993), ammonium (Lawrence & Breen, 1998; Boulton & Brock, 1999; Morin & Morse, 1999) and phosphorus (Mortimer, 1941; Laws, 1993; Martinova, 1993); conversion of dissolved organic nitrogen to ammonia and nitrate (Harris, 2001) and accumulation of redox sensitive compounds from anoxic sediments (e.g. Baldwin & Mitchell, 2000; Dahm et al., 2003) some of which (e.g. ammonium and sulfide) are toxic to many aquatic organisms (Vismann, 1996; Hickey & Martin, 1999).

DOC may be toxic to fish and other aquatic organisms at very high concentrations (e.g. >50 mg DOC L^{-1}), particularly if conditions are hypoxic (Temnick, 1989; McMaster & Bond, 2008). In catchments where water is harvested for potable supply, alterations to the composition and bioavailability of allochthonous DOC entering aquatic ecosystems may be highly problematic. DOC can function as the principal factor influencing treatment cost (Hine & Bursill, 1987). Natural organic matter (NOM) fouls membrane filters used in potable water treatment (Cho et al., 1999), and some DOC fractions (e.g. those with neutral charge) are resistant to traditional pre-treatment techniques (Chow et al., 2000; Chow et al., 2004). These fractions react with chlorine during the disinfection phase, to generate potentially toxic or carcinogenic by-products, and contribute to bacterial regrowth in distribution systems (Prevost et al., 1998; Simpson & Hayes, 1998). Furthermore, DOC complexes with metals (e.g. lead and zinc) and hydrophobic compounds such as hydrocarbons, herbicides and pesticides, and the transport of DOC and toxic pollutants is of substantial environmental concern (Ellis & Hvitved-Jacobsen, 1996).

Model 1:

Source of potential risk:
Insufficient water exchange and/or poor timing (i.e. summer inundation) leads to carbon load exceeding assimilation capacity within anabranch.

Impact of potential risk:

- Hypoxia leads to stress of higher level aquatic organisms (e.g. fish)
- Hypoxia interferes with recruitment ecology of fish
- Anoxia leads to death of higher level aquatic organisms (e.g. fish)
- Hypoxia/anoxia interferes with germination/establishment of aquatic vegetation
- Hypoxia/anoxia interferes with establishment of food resources (invertebrates) for higher level organisms (fish, frogs, birds)
- Anoxia leads to release of toxic compounds and nutrients from inundated sediments

Mean values for scores and risk ratings are presented in Table R14.

Frequency of impact:
The mean frequency score for hypoxia interfering with germination/establishment of aquatic vegetation was **annual**. For all other components, frequency scores were **2-4 years**.

Likelihood and Consequence:
The mean likelihood score for hypoxia interfering with germination/establishment of aquatic vegetation was **very unlikely.** The mean likelihood scores for all other components was **likely**. The mean consequence scores for all components ranged from **moderate** to **major**.

Risk rating:
The mean risk rating for hypoxia interfering with germination/establishment of aquatic vegetation was **very minor.** For all other components, risk ratings ranged from **moderate** to **major**.

Certainty:
The mean certainty scores ranged from **uncertain** to **moderately certain.**

Model 2:

Source of potential risk:
Downstream impacts resulting from high DOC load in water returning to the river from the floodplain

Impact of potential risk:

- High DOC load from floodplain challenges water treatment plants
- Heavy metals and other compounds/elements released from anoxic sediments challenges water treatment plants
- Low DO water from floodplain depresses DO in receiving water
- DOC from floodplain stimulates heterotrophic activity in receiving water and depresses DO in river

Mean values for scores and risk ratings are presented in Table R14.

Frequency of impact:
The mean frequency score for "DOC from floodplain stimulates heterotrophic activity in receiving water and depresses DO in river" was **10 years**. For all other components, mean frequency scores were **2-4 years**.

Likelihood and Consequence:
The mean likelihood scores were **likely** for impacts at treatment plants, and **possible** for impacts in the river**.** The mean consequence scores for all components was **moderate**.

Risk rating:
The mean risk rating for impacts at treatment plants was **moderate.** For all other components, risk ratings ranged from **very minor** to **minor**.

Certainty:
The mean certainty scores ranged from **uncertain** to **moderately certain.**

R15: Expansion of invasive plants associated with improved base-flows and managed inundations

Background

In an assessment of the risk of pest plant recruitment associated with the Chowilla environmental regulator, Nicol (2007) identified that there were eight species that posed and extreme invasion/expansion risk and fifteen species posing a high risk. The risk was considered to be largely confined to areas that will be inundated at low flows that have low soil salinity.

Cumbungi (*Typha* spp.) is a common riparian and wetland macrophyte in the River Murray and its floodplain wetlands. Narrow-leaf cumbungi (*Typha domingensis* Pers.) and broad-leaf cumbungi (*T.orientali*s Presl.) are native species that grow along the edges of streams and wetlands, in boggy areas and in shallow stationary water bodies up to 2 m deep (Sainty and Jacobs 1994). The ecology and biology of cumbungi is well adapted to rapid colonisation of wetlands and riparian zones (Nicol & Ganf, 2000; Roberts & Marston, 2000). The spread of cumbungi is viewed as a threat to regulated aquatic ecosystems due to (i) its vigorous growth, (ii) its ability to displace other plant species; (iii) to disrupt fish movement and (iv) to reduce the hydraulic capacity of floodplain channels and flood runners (Roberts & Wylks, 1992; Roberts & Marston, 2000). Monitoring at Webster's Lagoon (Lindsay Island) and Potterwalkagee creek (Mulcra Island) has highlighted the rapidity with which cumbungi has appeared and expanded over recent years within at LMW (Scholz et al., 2006; Scholz et al., 2007). While cumbungi plays an important ecological role, such as the provision of habitat for water-birds such as crakes, rails and reed-warblers (Roberts & Marston, 2000), extensive expansion of cumbungi in regulated reaches is viewed as an imbalance. The species is already present throughout the Pike system (Beyer et al., 2010). Nicol (2007) suggests that at Chowilla, this species poses a very low invasion risk. This is largely considered to be because it requires high soil moisture year round, and is already common. This rating may also apply at the Pike River.

Lippia (*Phyla canescens*) is a common weed of floodplains which can quickly invade large areas given favourable conditions (Cunningham et al. 1981). This species was considered to pose an extreme invasion risk by Nicol (2007) because it is well adapted to the types of water regime being proposed; propagules are spread by water, it is desiccation tolerant and grows year round. Capon et al., (2009) report that germination may be enhanced by drying and wetting. Those authors propose that a rapid rate of draw down could out pace the establishment of the tap root compromising this species ability to survive drought.

Arrowhead (*Sagittaria platyphylla*) is reported to prefer relatively constant water levels in slow flowing areas with water depth <0.3 m (Maxwell, 2008; Martin and Shaffer, 2005; as cited by Capon et al., 2009). Although summer flooding appears to be advantageous to this species, it does not appear to be drought tolerant (Maxwell, 2008; as cited by Capon et al., 2009).

Model 1:

Source of potential risk:
Changes to hydrology benefits typha

Impact of potential risk:

- Increased extent and distribution
- Channel capacity decreased

- Habitat value decreased due to mono-specific stands

Mean values for scores and risk ratings are presented in Table R15.

Frequency of impact:
The mean frequency score for all components was **annual**.

Likelihood and Consequence:
The mean likelihood scores were **possible** for increased extent and distribution, and **unlikely** for the remaining components**.** The mean consequence scores for all components was **minor**.

Risk rating:
The mean risk rating were **very minor** for increased extent and distribution, and **no change** for the remaining components

Certainty:
The mean certainty scores were **uncertain.**

Model 2:

Source of potential risk:
Changes to hydrology benefits lippia

Impact of potential risk:
- Increased extent and distribution
- Habitat value decreased due to mono-specific stands

Mean values for scores and risk ratings are presented in Table R15.

Frequency of impact:
The mean frequency score for all components was **annual**.

Likelihood and Consequence:
The mean likelihood scores were **very likely** and **unlikely** respectively**.** The mean consequence scores for all components was **major**.

Risk rating:
The mean risk ratings were **very major** for increased extent and distribution, and **moderate** for the remaining components

Certainty:
The mean certainty scores were **moderately certain.**

Model 3:

Source of potential risk:
Changes to hydrology benefits arrowhead etc.

Impact of potential risk:

- Increased extent and distribution
- Habitat value decreased due to mono-specific stands

Mean values for scores and risk ratings are presented in Table R15.

Frequency of impact:
The mean frequency score for all components was **annual**.

Likelihood and Consequence:
The mean likelihood scores were **very unlikely.** The mean consequence scores for all components was **major**.

Risk rating:
The mean risk ratings were **minor.**

Certainty:
The mean certainty scores were **uncertain.**

Model 4:

Source of potential risk:
Changes to hydrology benefits other invasive plants

Impact of potential risk:

- Increased extent and distribution
- Habitat value decreased due to mono-specific stands

Mean values for scores and risk ratings are presented in Table R1.

Frequency of impact:
The mean frequency score for all components was **annual**.

Likelihood and Consequence:
The mean likelihood scores were **very likely** and **very unlikely** respectively**.** The mean consequence scores for all components was **major**.

Risk rating:
The mean risk ratings were **very major** and **minor** respectively.

Certainty:
The mean certainty scores were **uncertain.**

R16: Failure of native vegetation condition to improve with managed inundations

Background

The information provided in sections B5-9 are directly relevant to this section. They are not repeated here in the interest of brevity.

Model 1:

Source of potential risk:
Soil moisture availability is not improved

Impact of potential risk:

- Growth conditions do not improve
- Germination and establishment not successful

Mean values for scores and risk ratings are presented in Table R1.

Frequency of impact:
The mean frequency score for all components was **annual**.

Likelihood and Consequence:
The mean likelihood scores were **very unlikely** and **possible** respectively**.** The mean consequence scores for all components was **major**.

Risk rating:
The mean risk ratings were **minor** and **major** respectively.

Certainty:
The mean certainty scores were **moderately certain.**

Model 2:

Source of potential risk:
Aseasonal (winter) flooding

Impact of potential risk:

- Propagules from upstream not available
- Germination and establishment not successful
- Life cycle of annual plants not completed

Mean values for scores and risk ratings are presented in Table R16.

Frequency of impact:
The mean frequency score for all components was **monthly**.

Likelihood and Consequence:
The mean likelihood scores were **very unlikely** for life cycles not completed, **possible** for germination and establishment, and **likely** for propagules from upstream not being available**.** The mean consequence scores

were **very major** for life cycles not begin completed, **major** for germination and establishment, and **minor** for propagules from upstream not being available

Risk rating:
The mean risk ratings were **moderate** for propagules from upstream not being available and **major** for the remaining components.

Certainty:
The mean certainty scores were **uncertain** for propagules from upstream not being available, and **moderately certain** for the remaining components.

Model 3:

Source of potential risk:

Inundation and river hydrology not synchronised

Impact of potential risk:

- Propagules from upstream not available

Mean values for scores and risk ratings are presented in Table R16.

Frequency of impact:
The mean frequency score for all components was **monthly**.

Likelihood and Consequence:
The mean likelihood scores was **likely.** The mean consequence score was **minor.**

Risk rating:
The mean risk rating was **moderate**.

Certainty:
The mean certainty score was **uncertain**.

Model 4:

Source of potential risk:

Repeated germination from seed banks without lifecycle closed

Impact of potential risk:

- Seed bank is depleted

Mean values for scores and risk ratings are presented in Table R16.

Frequency of impact:
The mean frequency score for all components was **2-4 years**.

Likelihood and Consequence:
The mean likelihood scores was **very unlikely.** The mean consequence score was **very major.**

Risk rating:
The mean risk rating was **minor**.

Certainty:
The mean certainty score was **moderately certain**.

Model 5:

Source of potential risk:

Grazing pressure is not reduced

Impact of potential risk:

- Vegetation benefits not realised

Mean values for scores and risk ratings are presented in Table R16.

Frequency of impact:
The mean frequency score was **weekly**.

Likelihood and Consequence:
The mean likelihood scores was **possible.** The mean consequence score was **very major.**

Risk rating:
The mean risk rating was **very major**

Certainty:
The mean certainty score was **moderately certain**.

R17: Carp population during improved base flows

Background

Managed inundations pose a risk in the form of an increase in non-native carp (Cyprinus carpio) populations. This is considered an unavoidable consequence of floodplain inundation and would also occur during a natural flooding event. The "additional" risk considered to occur with managed inundation are (i) the increased frequency of floodplain inundation relative to what is occurring under current (recent) conditions; and (ii) the impounded water will provide more carp spawning areas and increase recruitment, while these conditions rarely suit recruitment of large-bodied native fish (Stuart & Mallen-Cooper, 2011). A detailed assessment of the risks, and strategies for management of those risks is presented by Stuart and Mallen-Cooper (2011). Readers are directed to that report for further detail.

Model 1:

Source of potential risk:
Improved spawning habitat

Impact of potential risk:

- Increase in larval population in Pike habitats

Mean values for scores and risk ratings are presented in Table R17.

Frequency of impact:
For improved base flow conditions, all components are scored as **daily**

Likelihood and Consequence:
The mean likelihood score was **possible.** The mean consequence score was **minor.**

Risk rating:
The mean risk rating was **major**.

Certainty:
The mean certainty score was **moderately certain** for Likelihood and **moderately certain** for Consequence

Model 2:

Source of potential risk:

Improved downstream passage at inlets increases survival of larvae from the River Murray

Impact of potential risk:

- Increase in larval population in Pike habitats

Mean values for scores and risk ratings are presented in Table R17.

Frequency of impact:
For improved base flow conditions, all components are scored as **daily**

Likelihood and Consequence:
The mean likelihood scores was **very unlikely.** The mean consequence score was **very minor**

Risk rating:
The mean risk rating was **very minor**

Certainty:
The mean certainty score was **moderately certain** for Likelihood and **moderately certain** for Consequence

Model 3:

Source of potential risk:
Improved larval and YOY habitats

Impact of potential risk:

- Increased survival of larvae and YOY; local population increases and with emigration, the regional population increases

Mean values for scores and risk ratings are presented in Table R17.

Frequency of impact:
For improved base flow conditions, all components are scored as **daily**

Likelihood and Consequence:
The mean likelihood scores was **likely.** The mean consequence score was **minor.**

Risk rating:
The mean risk rating was **very major.**

Certainty:
The mean certainty score was **moderately certain** for Likelihood and **moderately certain** for consequence

Model 4:

Source of potential risk:
Increased habitat for juveniles, sub-adults and adults

Impact of potential risk:

- Local population increases and with emigration, the regional population increases

Mean values for scores and risk ratings are presented in Table R17.

Frequency of impact:
For improved base flow conditions, all components are scored as **daily**

Likelihood and Consequence:
The mean likelihood score was **possible.** The mean consequence score was **moderate.**

Risk rating:
The mean risk rating was **very major.**

Certainty:

The mean certainty score was **very uncertain** for Likelihood and **moderately certain** for Consequence

R18: Carp population associated with managed inundations

Background

The anticipated risk is an increase in the carp population

Model 1:

Source of potential risk:
Improved spawning habitat

Impact of potential risk:

- Increase in larval population in Pike habitats

Mean values for scores and risk ratings are presented in Table R18.

Frequency of impact:
For managed inundations, all components are scored as **2-4 years**

Likelihood and Consequence:
The mean likelihood score was **very likely.** The mean consequence score was **major.**

Risk rating:
The mean risk rating was **very major**.

Certainty:
The mean certainty score was **very certain** for Likelihood and **moderately certain** for Consequence

Model 2:

Source of potential risk:

Improved downstream passage at inlets increases survival of larvae from the River Murray

Impact of potential risk:

- Increase in larval population in Pike habitats

Mean values for scores and risk ratings are presented in Table R18.

Frequency of impact:
For improved base flow conditions, all components are scored as **daily**

Likelihood and Consequence:
The mean likelihood scores was **very unlikely.** The mean consequence score was **very minor.**

Risk rating:
The mean risk rating was **no change.**

Certainty:
The mean certainty score was **moderately certain** for Likelihood and **moderately certain** for Consequence

Model 3:

Source of potential risk:
Improved larval and YOY habitats

Impact of potential risk:

- Increased survival of larvae and YOY; local population increases and with emigration, the regional population increases

Mean values for scores and risk ratings are presented in Table R18.

Frequency of impact:
For improved base flow conditions, all components are scored as **daily**

Likelihood and Consequence:
The mean likelihood score was **very likely.** The mean consequence score was **major.**

Risk rating:
The mean risk rating was **very major.**

Certainty:
The mean certainty score was **very certain** for Likelihood and **moderately certain** for Consequence

Model 4:

Source of potential risk:
Increased habitat for juveniles, sub-adults and adults

Impact of potential risk:

- Local population increases and with emigration, the regional population increases

Mean values for scores and risk ratings are presented in Table R18.

Frequency of impact:
For improved base flow conditions, all components are scored as **daily**

Likelihood and Consequence:
The mean likelihood score was **very unlikely.** The mean consequence score was **major.**

Risk rating:
The mean risk rating was **very minor.**

Certainty:
The mean certainty score was **uncertain** for Likelihood and **moderately certain** for Consequence

R19: Weatherloach and gambusia during improved base flows

Background

Oriental weatherloach (*Misgurnus anguillicaudatus*) is an invasive non-native species that is becoming more widespread in the Murray-Darling Basin. It was first recorded in the Basin in the Ovens River in 1985 (McDowall 1996). The species has wide environmental tolerances. It can persist in water temperatures ranging from 2-38 °C, and can tolerate low dissolved oxygen, can use atmospheric oxygen, and can bury in substrates and aestivate. The preferred habitat is low velocity water with a sand or mud substrate and it is omnivorous. The species was not detected in the baseline survey undertaken by Beyer et al., (Beyer et al., 2010) but may be present following the recent flood.

Gambusia (*Gambusia holbrooki*) is a small body, invasive fish. Maturity can be reached after 2 months at a total length of ~25 mm. The species tolerates a wide range of temperatures, oxygen levels, salinities and turbidities. The species is aggressive and will fin-nip much larger fish and prey on the eggs of native fish and frogs. The species is implicated in the decline of more than 10 species of frogs in Australia (Lintermans, 2007).

Model 1:

Source of potential risk:
Improved spawning habitat

Impact of potential risk:

- Increase in larval population in Pike habitats

Mean values for scores and risk ratings are presented in Table R19.

Frequency of impact:
For improved base flows, all components are scored as **daily**

Likelihood and Consequence:
The mean likelihood scores was **unlikely.** The mean consequence score was **minor.**

Risk rating:
The mean risk rating was **minor**.

Certainty:
The mean certainty score was **moderately certain** for Likelihood and **uncertain** for Consequence

Model 2:

Source of potential risk:
Improved larval and YOY habitats

Impact of potential risk:

- Increased survival of larvae and YOY; local population increases and with emigration, the regional population increases

Mean values for scores and risk ratings are presented in Table R19.

Frequency of impact:
For improved base flows, all components are scored as **daily**

Likelihood and Consequence:
The mean likelihood scores was **unlikely.** The mean consequence score was **minor.**

Risk rating:
The mean risk rating was **minor**.

Certainty:
The mean certainty score was **moderately certain** for Likelihood and **uncertain** for Consequence

Model 3:

Source of potential risk:
Increased habitat for juveniles, sub-adults and adults

Impact of potential risk:

- Local population increases and with emigration, the regional population increases

Mean values for scores and risk ratings are presented in Table R19.

Frequency of impact:
For improved base flow conditions, all components are scored as **daily**

Likelihood and Consequence:
The mean likelihood score was **unlikely.** The mean consequence score was **moderate**

Risk rating:
The mean risk rating was **major.**

Certainty:
The mean certainty score was **very uncertain** for Likelihood and **uncertain** for Consequence

R20: Weatherloach and gambusia associated with managed inundations

Background

See section R19

Model 1:

Source of potential risk:
Improved spawning habitat

Impact of potential risk:

- Increase in larval population in Pike habitats

Mean values for scores and risk ratings are presented in Table R20.

Frequency of impact:
For managed inundations, all components are scored as **2-4 years**

Likelihood and Consequence:
The mean likelihood scores was **very likely.** The mean consequence score was **moderate.**

Risk rating:
The mean risk rating was **major**.

Certainty:
The mean certainty score was **moderately certain** for Likelihood and **uncertain** for Consequence

Model 2:

Source of potential risk:
Improved larval and YOY habitats

Impact of potential risk:

- Increased survival of larvae and YOY; local population increases and with emigration, the regional population increases

Mean values for scores and risk ratings are presented in Table R20.

Frequency of impact:
For improved base flows, all components are scored as **2-4 years**

Likelihood and Consequence:
The mean likelihood scores was **very likely.** The mean consequence score was **moderate.**

Risk rating:
The mean risk rating was **major**.

Certainty:
The mean certainty score was **very certain** for Likelihood and **uncertain** for Consequence

Model 3:

Source of potential risk:
Increased habitat for juveniles, sub-adults and adults

Impact of potential risk:

- Local population increases and with emigration, the regional population increases

Mean values for scores and risk ratings are presented in Table R20.

Frequency of impact:
For improved base flow conditions, all components are scored as **2-4 years**

Likelihood and Consequence:
The mean likelihood score was **very unlikely.** The mean consequence score was **major**

Risk rating:
The mean risk rating was **very minor.**

Certainty:
The mean certainty score was **uncertain** for Likelihood and **uncertain** for Consequence

R21: Impact on catfish population during improved base flows

Background

The anticipated risk is negative impacts on catfish populations due to increased interactions with introduced species. This is based on an assumption that the relative abundance of introduced species increases over time.

Model 1:

Source of potential risk:
Negative interactions with increased populations of carp (e.g. impact is on larvae, juveniles and adults)

Impact of potential risk:

- Population declines within Pike and regionally, if Pike is a source of recruits.

Mean values for scores and risk ratings are presented in Table R21.

Frequency of impact:
For improved base flows, all components are scored as **daily**

Likelihood and Consequence:
The mean likelihood score was **unlikely.** The mean consequence score was **major.**

Risk rating:
The mean risk rating was **very major**.

Certainty:
The mean certainty score was **uncertain** for Likelihood and **uncertain** for Consequence

Model 2:

Source of potential risk:
Negative interactions with increased populations of Gambusia (e.g. impact is on larvae)

Impact of potential risk:

- Population declines within Pike and regionally, if Pike is a source of recruits.

Mean values for scores and risk ratings are presented in Table R21.

Frequency of impact:
For improved base flows, all components are scored as **daily**

Likelihood and Consequence:
The mean likelihood scores was **unlikely.** The mean consequence score was **major**

Risk rating:
The mean risk rating was **very major**

Certainty:
The mean certainty score was **very uncertain** for Likelihood and **very uncertain** for Consequence

R22: Impact on catfish population associated with managed inundations

Background

The anticipated risk is negative impacts on catfish populations due to increased interactions with introduced species. This is based on an assumption that the relative abundance of introduced species increases over time.

Model 1:

Source of potential risk:
Negative interactions with increased populations of carp (e.g. impact is on larvae, juveniles and adults)

Impact of potential risk:

- Population declines within Pike and regionally, if Pike is a source of recruits.

Mean values for scores and risk ratings are presented in Table R22.

Frequency of impact:
For managed inundations, all components are scored as **2-4 years**

Likelihood and Consequence:
The mean likelihood score was **possible.** The mean consequence score was **major**

Risk rating:
The mean risk rating was **moderate**

Certainty:
The mean certainty score was **uncertain** for Likelihood and **uncertain** for Consequence

Model 2:

Source of potential risk:
Negative interactions with increased populations of Gambusia (e.g. impact is on larvae)

Impact of potential risk:

- Population declines within Pike and regionally, if Pike is a source of recruits.

Mean values for scores and risk ratings are presented in Table R22.

Frequency of impact:
For improved base flows, all components are scored as **daily**

Likelihood and Consequence:
The mean likelihood score was **unlikely.** The mean consequence score was **major**

Risk rating:
The mean risk rating was **minor**

Certainty:
The mean certainty score was **very uncertain** for Likelihood and **very uncertain** for Consequence

R23: Impact on threatened species that may be present under improved base flows

Background

The anticipated risk is negative impacts on threatened species that may be present but have not been detected. This is based on (i) the limited amount of data on fish communities in the Pike River, and recognition that cryptic and/or rare species may not have been detected; and (ii) an assumption that the relative abundance of introduced species increases over time.

Model 1:

Source of potential risk:
Negative interactions with increased populations of carp (e.g. impact is on larvae, juveniles and adults)

Impact of potential risk:

- Population declines within Pike and regionally, if Pike is a source of recruits.

Mean values for scores and risk ratings are presented in Table R23.

Frequency of impact:
For improved base flows, all components are scored as **daily**

Likelihood and Consequence:
The mean likelihood score was **unlikely.** The mean consequence score was **very major**

Risk rating:
The mean risk rating was **very major**

Certainty:
The mean certainty score was **uncertain** for Likelihood and **very uncertain** for Consequence

Model 2:

Source of potential risk:
Negative interactions with increased populations of Gambusia (e.g. impact is on larvae)

Impact of potential risk:

- Population declines within Pike and regionally, if Pike is a source of recruits.

Mean values for scores and risk ratings are presented in Table R23.

Frequency of impact:
For improved base flows, all components are scored as **daily**

Likelihood and Consequence:
The mean likelihood score was **unlikely.** The mean consequence score was **very major**

Risk rating:
The mean risk rating was **very major**

Certainty:
The mean certainty score was **very uncertain** for Likelihood and **very uncertain** for Consequence

R24: Impact on threatened species that may be present during managed inundations

Background

The anticipated risk is negative impacts on threatened species that may be present but have not been detected. This is based on (i) the limited amount of data on fish communities in the Pike River, and recognition that cryptic and/or rare species may not have been detected; and (ii) an assumption that the relative abundance of introduced species increases over time.

Model 1:

Source of potential risk:
Negative interactions with increased populations of carp (e.g. impact is on larvae, juveniles and adults)

Impact of potential risk:

- Population declines within Pike and regionally, if Pike is a source of recruits.

Mean values for scores and risk ratings are presented in Table R24.

Frequency of impact:
For managed inundations, all components are scored as **2-4 years**

Likelihood and Consequence:
The mean likelihood score was **possible.** The mean consequence score was **very major**

Risk rating:
The mean risk rating was **major**

Certainty:
The mean certainty score was **uncertain** for Likelihood and **very uncertain** for Consequence

Model 2:

Source of potential risk:
Negative interactions with increased populations of Gambusia (e.g. impact is on larvae)

Impact of potential risk:

- Population declines within Pike and regionally, if Pike is a source of recruits.

Mean values for scores and risk ratings are presented in Table R24.

Frequency of impact:
For improved base flows, all components are scored as **daily**

Likelihood and Consequence:
The mean likelihood score was **unlikely.** The mean consequence score was **very major**

Risk rating:
The mean risk rating was **moderate**

Certainty:
The mean certainty score was **very uncertain** for Likelihood and **very uncertain** for Consequence

R25: Monitoring

Background

The Pike River floodplain is in a highly altered state and is likely to be an extreme state of precariousness. It must be recognised that applications of environmental water are unlikely to return the floodplain to the condition that would have been observed pre-river regulation. It is not currently possible to predict how similar the conditions that can be achieved will be to pre-regulation conditions. This is largely because we lack sufficient ecological knowledge to predict how floodplains in different conditions will respond. This represents a major hurdle for managers as volumes of environmental water are limited and resilience is an ecosystem property that can be either created or destroyed (Colloff & Baldwin, 2010).

It is critical to recognise that using a regulator to inundate large floodplains under low flow conditions has not been used as a restoration technique anywhere in the world (Nicol, 2007). Consequently there is no precedent for this management activity (Brookes et al., 2006) and actual responses may differ from those expected (Rogers & Paton, 2008).

At the political and social scale, there is an expectation that managing "pieces" of a complex system can improve the condition of the Murray-Darling Basin. However, it is well recognised that landscape scale processes, connectivity and flow regime are key drivers of ecological systems. The expectation that fragmented sites will function as refuges that serve as the major sources of propagules and colonists for other areas (sensu Arthington & Pusey, 2003) is unproven. Consequently, the current investment in recovering water and construction of infrastructure for delivery of EWA needs to be underpinned by investment in research and monitoring to inform adaptive management to ensure that critical ecological processes and functions required to reinstate resilience are maintained (Kingsford et al., 2010).

The cost of environmental water recovery and construction of the upgraded inlets, proposed regulator and associated infrastructure is significant. Monitoring of responses needs to justify this investment of public money and in order to do this robustly, a substantial commitment of funding and resources will need to be made. Pragmatically, cost and available budgets will have a significant influence on what can be monitored and how intensively.

Model 1:

Source of potential risk:

Failure to implement and maintain appropriate monitoring program

Impact of potential risk:

- Inability to identify and manage drivers of change
- Inability to improve operations and prevent long-term damage
- Inability to justify investment into water recovery and construction of infrastructure
- Inflow/discharge rates and inundation regime not optimised

Mean values for scores and risk ratings are presented in Table R1.

Frequency of impact:

The mean frequency score was **annual**.

Likelihood and Consequence:
The mean likelihood scores were **likely.** The mean consequence scores were **moderate**

Risk rating:
The mean risk rating was **moderate** for inability to justify investment, and **major** for the remaining components.

Certainty:
The mean certainty score was **moderately certain**.

Model 2:

Source of potential risk:

Failure of program to detect change

Impact of potential risk:

- Inability to justify investment into water recovery and construction of infrastructure

Mean values for scores and risk ratings are presented in Table R1.

Frequency of impact:
The mean frequency score was **annual**.

Likelihood and Consequence:
The mean likelihood scores was **likely.** The mean consequence scores were **moderate**

Risk rating:
The mean risk rating was **major**

Certainty:
The mean certainty score was **moderately certain**.

8. Risk matrix tables

Table R1 Lack of data

Risk type	Source of potential risk	Impact of potential risk	Likelihood	Frequency	Consequence	Risk Score	Certainty
Lack of data	Distinct lack of data compared to other regionally relevant sites (i.e. Chowilla)	Key habitats for threatened species not identified and managed appropriately	5.0	3.8	4.2	5.0	2.7
		Presence of threatened and/or rare species not identified	4.8	4.3	4.4	5.0	2.4
		Role of aquatic habitats as regional recruitment zone for pest species not known	5.0	3.0	4.2	4.3	2.6

Table R2 Operations; improved base flow and managed inundations

Risk type	Source of potential risk	Impact of potential risk	Likelihood	Frequency	Consequence	Risk Score	Certainty
Operations	Operational capacity	Operations team not resourced sufficiently to respond to required changes in a timely manner	5.0	3.4	4.3	4.6	2.7
	Maintenance	Failure to maintain engineering integrity of structures over the long-term	3.8	1.0	4.0	2.5	2.5

Table R3 In-stream salinity impacts associated with managed inundations

Risk type	Source of potential risk	Impact of potential risk	Likelihood	Frequency	Consequence	Risk Score	Certainty
In-stream salinity impacts	Managed flooding produces a large salinity spike in the anabranch system	Salinity temporarily decreases crop water use efficiency	5.0	2.5	3.0	3.0	3.0
		Salinity temporarily precludes ability to use water for irrigation	5.0	2.5	4.0	4.5	3.0
	Managed flooding produces a large salinity spike in the river downstream	Salinity temporarily decreases crop water use efficiency	4.0	2.5	3.0	3.0	3.0
		Salinity temporarily precludes ability to use water for irrigation	3.5	2.5	4.0	3.0	3.0
	Significant salinity gradient at interface between groundwater and surface water in gaining streams	Localised impact on aquatic macrophytes	3.0	2.0	3.0	1.0	1.0
		Localised density driven stratification	6.0	6.0	3.0	6.0	3.0

Table R4 Changes in soil salinity associated with managed inundations

Risk type	Source of potential risk	Impact of potential risk	Likelihood	Frequency	Consequence	Risk Score	Certainty
Soil salinity	Flooding does not reduce soil salinity	Soil moisture availability is not increased	4.3	2.8	4.3	4.0	1.5

Table R5 Changes in soil sodicity associated with managed inundations

Risk type	Source of potential risk	Impact of potential risk	Likelihood	Frequency	Consequence	Risk Score	Certainty
Soil sodicity	Flooding does not improve sodicity	Soil moisture availability is not increased	4.0	3.5	4.5	5.0	2.0
	Flooding exacerbates sodicity	Water infiltration decreases, soil moisture availability decreases	4.5	4.0	5.0	5.5	2.0

Table R6 Disturbance of sulfidic material

Risk type	Source of potential risk	Impact of potential risk	Likelihood	Frequency	Consequence	Risk Score	Certainty
Sulfidic material	Acid sulfate soils	Areas containing acid sulfate soils are dried and re-wetted causing localised acidification events	2.7	3.0	4.7	3.3	3.0
		Mobilisation of sulfidic material due to increased scour causes rapid deoxygenation	2.7	2.7	4.7	3.7	3.0
		Mobilisation of sulfidic material due to dredging to increase flow rates	3.0	2.3	4.3	2.3	2.7

Table R7 Fringe degradation associated with managed inundations

Risk type	Source of potential risk	Impact of potential risk	Likelihood	Frequency	Consequence	Risk Score	Certainty
Fringe degradation	Managed flooding leads to fringe degradation in areas where depth to groundwater decreases in the absence of flooding	Saline groundwater intrudes into root zone	4.8	3.0	4.3	4.5	2.3
		Soil sodicity increases	5.0	4.0	4.5	5.5	2.0
		Soil salinity increases	4.8	3.0	4.3	4.5	2.3

Table R8 Geomorphology impacts associated with (i) improved base flows and (ii) managed inundations

Risk type	Source of potential risk	Impact of potential risk	Likelihood	Frequency	Consequence	Risk Score	Certainty
Geomorphology	High velocity flows	Banks eroded	3.0	2.0	4.5	3.0	2.5
		Excessive bed scour leads to channel incision	2.5	2.0	3.5	1.0	2.0
	Fast drawdown rates upon recession	Mass bank failure	3.0	2.0	4.0	4.0	2.5
	Slow velocity	Low velocity generates depositional zone and high rates of sedimentation on floodplain	2.5	2.0	2.5	1.0	2.0

Table R9 Hydrology during improved base flows

Risk type	Source of potential risk	Impact of potential risk	Likelihood	Frequency	Consequence	Risk Score	Certainty
Hydrology	Improved inflows	High velocity flows at structures during relatively high flows may not support fish passage	3.5	4.0	3.5	4.0	2.5
		Increased outflow improves attractant flow for fish during base flows but insufficient fish passage results in accumulation of fish downstream of structures	3.5	3.0	4.5	5.0	2.5
		Increased inflow is not combined with increased structural habitat diversity	4.8	4.5	3.7	5.0	2.3
		Increased inflow is not combined with increased hydraulic diversity	4.3	5.0	3.7	5.0	2.0
		Inflow/discharge rates not optimised	5.0	5.0	4.0	5.5	2.0

Table R10 Extraction for consumptive use during improved base flows

Risk type	Source of potential risk	Impact of potential risk	Likelihood	Frequency	Consequence	Risk Score	Certainty
Extraction	Uptake of prior commitment entitlements	Reduction in scale of benefit achievable from increased inlet capacity due to increased extraction	2.0	6.0	4.0	5.0	3.5

Table R11 Biochemical characteristics of EWA during managed inundations

Risk type	Source of potential risk	Impact of potential risk	Likelihood	Frequency	Consequence	Risk Score	Certainty
Biogeochemical characteristics of EWA	Source of water	Operations at low river flow (water derived from storages) limit productivity gains as benefits from upstream flooding are not available	3.7	3.0	3.0	4.5	2.7
		Operations during periods with high turbidity limit aquatic macrophyte and other primary productivity response	4.0	3.0	3.3	4.0	2.3

Table R12 Inundation regime during managed inundations

Risk type	Source of potential risk	Impact of potential risk	Likelihood	Frequency	Consequence	Risk Score	Certainty
Inundation regime	Inundation regime disconnected from river hydrology and meteorological cues	Disconnect between behavioural adaptations to hydrology and/or meteorological cues limits responses from higher trophic levels	5.4	3.0	3.4	4.0	3.0
	Aseasonal (winter) flooding	Potential benefits are not realised due to mismatch between prevailing thermal regime and day-length and behavioural adaptations of biota	4.4	2.5	3.2	2.5	2.0
	Short floods (<10 days)	Chemically mediated (e.g. nutrient release) and biogeochemically mediated process (e.g. blackwater events) occur but biotic responses are very limited	4.4	3.8	3.4	3.3	2.6

Table R13 Harmful of nuisance algal blooms associated with managed inundations

Risk type	Source of potential risk	Impact of potential risk	Likelihood	Frequency	Consequence	Risk Score	Certainty
Harmful or nuisance algal bloom	Insufficient water exchange and/or poor timing (i.e. summer inundation) leads to conditions conducive to bloom formation within anabranch	High phytoplankton biomass in isolated water bodies that do not drain back to river	5.0	2.0	2.0	1.0	3.0
		High phytoplankton biomass in connected water bodies that drain back to river	5.0	2.0	4.0	4.0	3.0
		Socio- amenity values are temporarily decreased	5.0	2.0	4.0	4.0	3.0
	Inundation coincides with high temperature and low flows in river. Dilution/mixing and turbulence is insufficient to "wash-out" phytoplankton biomass derived from anabranch	Phytoplankton bloom develops in river	5.0	2.0	4.0	4.0	3.0
		Toxin issues in river need to be managed for public safety (socio- amenity values are temporarily decreased)	5.0	2.0	4.0	4.0	3.0
		Toxins and taste and odour issues need to be managed in water treatment plants	5.0	2.0	4.0	4.0	3.0

Table R14 De-oxygenation and blackwater events associated with inundations

Risk type	Source of potential risk	Impact of potential risk	Likelihood	Frequency	Consequence	Risk Score	Certainty
Blackwater Event	Insufficient water exchange and/or poor timing (i.e. summer inundation) leads to carbon load exceeding assimilation capacity within anabranch	Hypoxia leads to stress of higher level aquatic organisms (e.g. fish)	5.3	2.3	5.0	5.0	3.3
		Hypoxia interferes with recruitment ecology of fish	5.0	2.0	4.5	4.0	2.8
		Anoxia leads to death of higher level aquatic organisms (e.g. fish)	5.0	2.0	5.0	4.7	3.0
		Hypoxia/anoxia interferes with germination/establishment of aquatic vegetation	2.0	3.5	4.0	2.0	2.0
		Hypoxia/anoxia interferes with establishment of food resources (invertebrates) for higher level organisms (fish, frogs, birds)	5.0	2.0	4.7	4.5	2.0
		Anoxia leads to release of toxic compounds and nutrients from inundated sediments	5.0	2.0	5.0	5.0	3.0
	Downstream impacts	High DOC load from floodplain challenges water treatment plants	5.0	2.0	4.0	4.0	3.0
		Heavy metals and other compounds/elements released from anoxic sediments challenges water treatment plants	5.0	2.0	4.0	4.0	3.0
		Low DO water from floodplain depresses DO in receiving water	4.7	2.0	4.7	3.5	2.7
		DOC from floodplain stimulates heterotrophic activity in receiving water and depresses DO in river	4.7	1.5	4.3	2.5	2.3

Table R15 Expansion of invasive plants associated with improved base flows and managed inundations

Risk type	Source of potential risk	Impact of potential risk	Likelihood	Frequency	Consequence	Risk Score	Certainty
Invasive plants	Changes to hydrology benefits typha	Increased extent and distribution	4.0	3.0	3.0	2.0	2.0
		Channel capacity decreased	3.0	3.0	3.0	1.0	2.0
		Habitat value decreased due to mono-specific stands	3.0	3.0	3.0	1.0	2.0
	Changes to hydrology benefits lippia	Increased extent and distribution	6.0	3.0	5.0	6.0	3.0
		Habitat value decreased due to mono-specific stands	3.0	3.0	5.0	4.0	3.0
	Changes to hydrology benefits arrowhead etc	Increased extent and distribution	2.0	3.0	5.0	3.0	2.0
		Habitat value decreased due to mono-specific stands	2.0	3.0	5.0	3.0	2.0
	Changes to hydrology benefits other invasive plants	Increased extent and distribution	6.0	3.0	5.0	6.0	2.0
		Habitat value decreased due to mono-specific stands	2.0	3.0	5.0	3.0	2.0

Table R16 Failure of native vegetation condition to improve with managed inundations

Risk type	Source of potential risk	Impact of potential risk	Likelihood	Frequency	Consequence	Risk Score	Certainty
Native vegetation	Soil moisture availability is not improved	Growth conditions do not improve	2.0	3.5	5.0	3.0	3.0
		Germination and establishment not successful	4.0	3.5	5.0	5.0	3.0
	Aseasonal (winter) flooding	Propagules from upstream not available	5.0	4.0	3.0	4.0	2.0
		Germination and establishment not successful	3.0	4.0	5.0	5.0	4.0
		Life cycle of annual plants not completed	2.0	4.0	6.0	5.0	4.0
	Inundation and river hydrology not synchronised	Propagules from upstream not available	5.0	4.0	3.0	4.0	2.0
	Repeated germination from seed banks without lifecycle closed	Seed bank is depleted	2.0	2.0	6.0	3.0	3.0
	Grazing pressure is not reduced	Vegetation benefits not realised	4.0	5.0	6.0	6.0	3.0

Table R17 Carp population under increased base flows (L) = likelihood, (C) = consequence

Risk type	Source of risk	Impact of potential risk	Likelihood	Frequency	Consequence	Risk Score	Certainty
Increase in carp populations	Improved **spawning** habitat	Increase in larval population in Pike habitats	4	6	3	5	3 (L) 3 (C)
	Improved **downstream passage** at inlets increases **survival of larvae** from the River Murray	Increase in larval population in Pike habitats	2	6	2	2	3 (L) 3 (C)
	Improved **larval and YOY habitats**	Increased survival of larvae and YOY; local population increases and with emigration, the regional population increases	5	6	3	6	3 (L) 3 (C)
	Increased habitat for **juveniles, sub-adults and adults**	Local population increases and with emigration, the regional population increases	4	6	4	6	1 (L) 3 (C)

Table R18 Carp population under managed inundations (L) = likelihood, (C) = consequence

Risk type	Source of risk	Impact of potential risk	Likelihood	Frequency	Consequence	Risk	Certainty
Increase in carp populations	Improved **spawning** habitat	Increase in larval population in Pike habitats	6	2	5	6	4 (L) 3 (C)
	Improved **downstream passage** at inlets increases **survival of larvae** from the River Murray	Increase in larval population in Pike habitats	2	2	2	1	3 (L) 3 (C)
	Improved **larval and YOY habitats**	Increased survival of larvae and YOY; local population increases and with emigration, the regional population increases	6	2	5	6	4 (L) 3 (C)
	Increased habitat for **juveniles, sub-adults and adults**	Local population increases and with emigration, the regional population increases	2	2	5	2	2 (L) 3 (C)

Table R19 Weatherloach and gambusia under increased base flows (L) = likelihood, (C) = consequence

Risk type	Source of risk	Impact of potential risk	Likelihood	Frequency	Consequence	Risk	Certainty
Increase in weatherloach and gambusia populations	Improved **spawning** habitat	Increase in larval population in Pike habitats	3	6	3	3	3 (L) 2 (C)
	Improved **larval and YOY habitats**	Increased survival of larvae and YOY; local population increases and with emigration, the regional population increases	3	6	3	3	3 (L) 2 (C)
	Increased habitat for **juveniles, sub-adults and adults**	Local population increases and with emigration, the regional population increases	3	6	4	5	1 (L) 2 (C)

Table R20 Weatherloach and gambusia under managed inundations (L) = likelihood, (C) = consequence

Risk type	Source of risk	Impact of potential risk	Likelihood	Frequency	Consequence	Risk	Certainty
Increase in weatherloach and gambusia populations	Improved **spawning** habitat	Increase in larval population in Pike habitats	6	2	4	5	3 (L) 2 (C)
	Improved **larval and YOY habitats**	Increased survival of larvae and YOY; local population increases and with emigration, the regional population increases	6	2	4	5	4 (L) 2 (C)
	Increased habitat for **juveniles, sub-adults and adults**	Local population increases and with emigration, the regional population increases	2	2	5	2	2 (L) 2 (C)

Table R21 Catfish under increased base flows(L) = likelihood, (C) = consequence

Risk type	Source of risk	Impact of potential risk	Likelihood	Frequency	Consequence	Risk	Certainty
Negative impacts on catfish populations	Negative interactions with increased populations of carp (larvae, juveniles and adults)	Population declines within Pike and regionally, if Pike is a source of recruits.	3	6	5	6	2 (L) 2 (C)
	Negative interactions with increased populations of Gambusia (e.g. larvae)	Population declines within Pike and regionally, if Pike is a source of recruits.	3	6	5	6	1 (L) 1 (C)

Table R22 Catfish under managed inundations (L) = likelihood, (C) = consequence

Risk type	Source of risk	Impact of potential risk	Likelihood	Frequency	Consequence	Risk	Certainty
Negative impacts on catfish populations	Negative interactions with increased populations of carp (larvae, juveniles and adults)	Population declines within Pike and regionally, if Pike is a source of recruits.	4	2	5	4	2 (L) 2 (C)
	Negative interactions with increased populations of Gambusia (e.g. larvae)	Population declines within Pike and regionally, if Pike is a source of recruits.	3	2	5	3	1 (L) 1 (C)

Table R23 Threatened species under increased base flows (L) = likelihood, (C) = consequence

Risk type	Source of risk	Impact of potential risk	Likelihood	Frequency	Consequence	Risk	Certainty
Potential negative impacts on threatened species that have not been detected (e.g. purplespotted gudgeons)	Negative interactions with increased populations of carp (larvae, juveniles and adults)	Population declines within Pike and regionally, if Pike is a source of recruits.	3	6	6	6	2 (L) 1 (C)
	Negative interactions with increased populations of Gambusia (e.g. larvae)	Population declines within Pike and regionally, if Pike is a source of recruits.	3	6	6	6	1 (L) 1 (C)

Table R24 Threatened species under managed inundations (L) = likelihood, (C) = consequence

Risk type	Source of risk	Impact of potential risk	Likelihood	Frequency	Consequence	Risk	Certainty
Potential negative impacts on threatened species that have not been detected (e.g. purplespotted gudgeons)	Negative interactions with increased populations of carp (larvae, juveniles and adults)	Population declines within Pike and regionally, if Pike is a source of recruits.	4	2	6	5	2 (L) 1 (C)
	Negative interactions with increased populations of Gambusia (e.g. larvae)	Population declines within Pike and regionally, if Pike is a source of recruits.	3	2	6	4	1 (L) 1 (C)

Table R25 Monitoring

Risk type	Source of potential risk	Impact of potential risk	Likelihood	Frequency	Consequence	Risk Score	Certainty
Monitoring	Failure to implement and maintain appropriate monitoring program	Inability to identify and manage drivers of change	5.3	3.3	4.4	5.2	3.4
		Inability to improve operations and prevent long-term damage	5.1	3.3	4.8	5.3	3.3
		Inability to justify investment into water recovery and construction of infrastructure	5.0	3.3	4.0	4.8	3.0
		Inflow/discharge rates and inundation regime not optimised	5.0	3.8	4.3	5.0	3.0
	Failure of program to detect change	Inability to justify investment into water recovery and construction of infrastructure	5.0	3.3	4.3	5.3	3.3

9. Key principles for consideration when planning the use of environmental water allocations

Landscape scale processes, connectivity and flow regime are key drivers of ecological systems. Wallace et al (2011) compiled the following list of key principles that must be taken into account when planning the use of environmental water in order to maximise positive outcomes.

- **It is not just the presence of water that is important for maintenance of ecosystem function**
    - The 'quality' of water is an important feature in addition to the quantity of water or the temporal patterns of flow
    - The method of achieving and maintaining inundation and the resultant dilution and downstream dispersal of carbon and nutrients will have a significant impact on water quality via biogeochemically mediated processes
    - Managed floods using infrastructure must maintain high rates of water exchange in order to maximise benefits and minimise risks
    - Ponded flooding should be avoided
    - The delivery of EWA to components of river systems cannot replace the function of natural overbank flows

- **Lateral and longitudinal connectivity drive system productivity**
    - Crucial functions of rivers depend on lateral and longitudinal hydrological connectivity
    - Movement of propagules that can colonise sites and improve condition of degraded sites is dependent on connectivity
    - Lateral and longitudinal connectivity is essential to the viability of populations of many species
    - Managed floods that do not provide strong lateral and subsequent longitudinal transfer of allochthonous material minimise or even preclude the potential for transfer of productivity gains
    - Returning water, that contains a high biomass of prey items and increased nutrient loads, to river channels is likely to improve the recruitment success of fish inhabiting those river channels

- **Habitat and primary productivity drive ecological outcomes**
    - The processes which are influenced by flow and floodplain inundation include hydrodynamics, biogeochemistry and primary productivity
    - Higher order organisms respond to these habitat and primary productivity drivers
    - Differences in the quality of outcomes between natural and managed floods will be driven by the effects of processes that cascade across multiple trophic levels
    - It is essential to manage processes to influence outcomes
    - Trying to improve the condition of only a small subset of the ecosystem without considering the consequences of the intervention on the ecosystem as a whole may cause unwanted and potentially catastrophic effects

- **Variability is essential**
    - Flow magnitude, frequency, timing, duration, rate of change and sequence all hold major ecological significance

- Variability in these factors is potentially more important than biological factors in structuring aquatic communities
- Ensuring EWA's are delivered with variability in all of these factors is essential to achieve positive outcomes for multiple abiotic processes and biotic groups
- Variability is essential to minimise the possibility for negative outcomes to become dominant over cumulative events

- **Ecological outcomes will be related to the antecedent conditions**
  - Sequential floods maintain soil moisture and water levels in wetlands increasing the potential for subsequent flows to travel further downstream and/or inundate larger areas
  - Sequential floods are likely to have positive cumulative effects on biotic responses
  - Meteorological cues may be important for some ecological processes
  - Timing of flooding will have a significant impact on outcomes
  - EWA's delivered into an individual site (i.e. wetland) during periods of low flow may restrict the ecological outcomes as the productivity gains from upstream flooding are not available to be transported into the managed site

- **Reinstate resilience in order to withstand future droughts**
  - Management needs to focus on reinstating resilience as the most pragmatic and effective way of managing ecosystems in order to withstand future droughts and provide ecosystem services
  - Reducing the persistence and severity of engineered droughts will increase the ability of floodplains to withstand climate derived droughts
  - EWA's should be used to capitalise on outcomes from preceding flows to (i) ensure germination/spawning/breeding leads to recruitment, and (ii) build resilience, rather than being primarily used as a management tool after long-dry periods to prevent collapse of systems
  - The scale of intervention needs to expand from the management of individual wetlands and preventing loss of populations of individual species, to ecosystem management at the landscape scale

10. Potential approaches to mitigate risks

This list of recommendations is not exhaustive but is provided to outline some of the issues that should be taken into account when considering how to mitigate against the risks associated with delivering improved base flows and managed inundation regimes at the Pike Floodplain. It is important to note that mitigation strategies will need to be developed, implemented and regularly reviewed by the operations committee that is established to oversee operations. Detailed information on tools and options for mitigating risks should be contained in the operating strategy that will need to be developed.

The large degree of uncertainty around outcomes currently requires operations to be undertaken with substantial degree of "buffer" between anticipated benefit/risk and acceptable level of risk. Once the risks and benefits are quantified and the level of uncertainty is reduced, operations will be able to be undertaken that are closer to the limits of acceptable risk.

- Rates of recession need to be carefully managed to avoid bank failure and maximise outcomes for birds, fish and vegetation.

- Altering the extent of inundation in subsequent floods will aid in reducing the development of a fringe of degradation at the outer extent of the flood extent (Overton & Doody, 2008).

- There have been previous recommendations on channel desilting and clearing to ensure the sustainability of the supply of irrigation water from the Pike Anabranch (Burnell & Watkins, 2008). However, it is considered that disturbance of sulfidic material that is known to be present and widely distributed in channels needs to be considered. For example, acid sulfate material is distributed throughout Snake Creek (Shand et al., 2009). The two options that were identified in the workshop (i) dredging of the creek to improve flow; and (ii) drying of this creek by isolating it from the permanent channels in order to improve flow through other creeks is not recommended without a detailed assessment of risk and benefit

- The two most important factors controlling the likelihood of a blackwater event are water temperature and carbon loading (Baldwin & Wallace, 2009; Hladyz et al., 2011). Consequently, the timing of managed inundations is critical in managing river systems. Flooding in summer is problematic as this coincides with peak litter fall; and for every 10 °C increase in water temperature the rate of oxygen depletion approximately doubles (Howitt et al., 2007).

- The risk of establishment of a blackwater event can be largely managed by (i) not utilising ponded floods for delivery of EWA's; (ii) maximising water exchange when using large constructed infrastructure; and (iii) avoiding flooding during warm periods (Baldwin & Wallace, 2009).

- If flows in the main channel are low when water is discharged from the floodplain, hypoxic blackwater is more likely to have negative outcomes on downstream systems. Where the risk of generating hypoxic blackwater is high, managed inundations should occur in conjunction with increased flows in the receiving waters to ensure sufficient dilution is available to mitigate potential negative outcomes (Whitworth et al., 2011)

- The ability of flows in the main channel to dilute hypoxic blackwater needs to take into account the oxygen concentration of water in both water sources, the proportion of flow and the potential for

the mixing of the two water sources to stimulate oxygen demand (Wallace, unpublished data Wallace & Lenon, 2010; Whitworth et al., 2011).

- The risk of initiating an algal bloom in the main channel is greatly increased if managed inundations are undertaken when flows in the main channel are low as: (i) the water column is more likely to be stratified; and (ii) there is less water to dilute and "wash-out" the biomass of phytoplankton coming from the river (Brookes et al., 2007)

- Reduced water exchange and water quality deterioration are a major threat. The critical flow threshold to prevent the onset of thermal stratification in the Pike River and the adjacent reaches of the River Murray should be determined. This information will inform minimum flows in the river at which operation of the proposed environmental regulator should be operated. For example, Bormans et al. (1997) demonstrated that under low flow conditions (<10,000 ML d^{-1}) periods of diurnal and persistent stratification occur in the River Murray when winds speeds are moderate (1.2–2.9 m s^{-1}) and low (<1.2 m s^{-1}).

- Flow rates within the inundated zone should be maintained as high as practicable to increase both the rate of movement of material from the floodplain back to the river channel, but also to increase the rate of exchange and re-aeration of the floodwater.

- A contingency flow needs to be held to manage any negative water quality outcomes. This may be delivered in the form of increased flow to (i) break down stratification and disperse any undesirable algal blooms, and (ii) decrease the relative proportion of hypoxic water from the floodplain in the river, and thereby increase dissolved oxygen concentrations. The logistics of being able to deliver this water in a timely manner requires careful consideration

- Previous studies have recommended that managed inundations be undertaken in winter to reduce the magnitude of spawning response from pests such as carp (Mallen-Cooper et al., 2011; Stuart et al., 2011). Brookes et al (2007) recommended that flooding in the cooler part of the natural flooding season may be used as a tool to minimise the potential for water quality risks. The risk of prolonged hypoxia increases when temperatures increase above 20°C (Whitworth et al., 2011). This concept of "early season" flooding should be utilised to reduce the potential for converting risks into hazards. However, a potential drawback of this approach is that this may further decouple floodplain inundation from (i) hydrology in the main channel and; (ii) day-length, thermal regime and behavioural adaptations of biota (seasonal cues) and the availability of propagules from upstream. The ecological tradeoffs in this area are poorly understood and this needs to become a research priority in order to ensure maximum positive outcomes are achieved at minimal risk.

- It is generally considered that improvements of the inlet structures will improve hydrology and connectivity and deliver some ecological benefits with low risk. The relative magnitude of risks associated with water quality and reduction of lotic habitat diversity are likely to diminish if 'moderate' and 'large' inundations are only generated during periods of relatively high (e.g. well in excess of 10,000 $MLday^{-1}$) flows . Consequently the level of risk during managed inundations is directly linked to the magnitude of the prevailing flow such that risk is likely to be relatively low at high flows. Achieving an acceptable point of utilisation of the structure will be dependent on a range of factors including:

- prevailing hydrograph
- condition of floodplain
- likely trajectory of floodplain condition without intervention
- objectives of the specific operation
- level of certainty for anticipated risks and benefits
- proven hazards
- availability of environmental water
- level to which the managers are risk adverse

11. Recommendations

This list of recommendations is not exhaustive but is provided to outline some of the issues that should be taken into account when considering the implementation of improved base flows and managed inundation regimes at the Pike Floodplain.

- A monitoring program that incorporates the ecological objectives, a set of preliminary yet defensible ecological targets, and the issues raised in this current document and risk assessments for other, large floodplain sites contemplating introduction of managed inundation regimes should be developed as a priority. The monitoring strategy recently developed for the Chowilla floodplain represents a basis for such a monitoring program to be built upon.

- The ability to incorporate BACI experimental designs is relatively unique. This feature of the Pike Floodplain should be utilised in site specific investigations, and the floodplain should be considered as a study site when undertaking research that will inform management at a range of sites.

- Spatial and temporal linkages between the locations and timing at which monitoring for respective components is undertaken need to be made. For example, it is well recognised that the type of understorey associated with floodplain trees is generally regarded as a key ecological feature, and that depth to groundwater and groundwater salinity are known drivers of vegetation condition. Locations of the standardised tree condition assessment sites, understorey vegetation transects (including lignum) and groundwater monitoring bores should be linked where practicable. Coupling the spatial and temporal monitoring will improve the potential to understand ecological processes and ecological outcomes.

- A monitoring program incorporating regular assessments of depth to groundwater and soil salinity and sodicity should be implemented as a priority. A baseline assessment of the distribution of sodic soils is currently underway and due for completion in late 2011.

- It is anticipated that the influence on scour processes will be highly localised, confined largely to the upper reaches of the inlet creeks. A baseline survey of channel geomorphology and depth of soft sediments should be carried out before the flow regime changes in order to assess the influence of (i) improved flows and (ii) managed inundations on scour and sedimentation.

- It is generally anticipated that increased hydraulic diversity will deliver positive outcomes during managed inundations (Wallace et al., 2011). However, poorly managed inundations may actually reduce the diversity of hydraulic habitats. Consequently, it will be important to test the assumption that improved inflow increases the diversity of hydraulic habitat types.

- It is anticipated that the influence on freshening the groundwater via vertical and lateral infiltration will be ecologically significant but relatively short lived due to the regional groundwater processes. A higher inundation frequency is likely to increase the benefit that could be achieved. This must be balanced with managing risks to other ecosystem components.

- The spatial extent, longevity and magnitude of benefits to soil moisture that can be achieved from managed inundation compared to (i) natural floods and (ii) rainfall should be a research priority. Maintaining relatively high soil moisture availability must be regarded as one of the overarching management objectives for the site.

- Black box communities are typically difficult to target via managed inundation regimes due to the relatively high elevations at which they are normally distributed. Maintaining sustainable communities of ecologically significant size that are connected to adjacent functional landscapes types needs to be a management priority.

- The role of increased floodplain vegetation condition in carbon sequestration and conversely the release of carbon dioxide and methane during inundations are currently major knowledge gaps requiring attention.

- Interactions between soil conditions (moisture, salinity, sodicity) and floodplain understorey vegetation community dynamics remains a knowledge gap. Increasing the level of understanding of the role of understorey vegetation in supporting diverse and sustainable communities of native fauna, and the role of understorey vegetation in nutrient/carbon cycling and food webs should be a management priority.

- Developing an understanding of the relative importance of small-scale waterbird breeding events within systems such as the Pike River anabranch at both local and regional scales should be a management priority.

- During flow pulses, there may be a substantial increase in propagules from upstream flooding available to be transported into the Pike system. The magnitude of benefit that may be derived from directing these resources into the Pike system and then returning any subsequent productivity gains to the river may be partially constrained by the relatively low proportion of total flow that can be passed through the Pike system compared to systems such as the Chowilla anabranch. Developing an understanding of the role of the Pike anabranch as a sink, source or pathway of resources should be a management priority.

- It is anticipated that methods of delivering environmental water that do not maximise connectivity will compromise the ability of the environmental water allocations to achieve positive ecological outcomes (Wallace et al., 2011). The low certainty scores combined with the high expectation of positive outcomes associated with improved structures identify this as a key knowledge gap requiring attention.

- Developing an understanding of the degree of resilience remaining within the floodplain, and limits of acceptable change must become a management priority.

- The existence of, or potential for salinity driven stratification due to discharge of saline groundwater in gaining reaches should be determined. The observation that sites in Punkah Creek (Wallace & Lenon, 2010) were persistently thermally stratified suggests that some gaining reaches in the Pike River system may be permanently stratified.

- There is currently no site-scale program specifically designed for monitoring water quality parameters. Data on nutrients, carbon and other physico-chemical (e.g. pH, turbidity) parameters should be collected at low temporal frequency during low flow periods and at high temporal frequency during inundations.

- A permanent water quality monitoring network building on the existing salinity pontoons should be established as a key priority. During managed inundations, parameters such as thermal stratification, dissolved oxygen, and chlorophyll should be recorded at very high (sub-hourly) temporal resolution. During inundations the data collected from this logger network must be available in real time (i.e. the system needs to be telemeted) in order to allow managers to respond to conditions in a timely and effective manner.

- It is not currently possible to measure DOC using *in-situ* equipment. However, there may be potential for the *in-situ* monitoring of UV-absorbance, a parameter that can be used as a surrogate for DOC (Baldwin, 1999; Brookes et al., 2007; Hackbusch, 2011).

- The frequency of managed inundations should take into account (i) the decline in soil moisture availability and exhaustion of freshwater lenses associated with long inter-flood periods and (ii) the effects of successive years of leaf litter accumulation on water quality (Whitworth et al., 2011).

- Improving the extent of data on the fish community should be a priority. This will (i) reduce the uncertainty regarding the potential presence of threatened or rare species that were not recorded in the baseline surveys and (ii) improve ability to robustly determine if changes to hydrology do benefit the fish community

- Beyer et al (2010) concluded that the system appears to provide conditions facilitating the increased presence of non-native fish species as opposed to native species. However, the Pike anabranch system may provide a good template for a habitat restoration approach. Management of the floodplain via the increase of the diversity of micro- and mesohabitats, i.e. through the increase of connectivity and flowing habitats, may facilitate increased fish species diversity and abundance within the Pike Anabranch system.

- Beyer et al (2010) suggested that the lack of habitat heterogeneity is a factor likely to be contributing to the relatively low species richness recorded at Pike River compared to the Chowilla Anabranch. The existing data on submerged woody habitat (Beyer et al., 2010) in the Pike system should be reviewed with consideration given to the potential for targeted reintroduction of submerged woody habitat (snags) to improve habitat quality and quantity

- The role of managed inundations in enhancing food resources and improving recruitment conditions for higher trophic levels is a major knowledge gap. Determining the relative abundance and quality of food resources in the Pike River and adjacent reaches of the Murray in (i) low flow, (ii) managed inundations and (iii) unregulated floods, should be a key research priority. This knowledge will enhance and improve managed inundations at a range of lowland river floodplains within and beyond the Murray-Darling Basin.

- Due to a combination of (i) lack of data, (ii) incomplete understanding of ecological processes; and (iii) the management actions being considered is unprecedented, there is a high degree of uncertainty in the assessments undertaken in this report. Many of the models tested are based on expert opinion and untested conceptual models. A key issue here is that excessive reliance on theory rather than empirically verified interactions (science) misleads ecology (Karr, 1999) such that

untested conceptual models become pseudo-fact. It is essential to test the models to the new disturbance regime to ensure that unforseen outcomes do not result in long-term or irreversible damage

- The panel did not have representation from an ecologist with expertise in (i) frog ecology or (ii) geomorphology. Consequently, the scores and benefit/risk ratings applied to these components needs to be considered with an appropriate level of caution. It is recommended that advice on these components is sought to validate the information outlined in this assessment.

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