REVIEW OF THE ACT *WATER RESOURCES ENVIRONMENTAL FLOW GUIDELINES 2013*

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Produced by:

Institute for Applied Ecology

appliedecology.edu.au

University of Canberra, ACT 2601

Telephone: (02) 6201 2795

Facsimile: (02) 6201 5651

Authors:

Dr. Adrian Dusting, Mr. Ben Broadhurst, Dr. Sue Nichols, Dr. Fiona Dyer

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Inquiries regarding this document should be addressed to:

Dr. Fiona Dyer

Institute for Applied Ecology

University of Canberra

Canberra 2601

Telephone: (02) 6201 2452

Facsimile: (02) 6201 5651

Email: Fiona.Dyer@canberra.edu.au

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Front cover photo: Cotter River at Top Flats. Photo by Fiona Dyer

TABLE OF CONTENTS

FIGURES

TABLES

EXECUTIVE SUMMARY

BACKGROUND AND OBJECTIVE

- The ACT's Environmental Flow Guidelines (EFG) identify components of flow necessary to maintain stream health, with the overarching objectives of the protection of biological diversity and the maintenance of ecological processes.
- It is a requirement that the current (2013) EFG are reviewed after five years of operation to determine if nominated ecological objectives remain the most appropriate, and to examine if the implemented environmental flow program meets those objectives. The present report provides advice on the efficacy of the current EFG and recommendations for revising the EFG in line with current scientific knowledge and the contemporary policy context.
- The approach taken for the current review was to evaluate the effectiveness of current environmental flows by assessing monitoring data from across the ACT's aquatic ecosystems. Findings were then used to inform the development of proposed changes to the EFG, supported by consultation with local scientific experts.

RESULTS AND CONCLUSIONS

- Since the implementation of the 2013 EFG, e-flows are likely to have had a beneficial influence on aquatic ecosystem health. Hydrological conditions have been conducive to the provision of environmental water, and the ecological objectives of environmental flows have been met in some cases, but not all.
- Some indicators of aquatic health have not been the subject of formal monitoring, these include sediment dynamics and macrophyte assemblages. This highlights the need for the closure of the adaptive management loop embedded in the EFG.
- The present report provides draft ecological objectives, flows and indicators, developed as part of the revision process. All proposed revisions include consideration of requirements under the Murray-Darling Basin Plan. These are incorporated into a draft revised EFG which accompanies this report.
- The review process identified numerous knowledge gaps which limit the formulation of ecological objectives and prescription of flows. Future reviews of the EFG will benefit from research into these areas.
- In addition to reach-specific recommendations, two broad suggestions are presented for consideration:
    - That the EFG include a clear articulation of links between the EFG and other relevant documents, including the Territory Plan and Icon Water's *Licence to Take Water*
    - The revised EFG include a formalisation of an adaptive management approach, incorporating clear feedback mechanisms for monitoring and reporting, as well as procedures to ensure this feedback takes place.

INTRODUCTION

HISTORY OF ACT ENVIRONMENTAL FLOW GUIDELINES

The aquatic ecosystems of the ACT are relied upon for a variety of competing demands, many with the potential to threaten the ecological health of waterways. The ACT's environmental flow guidelines identify the components of flow necessary to maintain stream health, with the aim of ensuring the persistence of critical habitat and ecosystem processes.

The ACT's *Water Resources Environmental Flow Guidelines 2013* (ACT Government 2013) is a legislative instrument under the ACT *Water Resources Act 2007* (ACT Government 2007b). The Environmental Flow Guidelines (EFG) were first introduced in 1999, and subsequently revised in 2006 and 2013 (ACT Government 1999, 2006, 2013). The continuing development of the EFG has been informed by EFG reviews in 2004 and 2010 (Ogden *et al.* 2004, Hillman 2010) and guided by an Environmental Flows Technical Advisory Group (EFTAG). The EFTAG comprises representatives from the ACT Government, ACTEW (now Icon Water) and the CRC for Freshwater Ecology (now the Institute for Applied Ecology, IAE, University of Canberra). Recurrent revision of the EFG has enabled the incorporation of improved understanding of the flow requirements of aquatic ecosystems in ACT under a range of climate conditions, and the application of the best available science.

SCOPE AND APPROACH OF REVIEW

TIMING AND CONTEXT

The EFG are central to planning and managing the ACT's water resources and it is a legislated requirement that the EFG are reviewed after five years. The 2017 review of the EFG is timely, given recent changes to the national water policy context to which the ACT is signatory. Central to this is the need for the ACT to provide a 10 year Water Resource Plan that demonstrates how surface water and groundwater is managed in the ACT consistent with the Basin Plan. The revised EFG will inform the development of an ACT Long Term Watering Plan, a requirement for the ACT's Water Resource Plan. More detail on alignment with the Basin Plan is provided below.

REVIEW SCOPE

The 2017 review was conducted to provide advice for revising the ACT's EFG. In particular, the review considered:

- the effectiveness of the current EFG, evaluated through monitoring and research conducted since the implementation of the 2013 EFG.
- ecological objectives for revised EFG, taking into account EFG evaluation outcomes, current policy context and advances in scientific knowledge base since 2013 EFG.
- revised flow regimes needed to meet ecological objectives
- indicators necessary to assess the efficacy of flows in achieving ecological objectives
- opportunities for increased adaptive management of environmental flows

See Appendix 1 for full terms of reference, as supplied by the ACT Government Environment, Planning and Sustainable Development Directorate.

REVIEW APPROACH

The 2017 review of the EFG was carried out in sequential stages:

1. 2013 EFG evaluation. Existing monitoring data and compliance reports were used to determine if the ecological objectives prescribed in the 2013 EFG are being met by the current implementation of e-flows. This highlighted some successes, areas for improvement and considerable knowledge gaps. These were summarised in a separate report and used to guide the subsequent stages of the review.

2. Expert workshops. Two workshops involving the Environmental Flows Technical Advisory Group (EFTAG), ACT Government Steering Committee, MDBA staff and local technical expertise were held in June/July 2017. This collaborative approach has the advantage of drawing on scientific and operational expertise, in combination with planning and policy expertise.

   The aim of the first workshop was to review the objectives in the EFG, revise objectives where necessary, and identify the flow and water level recommendations for achieving them. The second workshop built on the outcomes from workshop 1, identifying indicators for assessment of each of the revised EFG objectives. Implementation of effective adaptive management context was also discussed, along with operational issues associated with providing e-flows.

3. Draft report and revised EFG. A draft review report was prepared, tying together the above components of the review for consideration by the ACT Government, EFTAG and MDBA. It consists of a summary of the assessment of the 2013 EFG and recommendations for amendments to the EFG, based on workshop outcomes and scientific literature review. The draft report was prepared in part as supporting documentation to a draft set of revised EFG.

4. Final review report and revised EFG. The present report incorporates extensive feedback provided on the draft review report by stakeholders including the ACT Government, EFTAG, Icon Water and MDBA. It provides supporting documentation to a set of proposed revised EFG, which have been further revised in light of feedback from the above stakeholders. Components of the report are summarised and incorporated into appendices of the revised EFG.

REPORT STRUCTURE

The structure of this report largely mirrors the sequential stages of the review process. The overarching purpose and framework of the existing EFG are outlined first. The effectiveness of the current EFG is then assessed using compliance reports and an analysis of monitoring indicators against EFG ecological objectives. A summary is then provided of broader contextual factors considered as part of the 2017 review process, in particular ways in which the EFG can be designed to align with the Murray-Darling Basin Plan and to remain responsive to a changing climate. The methods and outcomes of the review process are discussed, before recommendations are presented. Other recommendations for consideration are highlighted throughout the report and summarised in the concluding remarks.

CURRENT ENVIRONMENTAL FLOW GUIDELINES

The provision of environmental flows (e-flows) has evolved over the last two decades from a narrowly focused aquatic conservation strategy into a means to provide broad ecological benefits (Poff and Matthews 2013). This evolution has been accompanied by advances in methods used to establish e-flows and in our understanding of the most effective application of e-flows. The process of providing e-flows within the ACT has paralleled the evolution of e-flow science and practise, with a sound scientific understanding and an adaptive management context underpinning the development of, and revisions to, the ACT's environmental flow guidelines (Peat and Norris 2007).

The current (2013) ACT EFG define environmental flows as:

"*Environmental flows are the flows of water in our streams, rivers and impoundments that are necessary to maintain aquatic ecosystems"* (ACT Government 2013).

PURPOSE AND FRAMEWORK OF CURRENT GUIDELINES

The philosophy behind the ACT's EFG is that in their natural state, aquatic ecosystems are adapted to particular flow conditions, and that alteration of those flow conditions will impact the ecosystem. Impacts will, in most cases, have negative consequences for biodiversity and conservation values. This is widely supported by the scientific literature (Petts 2009, Poff and Zimmerman 2010, Carlisle *et al.* 2011). In the ACT, natural flow conditions entail a flow regime that is highly variable and includes a range of flow conditions, from flood to cease flow events. The EFG identifies and protects components of this variable flow regime, with the aim of maintaining aquatic ecosystem health. Thus, the overarching objectives of the EFG are the protection of biological diversity and the maintenance of ecological processes.

Recognising differences among the aquatic ecosystems of the ACT and the way in which they are managed, four different categories of aquatic ecosystems are identified in the EFG: Natural, Water Supply, Modified and Created Ecosystems. Each have different flow management needs to achieve the broader ecological objectives and are considered separately within the EFG. The separate consideration of different types of aquatic ecosystems in the ACT also reflects the options available for managing flow regimes and the competing needs for water in different parts of the system.

The definitions and management goals of each ecosystem type were discussed at length as part of the review process. Several amendments to the existing framework are suggested in the Recommendations section toward the end of this report.

FRAMING ENVIRONMENTAL FLOWS

The purpose and framing of the ACT's EFG implies a broader definition of environmental flows than is provided within the current (2013) ACT EFG in which environmental flows are confined to the flow of water in streams, rivers and impoundments. The definition used in the 2013 EFG is a shortened version of the definition that appeared in the 1999 guidelines:

> '*Environmental flows are defined as the stream flow necessary to sustain habitats (including channel morphology and substrate), encourage spawning and the migration of fauna species to previously unpopulated habitats, enable the processes upon which succession and biodiversity depend, and maintain the desired nutrient*

> *structure within lakes, streams, wetlands and riparian areas. Environmental flows may comprise elements from the full range of flow conditions which describe long-term average flows, variability of flows including low flows and irregular flooding events'* (ACT Government 1999).

This definition still focusses on stream flow, but mentions lakes, streams, wetlands and riparian areas. Given the focus of the ACT EFG on a range of freshwater ecosystems, it is recommended that a broader definition be provided.

Definitions of environmental flows within the scientific literature and operational documents vary. One of the more accepted definitions is from the 2007 Brisbane Declaration:

> *'Environmental flows describe the quantity, timing and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend upon these ecosystems'* (Brisbane Declaration, 2007).

While this definition is a very anthropocentric view of environmental flows, the focus is on quantity, timing and quality for freshwater ecosystems, not just rivers. The current focus of the MDBA and the Commonwealth Environmental Water Office is the delivery of water. Consequently their definitions are focussed on improving health and establishing volumes of water:

> *Water used to improve the health of our rivers, floodplains and wetlands is known as environmental water* (http://www.environment.gov.au/water/cewo).

Such definitions of environmental water do not take into account situations in which freshwater ecosystems are protected by limiting or prohibiting extraction as occurs in the current EFG.

Recommendation: A broader definition of environmental flows be adopted in the revised EFG. The following definition is proposed:
Environmental flows describe the quantity, timing and quality of water required to sustain freshwater ecosystems.

ENVIRONMENTAL FLOW PROVISION IN THE ACT

There are a multitude of methods used around the world for establishing the environmental flow requirements for aquatic ecosystems (Tharme 2003, Acreman and Dunbar 2004), each with differing knowledge requirements and degrees of complexity. The overarching approach to establishing environmental flow requirements in the ACT is a holistic approach (sensu King *et al.* 2003). This whole of ecosystem approach recognizes the role of all the different components of the flow regime for biophysical outcomes and ecosystem health, rather than focussing attention on a few taxa (Arthington *et al.* 1992). Consequently, the components of the flow regime that are explicitly considered in establishing environmental flows are base flow; small floods (riffle maintenance) and larger floods (pool or channel maintenance flows). This approach is augmented by the establishment of special purpose flows directed at supporting specific ecological attributes (for example for the spawning of threatened fish) and limiting impoundment drawdown level (to protect aquatic macrophytes). This is more akin to the building block approach of establishing environmental flow requirements (King and Tharme 1994).

There are limitations to all methods used to establish environmental flow requirements. A criticism of holistic methods is that without returning large amounts of water (to the river) it is not possible to generate the ecosystem outcomes/improvements that are desired and the specific needs of charismatic species may not be met. Alternatively, the building block method has been widely criticised because it requires more knowledge of flow-ecology dependencies than is typically available. By combining elements of the holistic approach with elements of the building block approach, the ACT has attempted to overcome some of the limitations of each approach to achieve ecosystem outcomes. This remains a best-practise approach to establishing environmental flow requirements.

Environmental flows in the ACT can be provided through releases (or spills) from dams, or through restrictions on water abstraction. Environmental flow volumes are prioritised to the extent that the volume of water available for abstraction under non-drought conditions is limited to that which is remaining after environmental flows have been provided. Abstraction licence conditions also restrict the timing of abstraction such that critical flow events are not impacted or water levels drop below a particular threshold.

The provision of environmental flows can be reduced in water supply catchments during defined drought conditions, and the EFG specify environmental flows to be provided under different stage restrictions. There is an increased risk of degradation to aquatic ecosystems under such restrictions.

OBJECTIVES OF ENVIRONMENTAL FLOWS IN THE ACT

The 2013 EFG included ecological objectives for each of the four ecosystems types. Quantified ecological objectives are used to assess the effectiveness of environmental flows, and to inform adaptive management of future e-flows. Ecological objectives are selected to protect specific values (e.g. threatened species) or to represent ecosystem health more broadly (e.g. functional macrophyte community). The 2013 EFG ecological objectives and indicators have been used to assess the efficacy of the EFG, and the outcomes of this evaluation are summarised below.

The current ecological objectives and their indicators were based on recommendations in the 2004 review of the ACT's EFG (Ogden *et al.* 2004). They were established using best-available science and based on contemporary ecological circumstances. Changes to the ecological and policy context, along with advances in scientific understanding, mean that the 2017 revision of EFG objectives and indicators is timely. Recommendations for amendments to EFG ecological objectives/indicators are provided toward the end of this report. The revised objectives are based on the evaluation report, scientific literature review and outcomes of the review workshops.

ADAPTIVE MANAGEMENT

Adaptive management is the systematic process of continually improving management policies and practices by learning from the outcomes of operational programs. The principles of adaptive management have been embedded in the ACT's EFG since 1999, with e-flows management integrated with ecological objectives, monitoring and reporting requirements.

The present review of the EFG has maintained the approach of developing and revising flows and objectives within an adaptive management cycle. Presented later in this report are recommendations for extending and clarifying the adaptive management cycle in the EFG.

POLICY AND STRATEGY CONTEXT

The ACT's EFG sit within an array of complementary legislation and policy.

i) The EFG itself is a legislative instrument under the ACT *Water Resources Act 2007* (ACT Government 2007b). The protection of environmental flows is the central principle of the Act.

ii) The *ACT Water Strategy 2014-44* details how the ACT protects and manages water resources, targeted at providing healthy waterways and a sustainable water supply (ACT Government 2014).

iii) The *ACT and Region Catchment Strategy* addresses water security, water quality, biodiversity and landscape health at a regional catchment scale, working with neighbouring jurisdictions (ACT Government 2016a).

iv) The *ACT Aquatic Species and Riparian Zone Conservation Strategy* details approaches for protecting the ACT's aquatic biodiversity and ecosystem health (ACT Government 2007a). It is currently under revision.

v) The ACT Long-Term Watering Plan will provide long-term objectives and strategies for managing environmental water, aiming to contribute to Basin-wide environmental outcomes.

vi) The ACT Water Resource Plan demonstrates how management of surface water and groundwater is consistent with the *Murray-Darling Basin Plan*, including provisions for environmental watering (ACT Government 2016c).

vii) The Territory Plan is the key planning document in the ACT. Its purpose is to manage land use change and development in a manner consistent with strategic directions set by the ACT Government (ACT Government 2008).

viii) *Licence to Take Water* (Licence No. WU67), granted to Icon Water, details the volume and timing of water that can be taken from Cotter, Queanbeyan and Murrumbidgee rivers for the purposes of urban water supply .

Recommendation: The interface between these documents and the EFG is complex and in some cases, opaque. It is recommended that greater transparency is introduced into the EFG by explicitly stating how particular guidelines are influenced by other legislation.

EVALUATION OF CURRENT EFG

It is a requirement that the current (2013) EFG are reviewed after five years of operation to determine if nominated ecological objectives remain the most appropriate, and to examine if the implemented environmental flow program meets those objectives.

Compliance reports and monitoring data were used to determine if the prescribed ecological objectives for ACT aquatic ecosystems are being met by the current implementation of the EFG. The period of assessment was 2013-2017, though it necessarily incorporated legacy effects of earlier applications of superseded environmental flow guidelines. The evaluation was the subject of separate report, and a summarised version is provided below.

The prevailing hydrological conditions are provided as a background to understanding the capacity for e-flows to be delivered during the assessment period. Compliance with e-flow requirements is then briefly discussed before monitoring against EFG ecological objectives is assessed.

The evaluation informed subsequent stages of the revision processes by identifying strengths, weaknesses and knowledge gaps in the current EFG.

HYDROLOGICAL CONDITIONS

Regional hydrological conditions have performed a significant role in shaping the management of water resources in the ACT, particularly during periods of water scarcity. This has certainly been the case during the evolution of the EFG over the last two decades, and is evident in the inclusion of special provisions for Water Catchment Supply Ecosystems during times of drought.

Likewise, reviews of the efficacy of the EFG are influenced by the hydrological conditions during monitoring and evaluation periods. The previous review was dominated by consideration of the impacts of drought conditions on environmental flows and their outcomes (Hillman 2010). However, unlike the previous evaluation period (2006 to 2009, Hillman 2010), the current evaluation period has experienced average rainfall (Figure 1) and flow (Figure 2) conditions.

During the present evaluation period there has been a complete absence of water restrictions, noting that the ACT has permanent water conservation measures in place (Icon Water Ltd. 2017a). These water conservation measures were introduced in November 2010 following the breaking of the millennium drought and almost 8 years of water restrictions. At the time of review, ACT water storages were at capacity and had been at or above 80% capacity for the majority of the evaluation period (Icon Water Ltd. 2017b).

Hydrological conditions in the ACT are such that there has been no need to invoke the special provisions for environmental flows in water supply catchments during drought periods. There has been ample water available to provide for environmental flows, and in many cases flows have exceeded EFG requirements (see Figures 3-6). Indeed, the level of flows above minimum requirements may somewhat obfuscate assessment of ecosystem response to environmental flows. Assessing if minimum flows under the guidelines are appropriate to bring about the desired ecological outcome is difficult when flows consistently exceed those minimum levels. In such cases, the measured ecological outcome may be a result of required flows or flows above this level. This should be considered when attempting to assess the efficacy of EFG in meeting ecological objectives.

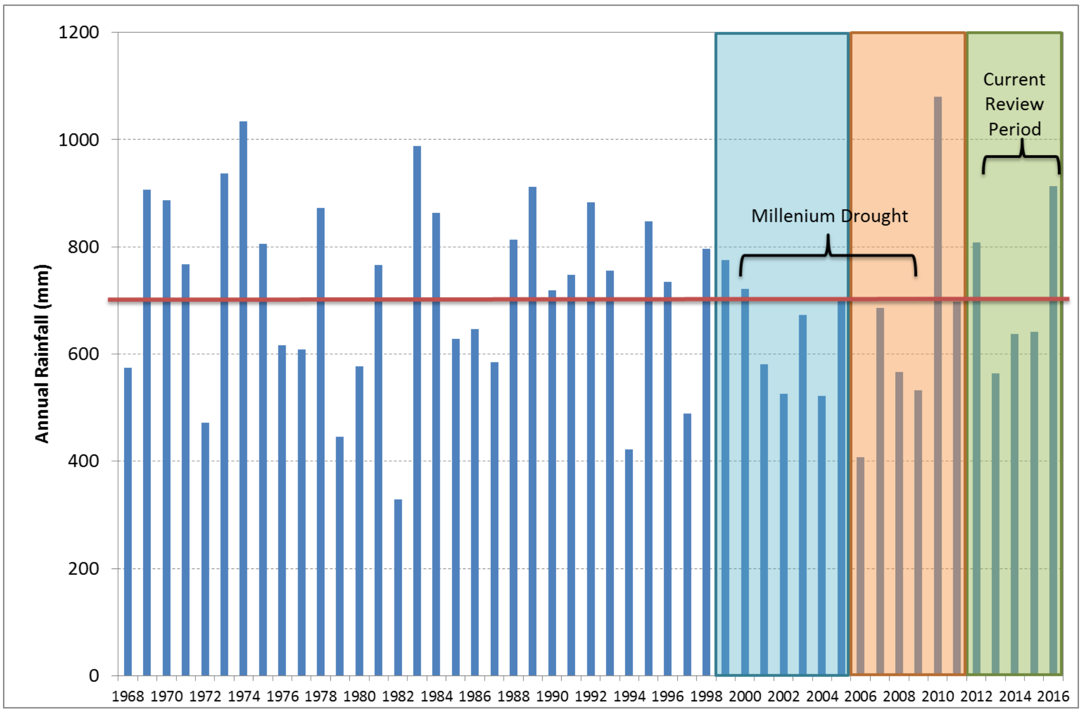

Figure 1. Total annual rainfall from the gauge at the National Botanic Gardens (Station no. 070247) in Canberra. The red line shows the long term mean annual rainfall (703 mm/year). The coloured backgrounds show the different environmental flow guideline periods for the ACT's water resources. Data from the Bureau of Meteorology (www.bom.gov.au).

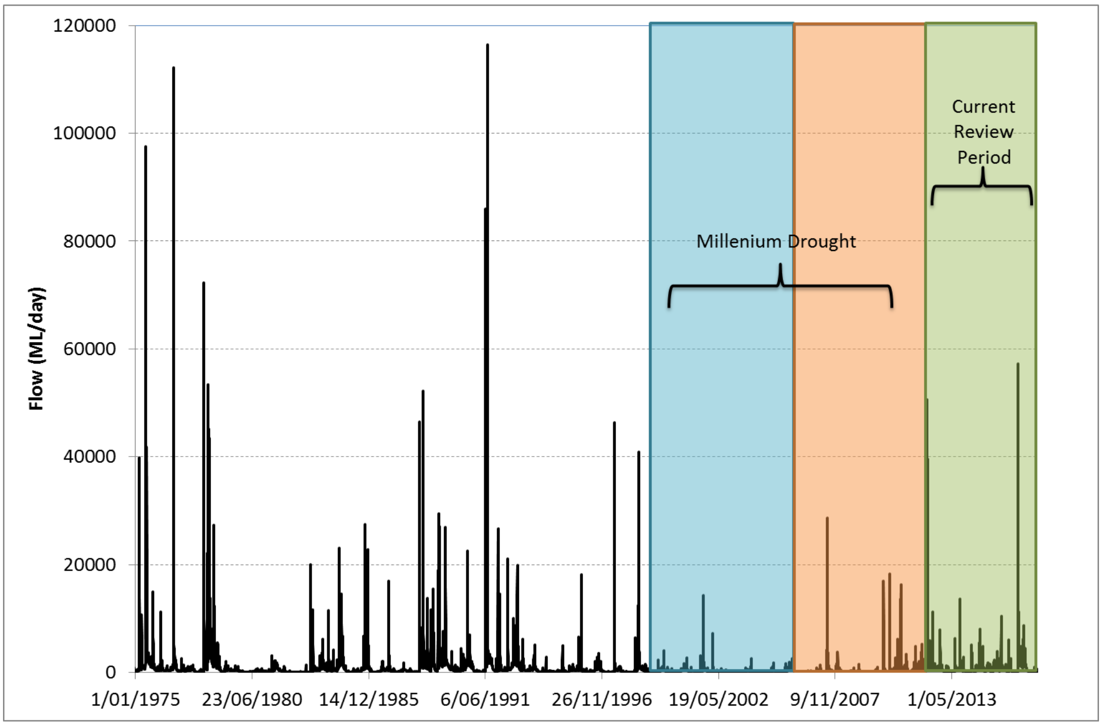

Figure 2. Daily flow in Murrumbidgee River at Lobbs Hole (station 410761) in the ACT illustrating regional flow patterns. The coloured background shows the different environmental flow guidelines periods for the ACTs water resources. Data from NSW Waterinfo (http://waterinfo.nsw.gov.au/)

COMPLIANCE WITH ENVIRONMENTAL FLOWS

In the ACT, environmental flow requirements are fulfilled through releases or spills from reservoirs (in Water Supply Ecosystems) or limits on abstraction. Base flows, riffle maintenance, pool maintenance and channel maintenance flows are all achieved in this way. In Water Supply Ecosystems, flows are managed as part of urban water supply licence requirements, and as a result there is comprehensive monitoring of flows in these systems. Monitoring data are more scarce for other ecosystems categories.

In general, there is little time-series data on abstraction compliance. However, some data exists for impoundment water level, thus adherence to abstraction limits can be inferred for some waterbodies. In impoundments in Modified and Created Ecosystems, drawdown is limited to 0.20 m below spillway (see Appendix 2 for particular ecosystem guidelines). The data available for water levels in urban lakes and ponds are analysed below. No abstraction is permitted from natural lakes and ponds, and these waterbodies are protected in Namadgi National Park and Tidbinbilla Nature Reserve.

The EFG limit groundwater abstraction to ensure that there is no impact from groundwater abstractions on aquatic ecosystems. It appears from the current wording of the EFG that the focus is on groundwater input to streams, as opposed to other types of groundwater dependent ecosystems (such as wetlands, floodplains or aquifer and cave ecosystem). As a consequence, groundwater abstractions are limited to ensure no adverse effects on baseflows. This is consistent with recommendations made by Barlow *et al.* (2005), suggesting that the current EFG limit (abstraction of no more than 10% of groundwater annual recharge) is likely to have little effect on in-stream aquatic ecosystems. It is assumed that the groundwater abstraction limit would also protect other types of groundwater dependent ecosystems in the ACT.

In terms of evaluating compliance with the EFG, groundwater abstraction licence data are available for the ACT and the total licensed volumes are less than 10% of the groundwater annual recharge in all water management areas except Central Molonglo. Licensed groundwater use is metered to ensure compliance and there have been occasional instances of overuse between 2013 and 2017. The overuse volumes by individual licensees were in the order of 50 ML in 2013; 20ML in 2014; 30ML 2015; 10ML 2016 and 50ML in 2017 and predominantly occurred in water management areas of Central and Lower Molonglo. These are not likely to significantly affect annual groundwater recharge given that the total allowable volume of groundwater use for each of those water management areas was not exceeded (i.e. Central Molonglo has an allowable volume of 685ML; total use was 370ML in 2013; 301ML in 2014; 391ML in 2015; 573ML in 2016 and 551ML in 2017).

WATER SUPPLY ECOSYSTEMS

Compliance with environmental flow requirements prescribed in the EFG is managed under Icon Water's (formerly ACTEW Water's) *Licence to Take Water,* Licence WU67. The performance, timing and volume of environmental water releases are reported annually by Icon Water to the Environment Protection Authority (ACTEW Corporation Ltd. 2013, 2014; Icon Water Ltd. 2015, 2016). Environmental release requirements and actual releases are summarised for reaches below each of the ACT's water supply reservoirs (Figures 3-6). It is notable that the resulting flows below Corin Dam are an inversion of the seasonal flows that might be expected in an unregulated system.

Compliance with the EFG has been consistently achieved in water supply catchments. The Icon Water compliance reports list minor adjustments that are made to operations or to measurements (e.g. because of maintenance or logger fault), however compliance is generally achieved. There are some exceptions to this, such as pool maintenance flows (>550 ML/day) not being achieved below Bendora and Corin Dams in 2015. In these cases infrastructure and maintenance limitations meant it was not possible to achieve the full 550 ML/day required. In other cases, reduced flows have also been applied to assist spawning migration of threatened fish species. Such reductions are applied in consultation with the EPA.

Across the period of evaluation, reaches downstream of all four major ACT water supply reservoirs had flows in excess of minimum requirements prescribed in the 2013 EFG. Ecosystem responses to environmental flows should be interpreted with this in mind, as ecological outcomes may not truly reflect the influence of EFG.

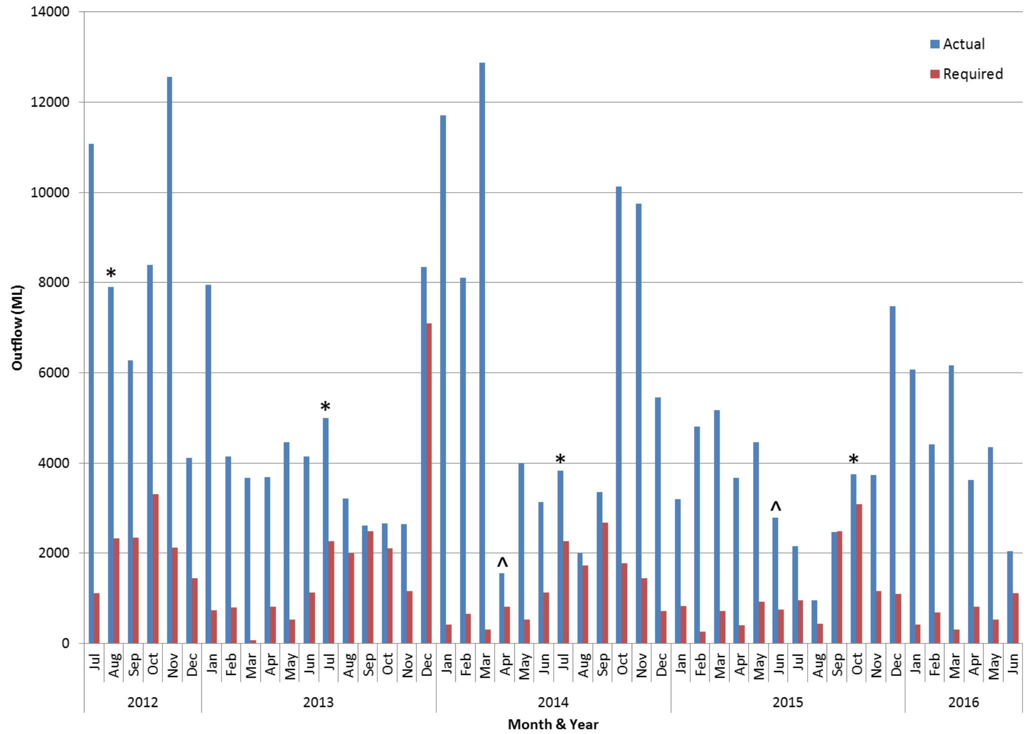

Figure 3 Summary of monthly environmental flow releases (or spills) from Corin Dam during the period July 2012-June 2016. Required flows (ML) are represented in red, actual flows (ML) in blue. Data retrieved from ACTEW Corporation Ltd. (2013, 2014) and Icon Water Ltd. (2015, 2016). * indicates timing of pool maintenance flow. ^ indicates issue with depth gauge.

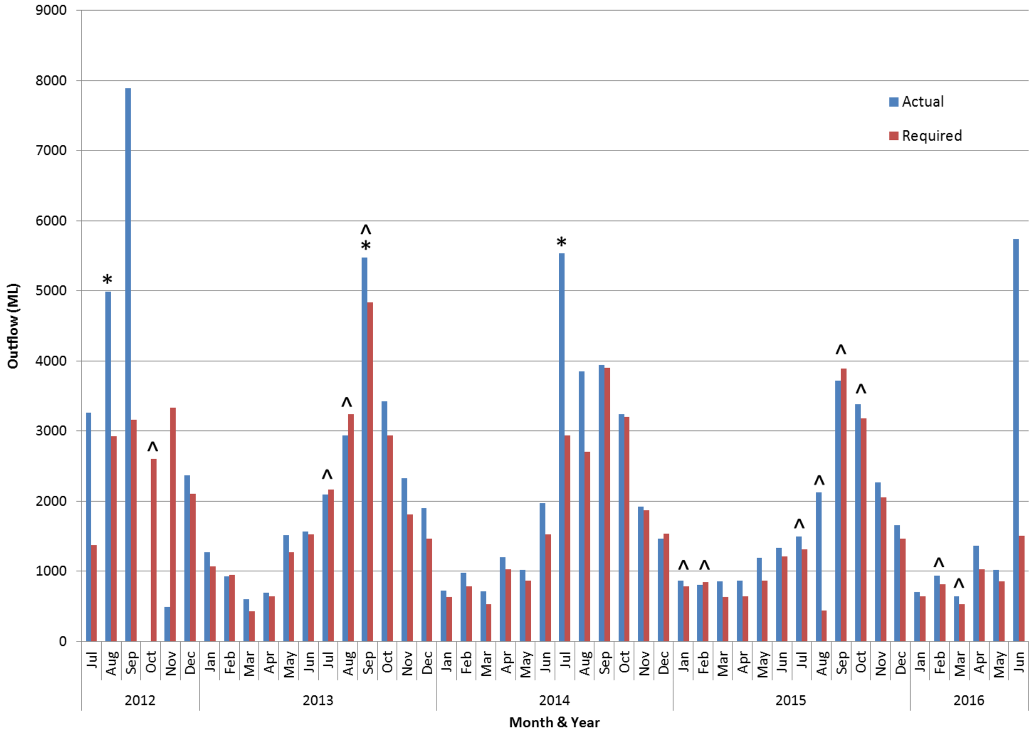

Figure 4 Summary of monthly environmental flow releases (or spills) from Bendora Dam during the period July 2012-June 2016. Required flows (ML) are represented in red, actual flows (ML) in blue. Data retrieved from ACTEW Corporation Ltd. (2013, 2014) and Icon Water Ltd. (2015, 2016). * indicates timing of pool maintenance flow. ^ indicates issue with depth gauge.

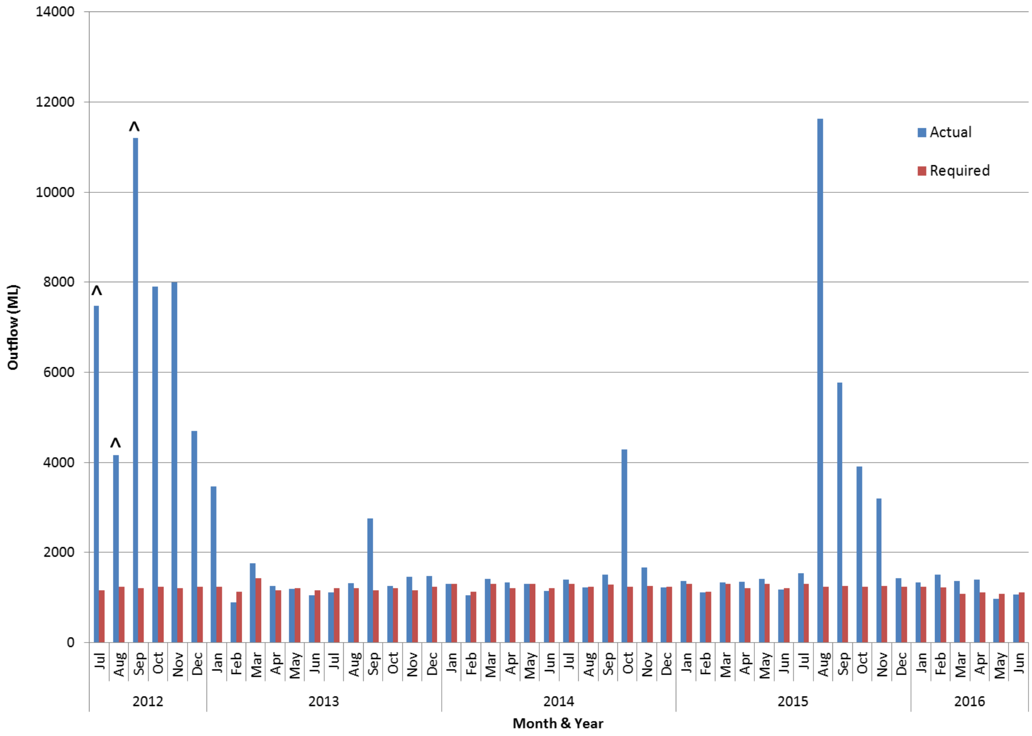

Figure 5 Summary of monthly environmental flow releases (or spills) from Cotter Dam during the period July 2012-June 2016. Required flows (ML) are represented in red, actual flows (ML) in blue. Data retrieved from ACTEW Corporation Ltd. (2013, 2014) and Icon Water Ltd. (2015, 2016). ^ indicates issue with depth gauge.

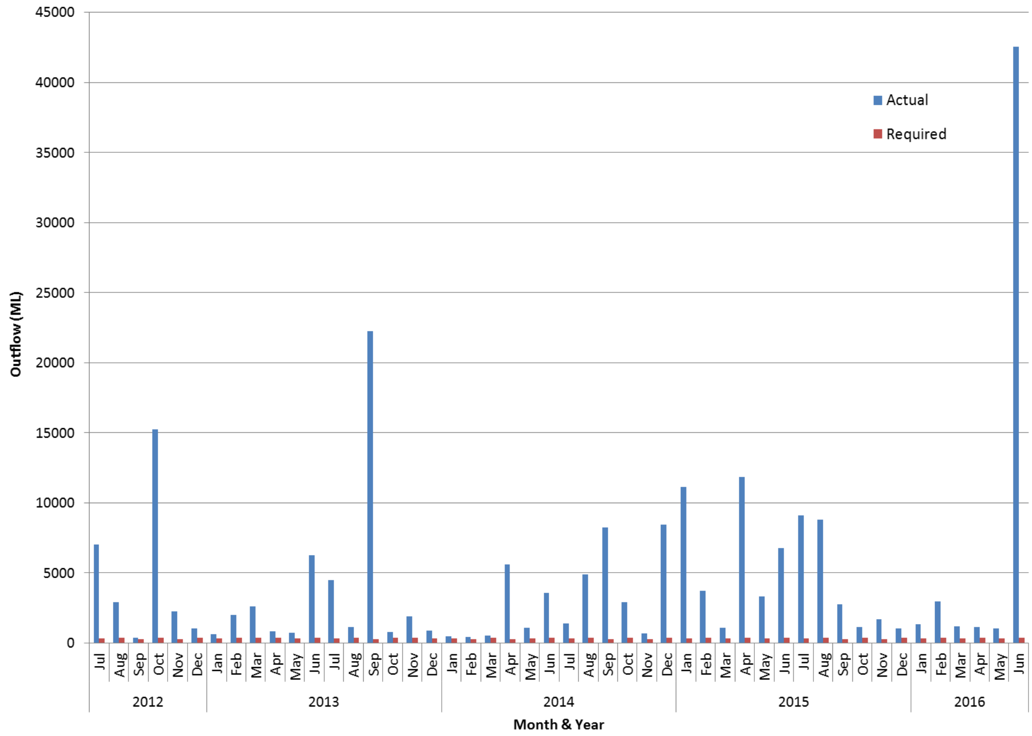

Figure 6 Summary of monthly environmental flow releases (or spills) from Googong Dam during the period July 2012-June 2016. Required flows (ML) are represented in red, actual flows (ML) in blue. Data retrieved from ACTEW Corporation Ltd. (2013, 2014) and Icon Water Ltd. (2015, 2016).

NATURAL ECOSYSTEMS

Natural Ecosystems are those that persist in a state similar to pre-European settlement condition. In the ACT, natural aquatic ecosystems include waterbodies within Namadgi National Park (outside of the Cotter River Catchment) and those within Tidbinbilla Nature Reserve. Conservation is the primary management goal in Natural Ecosystems and thus the ecological objective in the 2013 EFG is to maintain healthy aquatic ecosystems in all ACT Natural Ecosystems.

Environmental flows are achieved in Natural Ecosystems through restricting abstraction. No abstraction is permitted from lakes and ponds in Natural Ecosystems, and base and flooding flows are protected in all other waterbodies.

MODIFIED ECOSYSTEMS

The Modified Ecosystems of the ACT are those that have been significantly altered by catchment activities, including changing land use and modifications to the natural flow regime. The EFG are designed to mitigate such changes by managing flows and water abstraction in order to maintain Modified Ecosystems in as natural a state as possible.

Waterbodies outside of Namadgi National Park, Tidbinbilla Nature Reserve and the Canberra urban area are considered in the Modified Ecosystem category. For the purposes of the EFG, Lake Burley Griffin, the Molonglo River, and the Queanbeyan River above Googong Reservoir are also considered Modified Ecosystems. The ecological objectives for this system are targeted at maintaining a healthy ecosystem.

Control of abstraction is the main mechanism for achieving environmental flows in Modified Ecosystems (though some impoundments may overtop). Abstraction is limited through licencing, but direct implementation of environmental flows achieved through restricting abstraction does not regularly occur.

The 2013 EFG includes discussion of drawdown of urban impoundments within Modified Ecosystems, however these are earlier defined as components of Created Ecosystems (ACT Government 2013). Hence, analysis of urban lake drawdown is considered under Created Ecosystems.

CREATED ECOSYSTEMS

Flows in urban areas are typified by high nutrient and contaminant loads, “flashier” hydrology, altered channel morphology and reduced biodiversity (Walsh *et al.* 2005). Alteration to urban waterbodies is acute enough that they are classified as Created Ecosystems. All streams, lakes and ponds within the urban areas of the ACT (excluding the Molonglo River) are grouped into this category.

The 2013 EFG cite significant community support for restoring urban streams to a more natural condition. The Guidelines reflect this through recommendations that flows in urban streams be restored to natural flow regimes as far as practicable. The stated ecological objective of such flows is to maintain a range of healthy aquatic ecosystems across all Created Ecosystems (ACT Government 2013).

The water resource management actions designed to achieve these outcomes are the control of water levels in the lakes and ponds through limiting abstraction. Drawdown for urban lakes and ponds constructed prior to the year 2000 was historically limited to 0.2 m on the basis that the ecosystems associated with these impoundments were designed around relatively stable water levels, operating at or close to full supply level. The 2013 EFG refers to research that suggests a drawdown of 0.6 m is unlikely to adversely affect the macrophytes, and thus allows for greater drawdown of the impoundments if accompanied by intensive management and monitoring. For urban lakes and ponds constructed after the year 2000, a greater drawdown may be allowed if the impoundments have been explicitly designed to provide their water quality and ecological functions within a greater water level operating regime.

Abstraction licences have been granted for 30 of the urban lakes and ponds (Table 13: Appendix 5) some of which are effectively small water supply dams. Water level data are only available from six of the ACT’s urban lakes, a small fraction of those for which licences have been granted. Analysis of the water level data from six of the urban lakes for 2013-2017 shows that only Lake Burley Griffin has experienced a significant period of draw down beyond 0.2 m with water levels approximately 0.6 m below full supply level in 2012 and 2013 the result of repair work on Scrivener dam (Figure 7). Data from the other five urban lakes indicates drawdown is generally less than 0.2 m with only one instance where this has been exceeded during the evaluation period; a number of the lakes were drawdown by approximately 0.4 m for a short period in February 2014 (Figure 7).

Direct monitoring data on base and flooding flows in Created Ecosystems was not available. However, given that these flows are provided by limiting surface and groundwater abstraction, there is the potential for them to be inferred by compliance with abstraction licence conditions.

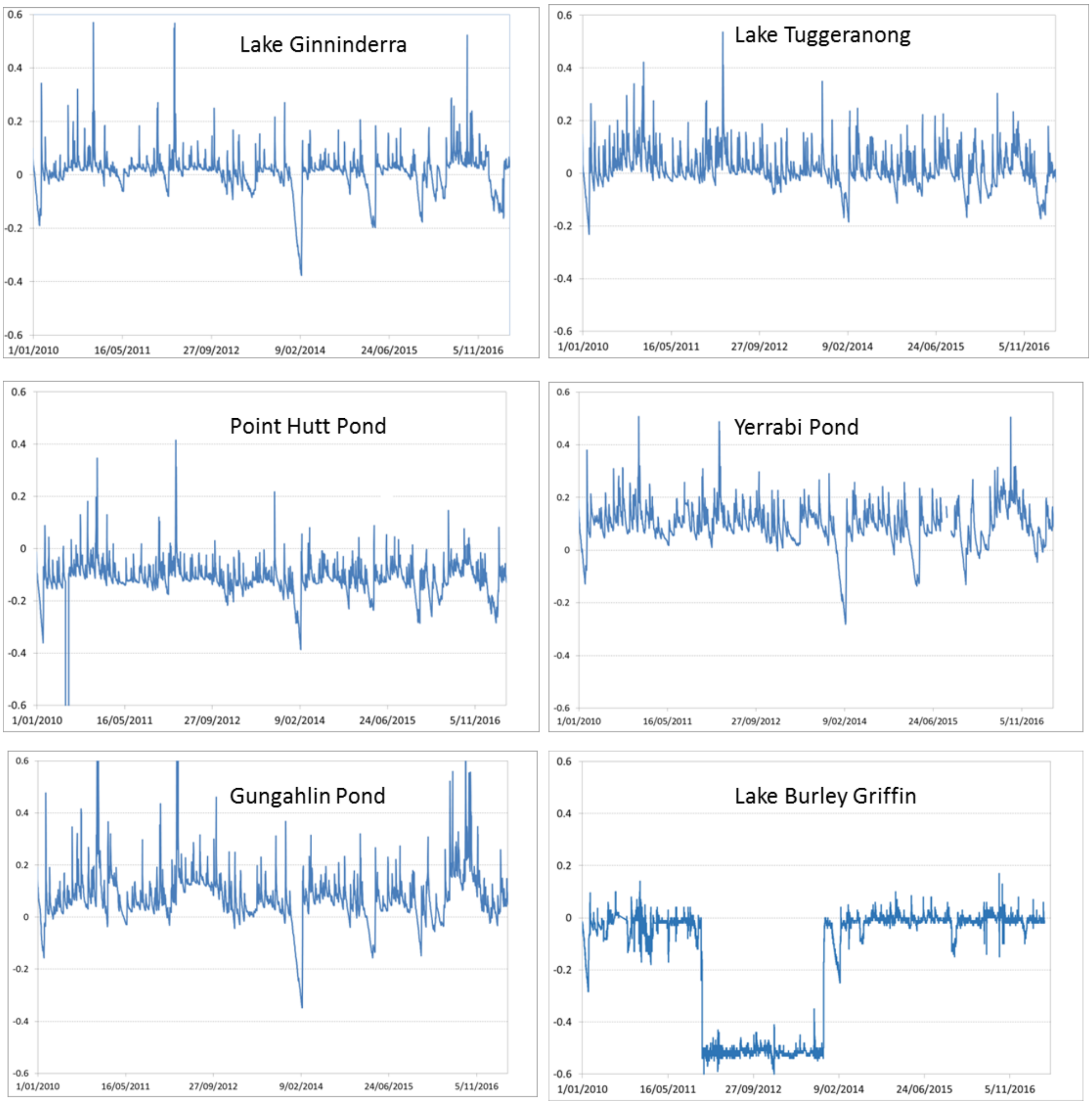

Figure 7. Water level variation (m) relative to full supply for six of the ACTs urban lakes. Data from the ACT Government and the National Capital Authority

MONITORING AND EVALUATING ECOLOGICAL OBJECTIVES OF EFG

In the present evaluation, existing monitoring data and reports are used to determine if:

i) ecological objectives for ACT aquatic ecosystems are being met by current implementation of the EFG; or

ii) insufficient monitoring occurs to make such an assessment.

The EFG identifies ecological objectives and indicators for each ecosystem category, and for specific reaches within water supply catchments. During the period 2013-2017, various monitoring programs have been used to assess the nominated indicator variables, and these are summarised below. An overview of objectives, indicators and relevant monitoring are summarised in Table 1, below. Table 1 also incorporates a brief evaluation of each ecological objective, as assessed using the indicators. In many cases these assessments led to recommendations and considerations for subsequent stages of the review.

More detailed analysis of the monitoring data is included in Appendix 3 and a separate evaluation report.

ASSESSMENT SUMMARY – WATER SUPPLY ECOSYSTEMS

The ecological objectives in Water Supply Ecosystems are achieved intermittently. Monitoring confirms that indicator targets are usually met for filamentous algae, often met for macroinvertebrates and occasionally met for some fish indicators in some reaches. Paucity of data means that sediment and frog indicators cannot be assessed.

Elements of the monitoring program in Water Supply Ecosystems are very robust. Macroinvertebrate monitoring and filamentous algae are both assessed and reported regularly. These ecological indicators can also be closely associated with water management practices because of the control, monitoring and reporting of hydrological dynamics in these ecosystems. This allows for a tight feedback loop into an adaptive management cycle. However, knowledge pertaining to the ecological performance of environmental flows might be augmented by assessing these parameters at sites further downstream from dams.

Other elements of the monitoring program would also benefit from considered revision. As highlighted above, interpretation of the Two-spined Blackfish indicator is potentially clouded by ambiguity, and both Two-spined Blackfish and Macquarie Perch indicators may need revising in light of changed habitat conditions in the enlarged Cotter Reservoir.

There are also those indicators that were not assessed – sediment dynamics and Cotter River Frog demographics. Some consideration needs to be given to whether it is the monitoring, indicator and/or objective that needs to be revised in these cases.

NATURAL ECOSYSTEMS

Assessment of ecological objectives in Natural Ecosystems was not possible because of the lack of relevant monitoring. Indicators are most likely not appropriate in these ecosystems because of an absence of means to actively manage e-flows.

MODIFIED ECOSYSTEMS

Where monitoring data exist, they indicate that the ecological objectives in Modified Ecosystems are occasionally achieved. Indicator targets are often met for macroinvertebrates, though a paucity of data means that filamentous algae, sediment and macrophyte indicators cannot be assessed.

Macroinvertebrate community assemblage is surveyed and reported regularly at four sites. These sites are in generally good condition and often meet the indicator target. However, given the considerable total length of streams categorised as Modified Ecosystems in the ACT, there is limited capacity to generalise about the performance of ecological objectives on the basis of these four sites.

Some consideration needs to be given to whether it is the monitoring, indicator and/or objective that needs to be revised in cases where indicators were not assessed. In particular, the macrophyte assemblage objective needs clarification of the classification of "urban lakes and ponds".

CREATED ECOSYSTEMS

Where monitoring data exist, they indicate that the ecological objectives in Created Ecosystems are rarely achieved. The only formal monitoring takes place for macroinvertebrate indicator targets, and these are rarely met. A paucity of data means that filamentous algae, sediment and macrophyte indicators cannot be assessed.

Macroinvertebrate community assemblage is surveyed and reported regularly at six sites. In general, these sites are severely biologically impaired and rarely meet the indicator target.

However, acceptable targets for indicators in Created Ecosystems may be less than the specified objective value.

Table 1 Ecological objectives, indicators and monitoring summaries for aquatic ecosystems in the ACT, 2013-2017. Based on Table 2 in the *Water Resources Environmental Flow Guidelines 2013* (ACT Government 2013).

Ecosystem and Reach	Objective	Indicators	Relevant monitoring/report	Evaluation and recommendations
Water Supply Ecosystems				
Corin Dam to Bendora Reservoir	To maintain populations of **Two-spined Blackfish**	Young of the year and year 1+ ages classes comprise >40% of the monitoring catch, and catch is >80 fish per standard monitoring effort.	Annual to biennial sampling of reach (multiple sites). Indicator has never been achieved (2012-2016). Demographic requirements are typically met, but catch is insufficient.	Data indicates that e-flows, indicator or monitoring method are not sufficient and need to be revised.
	Maintain population numbers and distribution of the **Cotter River Frog**	Extant populations are maintained at current levels.	No formal monitoring of Cotter River Frog populations in this reach.	Cotter River Frog is most likely a colour-morph of a common species. Remove Cotter River Frog from future EFG.
Bendora Dam to Cotter Reservoir	To maintain populations of **Macquarie Perch**	Young of the year and year 1+ ages classes comprise >30% of the monitoring catch, and >40 fish captured per standard monitoring effort.	Annual to biennial sampling of Cotter Reservoir (effort has changed over time). Indicator generally not met, likely due to habitat fragmentation during filling of enlarged Cotter Reservoir.	Limited power to assess objective. Indicator needs to be revised in light of significant alterations to habitat.
	To maintain populations of **Two-spined Blackfish**	Young of the year and year 1+ ages classes comprise >40% of the monitoring catch, and catch is >80 fish per standard monitoring effort.	Annual to biennial sampling of reach (multiple sites). Indicator is generally met, though occasionally catch per effort is insufficient.	Limited power to assess objective. Indicator needs to be revised in light of significant alterations to habitat.
All reaches	To maintain healthy aquatic ecosystems in terms of biota	Macroinvertebrate assemblages are maintained at AUSRIVAS band A level assessed using protocols in the ACT AUSRIVAS sampling and processing manual	Bi-annual (autumn and spring) report to Icon Water: *Biological response to flows downstream of Corin, Bendora, Cotter and*	Objective is largely met. Indicators and monitoring are appropriate.

		(http://ausrivas.canberra.edu/au/ausrivas)	*Googong Dams.* All sites achieved AUSRIVAS band A during the period, but are generally ranked B or C.	
		Non-dominance (<20% cover) of filamentous algae in riffles for 95% of the time. Assessed using standardised collection and processing methods as per Norris *et al*. 2004.	Bi-annual (autumn and spring) report to Icon Water: *Biological response to flows downstream of Corin, Bendora, Cotter and Googong Dams.* Tested sites generally achieve objective.	Objective is largely met. Greater clarity required around indicator, including definition of "95% of the time"
	To prevent degradation of riverine habitat through sediment deposition	Sediment deposition is limited to <20% of total depth of pools measured at base flow using techniques as per Ecowise Environmental 2005.	Formal monitoring not undertaken. Unable to adequately assess indicator.	Unable to assess objective. Adaptive management process needs to be articulated so this loop is closed.
Natural Ecosystems				
All reaches	To maintain healthy aquatic ecosystems in terms of biota	Macroinvertebrate assemblages are maintained at AUSRIVAS band A level. Assessed using protocols as per the ACT AUSRIVAS sampling and processing manual (http://ausrivas.canberra.edu/au/ausrivas)	No formal monitoring of macroinvertebrates in Natural Ecosystems.	Unable to assess objectives. Specific indicators may not be relevant in Natural Ecosystems, where e-flows cannot be actively managed.
		Non-dominance (<20% cover) of filamentous algae in riffles for 95% of the time. Assessed using standardised collection and processing methods as per Norris *et al* 2004.	No monitoring of filamentous algae in in riffles in Natural Ecosystems.	
	To prevent degradation of riverine habitat through sediment deposition	Sediment deposition is limited to <20% of total depth of pools measured at base flow using techniques as per Ecowise Environmental 2005.	Formal monitoring not undertaken. Unable to adequately assess indicator.	

Modified Ecosystems				
All reaches	To maintain healthy aquatic ecosystems in terms of biota	Macroinvertebrate assemblages are maintained at AUSRIVAS band A level. Assessed using protocols as per the ACT AUSRIVAS sampling and processing manual (http://ausrivas.canberra.edu/au/ausrivas)	Bi-annual (autumn and spring) report to ACT Government: *ACT water quality monitoring program: macroinvertebrate component.* Indicator is rarely met at test sites.	Objective occasionally met. Indicator target value may need revision for these systems.
		Non-dominance (<20% cover) of filamentous algae in riffles for 95% of the time. Assessed using standardised collection and processing methods as per Norris *et al* 2004.	AUSRIVAS assessments mention algae, but there is no quantified monitoring of filamentous algae in riffles.	Unable to assess objective. Appropriateness of indicator to be revised.
	To prevent degradation of riverine habitat through sediment deposition	Sediment deposition is limited to <20% of total depth of pools measured at base flow using techniques as per Ecowise Environmental 2005.	Formal monitoring not undertaken. Unable to adequately assess indicator.	Unable to assess objective. Adaptive management process needs to be articulated so this loop is closed.
	To maintain functional assemblages of macrophytes in urban lakes and ponds	Presence of emergent macrophytes in density and diversity that perform beneficial water quality processes and provide habitat for desired fauna. Submerged macrophytes present and at densities that perform beneficial water quality processes.	Formal monitoring not undertaken. Unable to adequately assess indicator.	Unable to assess objective. Revise macrophyte indicators as part of Basin Plan alignment.
Created Ecosystems				
All reaches	To maintain healthy aquatic ecosystems in terms of biota	Macroinvertebrate assemblages are maintained at AUSRIVAS band A level. Assessed using protocols as per the ACT AUSRIVAS sampling and processing manual (http://ausrivas.canberra.edu/au/ausrivas)	Bi-annual (autumn and spring) report to ACT Government: *ACT water quality monitoring program: macroinvertebrate component.* Test sites in urban areas are heavily impaired.	Objective rarely met. The acceptable target value for the indicator may need to be revised. Indicators for some ecosystem types (e.g. standing water) may not be appropriate.
		Non-dominance (<20% cover) of filamentous algae in riffles for 95% of the time. Assessed using standardised collection and processing	No monitoring of filamentous algae in riffles in Created Ecosystems.	Unable to assess objective. Indicator may not be appropriate for Created

		methods as per Norris *et al* 2004.		Ecosystems
	To prevent degradation of riverine habitat through sediment deposition	Sediment deposition is limited to <20% of total depth of pools measured at base flow using techniques as per Ecowise Environmental 2005.	Formal monitoring not undertaken. Unable to adequately assess indicator.	Unable to assess objective. Indicator may not be appropriate for Created Ecosystems
	To maintain functional assemblages of macrophytes in urban lakes and ponds	Presence of emergent macrophytes in density and diversity that perform beneficial water quality processes and provide habitat for desired fauna. Submerged macrophytes present and at densities that perform beneficial water quality processes.	No formal monitoring of macrophytes. Limited research data suggest that water level influences distribution and density of emergent vegetation along littoral zone of urban lakes.	Unable to assess objective. Revise macrophyte indicators as part of Basin Plan alignment.

EVALUATION CONCLUSIONS

Hydrological conditions in the ACT since the commencement of the 2013 EFG have been conducive to the provision of environmental water. There has been ample water available to provide for the stated environmental flows, and in many cases flows have exceeded EFG requirements.

Compliance with environmental flow guidelines has been met and exceeded in riverine systems. This is particularly evident in water supply catchments, where flows are more regulated and compliance reporting is frequent.

The ecological objectives of environmental flows are met in some cases, but not all. Overall, macroinvertebrate assemblages were in reasonable condition across monitored sites, with the exception of urban waterbodies. Fish indicator targets were met intermittently. This suggests that environmental flows may be having a beneficial influence on aquatic ecosystem health, though this result needs to be interpreted in the context of flows exceeding EFG minimum requirements. Higher flows may potentially obfuscate the assessment of the effectiveness of flow guidelines in bringing about ecological outcomes.

The monitoring of ecological health across the ACT is well-established in some ecosystems and would benefit from improvement in others. Formal monitoring against some ecological objectives has not occurred since the commencement of the 2013 EFG.

Evaluation of the 2013 EFG helped to identify places where objectives, indicators and monitoring can be improved, or added, in order to fulfil the aims of the EFG. The process also led to the identification of knowledge gaps which, if filled, would be valuable in the development of indicators and the assessment of objectives. Potential improvements and knowledge gaps were used as interim recommendations to be considered as part of the review workshops.

FUTURE OF ENVIRONMENTAL FLOW GUIDELINES

In revising the current EFG there is a need consider higher order factors, such as changes in the policy setting in which the EFG are embedded, as well as external drivers that may affect the ability of the EFG to achieve outcomes for biodiversity and ecosystem processes. Thus, there are two important considerations for the review:

1) Changes in the current policy setting: As a signatory to an intergovernmental agreement established under the Murray-Darling Basin Plan (the Basin Plan), the ACT is required to manage water resources in a way that is consistent with the requirements of the Basin Plan.
2) Future climates: Climate change is predicted to affect both the quantity and quality of water in rivers and wetlands and this may, in turn, affect freshwater ecosystems. Population growth, community preferences and management policies can be expected to interact in various ways with climate change and stream flows and the challenge for e-flow planning is to maintain the resilience and adaptive capacity of aquatic ecosystems within the broader socio-ecological system.

ALIGNMENT WITH THE MURRAY-DARLING BASIN PLAN

The establishment of the Murray-Darling Basin Plan (the Basin Plan) in 2012, under the *Commonwealth Water Act 2007*, was a major change to the way in which water is managed across the Murray-Darling Basin. As a signatory to an intergovernmental agreement established under the Basin Plan, the ACT is required to develop a 10 year Water Resource Plan (WRP) that will show how surface and ground water will be managed in the ACT in a way that is consistent with the requirements of the Basin Plan. The WRP is required to set out the amount of water that is available for the environment and the rules and arrangements for using that water, ensuring consistency with the Basin-wide environmental watering strategy (BWS). Thus, the revised EFG will be central to the ACT's WRP.

Meeting the ACT's obligations necessitates consideration of Basin Plan requirements and incorporation of the environmental outcomes expected by the BWS. The Basin Plan sets out three broad environmental objectives for water-dependent ecosystems (section 8.04):

1. Protect and restore water-dependent ecosystems
2. Protect and restore the ecosystem functions of water-dependent ecosystems
3. Ensure that water-dependent ecosystems are resilient to climate change and other risks and threats.

The BWS expands on these objectives by detailing expected outcomes for four ecological components of water-dependent ecosystems: river flows and connectivity, native vegetation, waterbirds and native fish. In many cases the outcomes described in the BWS are already addressed in by the ACT's current EFG or are specific to regions, ecosystems or biota that do not occur in the ACT. In other cases, BWS outcomes may require new ecological objectives to be developed for the ACT, particularly around vegetation and waterbird outcomes.

THE BASIN PLAN

Chapter 10, Part 6 of the Basin Plan details "Planning for environmental watering", describing some of the requirements for drafting of environmental watering plans. It has three components: sections 10.26-10.28.

Section 10.26 is simply a requirement that WRP operate in a manner that is consistent with the BWS and the broad environmental watering objectives listed above.

Section 10.27 requires the coordination of environmental watering between connected areas. In the ACT this requirement relates to reaches of the Murrumbidgee River upstream of the ACT border near Angle Crossing, downstream of ACT border near Halls Crossing, and the Molonglo and Queanbeyan rivers. It also requires coordination with National Capital Authority who are responsible for the management of Commonwealth waters (Lake Burley Griffin), that occur within the ACT. While this must be considered as part of the WRP, it does not need to be explicitly addressed in the EFG.

Section 10.28 states that there must be no net reduction in the protection of planned environmental water. Meeting this requirement may involve providing proof that the revised EFG have not changed the volume or characteristics of planned environmental water (PEW). The MDBA's *WRP Handbook for Practitioners* indicates that this proof may be provided through modelling of both new and old EFG under historical climate in order to compare volumes delivered. A position statement by the MDBA declares that:

"For accreditation purposes supporting documentation will need to demonstrate:

a) that the level of legal protection given to PEW is at least maintained by the net effect of the WRP; and

b) that the quantity and effectiveness of the PEW are at least maintained by the net effect of the WRP.

The MDBA will apply the principle that there should be no backsliding arising from the net effect of any changes in rules and that environmental outcomes should be the same or enhanced but not reduced."

Under the Basin Plan the ACT is required to prepare a long-term environmental watering plan, the basis of which will naturally be formed by the EFG. Amongst other conditions, the Basin Plan requires the protection of the ACT's only Ramsar wetland, the Mt Ginini and Cheyenne Flats wetland. It is noted that these wetlands cannot be managed with environmental water except through protection of flows. Other requirements potentially relevant to the EFG are the identification of Priority Environmental Assets (PEAs) and Priority Ecosystem Functions (PEFs) (section 8.19) and their watering needs.

For the purposes of our review, we consider that PEW to be the water that is either actively delivered or protected from abstraction to achieve environmental outcomes. We recognise that in many instances the protection of a natural flow regime in ungauged systems means that the PEW may not be able to be quantified.

PRIORITY ENVIRONMENTAL ASSETS AND PRIORITY ECOSYSTEM FUNCTIONS

The Basin Plan requires that Priority Environmental Assets (PEAs) and Priority Ecological Functions (PEFs) are identified in the forthcoming ACT Long Term Watering Plan. The methods for formally identifying PEAs, PEFs and their environmental watering requirements are detailed in the Basin Plan (Chapter 8, Part 5; reproduced in Appendix 6). Fundamental to identifying the PEAs and PEFs in the ACT Long Term Watering Plan is that they are environmental assets or functions *that can be managed with environmental water*. Many of the ACT's important freshwater assets are located in conservation areas and cannot be managed with environmental water, beyond limiting extractions. For example, the Ginini Flats Wetlands Ramsar Site is located in the headwaters of Ginini Creek in Namadgi National Park. Water cannot be *delivered* to this asset, the only way of managing water at this site is to prevent extraction (see Appendix 6).

The potential for ecosystems to be classified as a PEA or PEF was discussed on a reach-by-reach basis, and where a PEA or PEF was identified it is recorded in the tables of recommendations in the present report.

BASIN-WIDE ENVIRONMENTAL WATERING STRATEGY (BWS)

The BWS builds on the Basin Plan and is designed to assist managers of waterways in meeting the environmental objectives of the Basin Plan. It details the expected ecosystem responses to environmental watering across the Murray-Darling Basin. The four components – river flows and connectivity, native vegetation, waterbirds and native fish – each have specific environmental expected outcomes, some of which will necessitate the development of new ecological objectives to be incorporated into the revised EFG. Note that in many cases BWS outcomes are not relevant to the ACT, and these are omitted from subsequent discussions (see Table 2).

The expected outcomes forecasted for 2024 are "enhancing", "extending" and "improving" various population parameters for native species. During the workshops some ambiguity became apparent regarding how these terms are to be applied to the ACT. The issues discussed fell into three categories:

i) The timing and nature of baseline measurements against which improvement could be assessed
ii) The scale upon which improvement was to be assessed (e.g. is each individual population to show improvement, or is a net improvement across the ACT acceptable?)
iii) Whether improvement in some populations is possible through the use of environmental flows.

For example, it was felt that improvement across all BWS objectives (population distribution, breeding success, structure and movement) was not possible for each population of some key fish species in the ACT. It was generally agreed that it was beyond the capacity of environmental flows alone to bring about these outcomes for each population. However, an objective of net improvement across the ACT by 2024 is achievable.

Where the above issues are applicable, the approach taken was to initially target aspirational objectives, but to then moderate them according to operational constraints informed by underlying science and local expertise. This approach ensures that objectives are beneficial for freshwater ecosystems, while remaining amenable to meaningful assessment.

Consideration of Basin Plan requirements are not always explicitly stated in the present report, but they permeate all recommendations regardless. Likewise, the revised EFG do not explicitly detail how the Basin Plan has been integrated in every instance, but rather assume the requirements of the Basin Plan as essential criteria at all times.

To help ensure consistency with the BWS, MDBA representatives were present at both EFG revision workshops and provided extensive feedback on drafts of revised EFG. In addition to assisting with queries pertaining to the Basin Plan, the representatives were able to observe the thorough process underpinning the EFG revision.

Table 2: Expected ecological outcomes by 2024 listed in Basin-wide Environmental Watering Strategy and relevance to ACT. Note that only geographically relevant outcomes are listed.

Ecological component	Outcome	Relevance to ACT
River flows and connectivity		
Longitudinal connectivity	To keep base flows at least 60% of natural level	Addressed in EFG
Lateral connectivity	A 30 to 60% increase in the frequency of freshes, bank-full and lowland floodplain flows in Murrumbidgee catchment	Largely regarded as downstream outcome. The frequency of freshes may be able to be addressed through current operational flexibility in the Cotter system but will not result in floodplain outcomes.
Water-dependent vegetation		
Overall	Maintain extent and improve condition of water-dependent vegetation on the parts of the Basin's floodplain that can be actively managed	The rivers of the ACT have limited floodplains, mostly inset, confined features of the upland riverine landscapes. This is consequently regarded as a largely downstream outcome.
Forests and woodlands	To maintain the current extent of forest and woodland vegetation. Specifically, River Red Gum, Black Box and Coolibah.	Vegetation targets are discussed below. The listed species are not native to the ACT.
Shrublands	To maintain the current extent and improve condition of extensive lignum shrubland areas within the Basin	Lignum shrubland is not a vegetation class in ACT
Non-woody vegetation	To maintain the current extent of non-woody vegetation	Vegetation targets are discussed below.
	Increased periods of growth for communities that closely fringe or occur within the main river corridors	Vegetation targets are discussed below.
Waterbirds		
Overall	Increased abundance and maintenance of current species diversity	Waterbird targets are discussed below, however, it should be noted that none of the 'significant sites for waterbirds' identified in the BWS are located in the ACT. Futhermore, it is anticipated that the main habitat for waterbirds in the ACT are outside of areas where flow is regulated beyond protection of flows.
	Number and type of waterbird species present in the Basin will not fall below current observations	
	A significant improvement in waterbird populations in the order of 20 to 25% over the baseline scenario, with increases in all waterbird functional groups	
	Breeding events (the opportunities to breed rather than the magnitude of breeding *per se*) of colonial nesting waterbirds to increase by	

	up to 50% compared to the baseline scenario	
	Breeding abundance (nests and broods) for all of the other functional groups to increase by 30-40% compared to the baseline scenario.	
Native fish		
Overall	A diverse native fish community with sustainable populations occupying a greater proportion of their historic distribution than is currently the case	Key species include Silver Perch, Golden Perch, Murray Cod, Trout Cod, Macquarie Perch, Two-spined Blackfish, all of which occur in the ACT. Key populations and key fish passages are not defined in the BWS. Key sites within the ACT for fish have been identified as the Upland Murrumbidgee main channel[1] and the Cotter River[2]. Targets for populations of threatened and endangered species in the ACT are included in the current EFG, including demographic targets. Revision and addition of fish objectives are discussed below.
	No loss of native species currently present within the Basin	
	Improved population structure of key species through regular recruitment	
	Increased movement of key species	
	Expanded distribution of key species and populations in the southern Basin	
Short-lived species	Restored distribution and abundance to levels recorded pre-2007.	
Moderate to long-lived species	Improved population structure in key sites	
	10-15% increase in mature fish for recreational target species (Murray Cod and Golden Perch) in key populations	
	Annual detection of species and life stage representative of the whole fish community through key passages.	
Key species	Significant increases in the distributions of key species in the southern Basin	
Estuarine species	Various	There are no estuarine species native to the ACT

1. As a key movement corridor, a site of other significance and a site that provides for threatened species
2. As a site of other significance and a site that provides for threatened species

Specific BWS objectives for native fish

The BWS sets priorities for improving outcomes for native fish and nominates candidate sites in the ACT where water management actions to achieve these outcomes should be considered. The priorities are:

- no loss of native species currently present in the Basin
- improved population structure of key species through regular recruitment
- increased movement of key species
- expanded distribution of key species and populations.

The ability to facilitate meeting these objectives through improved water management and flows is a key test that has informed the development of the current EFG. Where water management and flows are unable to achieve these objectives, they have not been considered within the proposed revision to the EFG. Of particular note is the recommendation within the BWS of the ACT reaches of the Murrumbidgee as candidate sites for the establishment of additional populations of Silver perch. Silver perch are functionally extinct within the ACT and the only way to establish additional populations in the ACT is to undertake a stocking program. This is outside of the scope of the EFG and is not considered in the development of objectives for the EFG.

CLIMATE CHANGE

Climate change is predicted to affect Australian freshwater ecosystems by altering the quality and quantity of water in rivers. In turn, this may increase the vulnerability of aquatic ecosystems to human impacts and management strategies. The key climate impacts forecast by the NSW and ACT Regional Climate Model (NARCliM) include: increased maximum and minimum temperatures, changed seasonality of rainfall, longer storm and fire seasons, and longer periods of hotter weather resulting in drier environment (ACT Government 2016b). These climate change projections are likely to affect water-dependent ecosystems in a range of ways, but most directly through changes to temperature and water availability (Prober *et al.* 2015, Dyer *et al.* 2013). Other possible consequences include: insufficient water to support fish spawning during crucial reproductive windows; reduced connectivity in streams, limiting the dispersal ability of plants and animals; reduced connectivity through the riparian zone as drier conditions reduce vegetation condition, and potentially facilitate weed invasion (Lavergne *et al.* 2010, ACT Government 2016b).

In modelling of projected climate change impacts on freshwater ecosystems across the Upper Murrumbidgee catchment, Dyer *et al.* (2013) showed that temperature changes in the Cotter River system were likely to have a far greater effect on aquatic ecosystems (macroinvertebrates and native fish species) than changes in flow regimes. This was considered, in part, to be a function of the on-going provision of environmental flows protecting the reaches of the Cotter River from changes in flow regimes.

The Biodiversity Adaptation Pathways Project discusses e-flows in regards to “improve cross-border implementation of environmental flows” and “identify, establish, manage and protect refugia (including use of cold water dam releases)” and “rehabilitate and expand (cold water) fish habitat and enhance in-stream connectivity”.

Different climate change scenarios were considered where possible, though there remains a lot of uncertainty around the specific impacts on a reach-to-reach scale. Instead, the approach adopted was one of ensuring maintenance of good catchment condition, with the principle of assisting adaptation to a changing climate by promoting ecosystem resilience. This ‘whole of landscape’ approach focused on ecosystem resilience is consistent with the *ACT Nature Conservation Strategy 2013-2023* and *ACT Climate Change Adaptation Strategy,* and provides a best practise approach to managing freshwater ecosystems in an uncertain and changing climate.

RECOMMENDATIONS FROM PREVIOUS EFG REVIEWS

The ACT EFG were established in 1999 (ACT Government 1999) and have since been reviewed twice, in 2004 and 2010 (Ogden *et al.* 2004, Hillman 2010). The recommendations stemming from the 2004 review have largely been incorporated into the EFG, including the important principle of setting ecological objectives for each ecosystem type, and tailoring flows accordingly.

Recommendations from the 2010 review have only been included in the EFG in the sense that they are listed in the introductory chapters (see EFG section 2.1.1, ACT Government 2013). The core recommendations are (abridged, based on Hillman 2010):

1. In the event that the delivery of environmental flows remains a challenge in the immediate future, specific investigations should be aimed at assessing the state of resilience of native fish and macroinvertebrate populations.
2. Hydrological data should be compiled in a form and timely manner that permits water managers to monitor progress towards compliance with the Guideline’s flow rules and adapt management practise accordingly.
3. The performance monitoring program should be assessed with a view to more closely aligning it with the Ecological Objectives and proposed indicators set out in the Guidelines.
4. Consideration should be given to developing a program that investigates sediment dynamics in ACT streams, particularly deposition of sediment in key areas including known breeding habitats for native fish.
5. Compliance and performance monitoring should be undertaken to close the adaptive management cycle for urban lake drawdown and macrophyte maintenance.

The first recommendation relates to the severe drought conditions that preceded the 2010 review and is not critical to the present revision of the EFG. The recommendation relating to hydrological reporting has been largely adopted into water management practices in the ACT, with Icon Water subject to ongoing compliance reporting as a requirement of their Licence to Take Water.

The issues addressed by the remaining 2010 review recommendations continue to be unresolved and were confronted again as part of the 2017 review. The adequacy of monitoring programs, particularly those relating to sediments and macrophytes, remain deficient (see EFG evaluation above). As far as possible, these issues were addressed in the present review through the revision of ecological objectives and indicators. However, the ability to set meaningful objectives or indicators was impeded in many reaches by a lack of baseline data. This is discussed at length below.

RECOMMENDATIONS AND CONSIDERATIONS FOR REVISED EFG

APPROACH

The 2017 review of the ACT's EFG has aimed to be consistent with best-practice approaches to environmental flow management, including employment of a holistic approach. Use of a whole-of-ecosystem approach for establishing environmental flow requirements is consistent with the ACT's water management policy, and the present review maintains and extends this approach.

To complement this approach, the selected ecological values, objectives and indicators are representative of broader ecosystem health. The ecological values discussed for each reach are not to be considered an exhaustive list of all values in their respective waterbodies. Instead, listed values and objectives fulfil the above criterion as being broadly representative and, importantly, are known to respond to flow. The selection of values, objectives and indicators is based on these two primary criteria, as assessed using the best available science and local technical expertise.

In addition to aligning with holistic principles, the approach allows efficient application of monitoring resources to indicators that are known to respond to flow and are good indicators of general ecosystem health.

Consistent with this approach, ecological objectives have only been nominated for reaches where environmental flows can be actively managed. Reaches in Natural Ecosystems and those of catchments supplying water to impoundments in Water Supply Ecosystems have their natural base flow protected by restrictions on extraction. In the absence of options to actively manage e-flows for particular outcomes in these reaches, indicators are of limited use. Instead, such reaches are best used to establish reference conditions.

KNOWLEDGE GAPS

The workshops and the authors have identified a number of knowledge gaps. Knowledge gaps ranged from narrow (e.g. fish recruitment in a particular reach) to broad (e.g. consequences of various future climate scenarios). Where knowledge gaps were encountered a conservative approach was applied to recommendations, and these will benefit from future review. This is consistent with the approach throughout the EFG revision process – any changes are based on robust justification informed by the best available science.

Many knowledge gaps relate to the hydrological outcomes of alterations to flow guidelines. Largely, these questions may be answered through comprehensive modelling, when the ACT source model becomes available. Other knowledge gaps will only be addressed through ecological research and/or an adaptive management approach.

Knowledge gaps are identified for each reach in the tables below. They are classified as either crucial ("Priority A") to determining e-flows, objectives or indicators, or as valuable ("Priority B") additions to our understanding of ecological responses to flow. This classification process is based on how critical the knowledge gap is to decision making, as well as the perceived value of the relevant entity (e.g. knowledge gaps pertaining to threatened species are potentially more critical).

RELATIONSHIP OF REVIEW REPORT TO EFG

The following recommendations are the result of scientific literature review, the EFG evaluation and revision workshops. The intention is to revise the EFG and incorporate recommendations where appropriate. Thus, we have prepared a revised EFG to mirror the amendments proposed in the present report.

The framework of the EFG was examined as part of the review process, and a number of amendments are recommended. Some constitute small definitional ambiguities which are dealt with in the EFG glossary, while others require more substantial modification of the ecosystem categories used to classify reaches. These are detailed below.

The principal components of the EFG – flows and ecological objectives – were reviewed on a reach-by-reach basis, and this is reflected in the present report. Each reach type is presented as a table, displaying its ecological values, objectives and flows. The benefit of analysing e-flow requirements in this fashion is that it puts the ecology of a reach at the centre of the process. In this way, the links from ecology to objectives to flows are made evident, and the justification for links is provided in support. Indicators to assess each objective are then developed to take into account operational flexibility and similar issues particular to a reach.

As a legislative instrument, the EFG document may be structured differently to the following tables of recommendations (e.g. as a table of flows and a table of objectives, rather than a series of tables for each reach). However, it is intended that the following tables may be incorporated into the appendices of the EFG as supporting documentation, along with scientific justifications from earlier reviews.

RECOMMENDATIONS FOR EFG FRAMEWORK AND IMPLEMENTATION

In general, the division of aquatic ecosystems into categories based on differing demands on water resources, flow requirements and management options continues to be a robust method for recognising differences among the aquatic ecosystems of the ACT and allocating e-flows. However, there is a need for greater clarity around the management goals for each ecosystem type, as well as clear links to be drawn between each category and the relevant ecosystem description in the Territory Plan. Suggested ecosystem categories and their characterisation are provided in Table 3.

Recommendations:
The revised EFG include:

- a considered and clear articulation of revised management goals for each of the ecosystem types, with differences among ecosystems made obvious
- clarification of links between EFG ecosystem categories and those of the Territory Plan
- a more detailed list identifying the specific waterbodies (or reaches) associated with each ecosystem type
- renaming “Created Ecosystems” to “Urban Ecosystems” to remove ambiguity and more precisely identify the management purposes of the respective waterbodies

The current delineation of reaches remains largely appropriate, but we recommend that standing waterbodies be managed separately from flowing reaches. For example, in Water

Supply Ecosystems, the primary management goals and desired ecological outcomes for water supply reservoirs are considerably different from riverine sections, suggesting they should be considered separately. Similarly, in Urban Ecosystems, the same flow guidelines are not appropriate for urban ponds and urban streams. Separating standing water from flowing reaches will improve management of the system for ecological outcomes. Suggested changes are included in reach tables.

The re-classifications of some iconic waterbodies were considered during the review process. The merits of re-classifying Lake Burley Griffin (LBG) as an Urban Ecosystem were considered, moving it from Modified Ecosystems. While LBG is within the urban environment, a classification of Modified is more closely aligned with the Territory Plan. Furthermore, changing classification may reduce the level of protection applied to LBG. This would violate the requirement under the Murray-Darling Basin Plan to prevent any net reduction in the protection of planned environmental water. A similar argument applies to a proposal of re-classifying the Murrumbidgee River as a Water Supply Ecosystem (instead of “Modified”). Such a move would define the river’s primary management goal as that of water supply, potentially risking a reduction in current protection offered under the present classification.

During the workshops, it was questioned if a provision is needed in the EFG for allowing a reach to change classification, such as from a Modified to Urban Ecosystem (e.g. new urban developments). However, the current mechanism of re-assessing reach classifications during EFG review is probably sufficient to address this concern. Future reviews should continue to take into account on-going development in the region.

Table 3 Types of aquatic ecosystems and their characterisation as defined in the 2013 ACT Environmental Flow Guidelines (ACT Government 2013), along with recommended alteration to ecosystem and reach classifications.

Category of aquatic ecosystem	Description	Management goal	Waterbodies in this category	Recommendations for revised EFG	Justification
Natural Ecosystems (Territory Plan: conservation catchments)	Ecosystems that have persisted in a relatively pristine condition.	Primary goal: maintain aquatic ecosystems in their pristine state. Secondary goals: range of functions including **flow management and protection goals related to** recreational activities.	Waterbodies in Namadgi National Park, excepting the Cotter River catchment. Waterbodies in Tidbinbilla Nature Reserve.	**Rivers that cross ecosystem types be divided into reaches based on land management units (e.g. Naas River be managed as Natural when in national park and Modified when in rural areas).**	**The ecological objectives and flow management requirements of reaches differ along the length of some rivers. This is particularly relevant to the Naas and Gudgenby rivers, which flow from a relatively pristine state in Namadgi National Park before entering rural landscapes.**
Water Supply Ecosystems (Territory Plan: water supply catchments)	Ecosystems in catchments designated to provide the ACT water supply.	Primary goal: provide water supply. Secondary goals: range of functions including **protection of downstream ecological values, protection of ecological values associated with the reservoirs**, conservation and recreation.	Waterbodies in the Cotter River catchment. The Googong Foreshore area and the Queanbeyan River downstream of Googong Dam.	**Murrumbidgee River to remain as a Modified Ecosystem** **Manage the Naas and Gudgenby rivers as either Natural Ecosystems when in national park and Modified when in rural areas.**	**Murrumbidgee R. is not managed primarily as a water supply catchment.** **Redefining Murrumbidgee R. primary management goal as “provide water supply” may reduce the protection the ecosystem currently has under the classification as a Modified Ecosystem. The MDB Plan states that any change to environmental flow guidelines (via the Water Resource Plan) should not reduce the protection of planned environmental water (PEW) (MDB Plan, s.10.28).** **While the Naas and Gudgenby subcatchments have been identified as potential water supply catchments, they will not be used for the ACT’s water supply in the foreseeable future (at least the next 10 years). This will not reduce the protection of PEW (MDB Plan, s.10.28)**

Category of aquatic ecosystem	Description	Management goal	Waterbodies in this category	Recommendations for revised EFG	Justification
Modified Ecosystems (Territory Plan: conservation catchments)	**Majority** of ecosystems modified by catchment activities (land use change, discharges) or by changes to the flow regime.	Primary goal: Range of functions including **protection of downstream ecological values**, recreation and conservation. **Secondary goal: provide water supply.**	All waterbodies not included in the other three categories. Includes the Murrumbidgee and Molonglo Rivers, and **Lake Burley Griffin**. **Naas and Gudgenby rivers below Namadgi National ParkP**	**Revise the 'Modified Ecosystem' definition. Description could include reference to the inclusion of some conservation reaches/reserves.** **List secondary goal as "provide water supply"** **Leave Lake Burley Griffin as Modified Ecosystem**	**The majority of Modified Ecosystems are not conservation catchments for EFG purposes. Conservation reaches of otherwise modified waterbodies can be classified as Natural Ecosystems (see Naas R. example above).** **To accommodate leaving Murrumbidgee R. as a Modified Ecosystem (see justification above). The ecological objectives will be consistent along the Murrumbidgee R. within the ACT** **The current classification is more closely aligned with the Territory Plan. Re-classifying LBG as an Urban Ecosystem may reduce its level of protection, hence violating requirements under the MDB Plan**
Urban Ecosystems (Territory Plan: drainage and open space catchments)	Ecosystems in urban lakes, ponds, **wetlands** and streams that have developed as a result of urbanisation.	Primary goal: Range of functions including recreation, conservation, irrigation **and stormwater runoff**.	Waterbodies within the urban area, excluding the Molonglo River.	**Change ecosystem type named "Created" to "Urban Ecosystems"** **Define two separate reaches for urban streams and urban lakes/ponds/wetlands. Sub-divide urban streams into concrete and naturalised** **Include wetlands in ecosystem description**	**The threshold for classifying an ecosystem as "created" is ambiguous. Relevant systems are contained in urban environments. Aligns better with Territory Plan catchment category.** **There is currently a lack of clarity around which objectives are relevant to which type of waterbody because of the use of the catch-all term 'all reaches'.** **To ensure that wetlands can be dealt with separately as required**

ADAPTIVE MANAGEMENT

The flow regimes specified within the current EFG have been developed within an adaptive management cycle (Peat, 2007), with investment in monitoring, assessment and research (particularly through the CRC for Freshwater Ecology, the University of Canberra, Icon Water and the ACT Government) to fill knowledge gaps. The focus has been on balancing the needs of the water users with the requirements of the freshwater ecosystems and has resulted in the refinement of the defined flow requirements and recommended flow regimes.

The current process for modifying rules within the EFG in the ACT is to present a case to the ACT Government and EFTAG, who review such proposals. Examples of how this can be applied include delaying e-flow because of an algae bloom or timing releases to piggy-back on other flows. Adaptive management has been used well in the ACT's water supply catchments in the past.

Strategies were considered for improving EFG implementation within an adaptive management framework. There is some need for to formalise processes around monitoring and reporting. That is, regular monitoring reports should be produced and reviewed as part of a documented process to ensure that adequate monitoring takes place, that reporting occurs and information is fed back into management decisions. The process of identifying how, why and by whom e-flow management decisions are made should be transparent.

One potential method to achieve this is for the role of EFTAG as an advisory group to be augmented to assist in decision making. Such a scheme might involve regular meetings to review monitoring reports, consider relevant variables and provide explicit recommendations for flows in response. The group would also be able to report back where and when further monitoring may be needed. This process will be greatly assisted by ensuring that representatives from all relevant stakeholders are part of the decision-making process.

Recommendations:
The revised EFG include a formalisation of an adaptive management approach, incorporating clear feedback mechanisms for monitoring and reporting, as well as procedures to enable recommendations to be implemented.

OPERATIONAL FLEXIBILITY

Operational flexibility refers to the ability to use existing infrastructure to manipulate flow or water level within a waterbody to achieve certain outcomes. Potential operational flexibilities include the timing, capacity of regulate the temperature of releases, volume and water quality of flows, as well as the potential for ramping up and ramping down flow volumes. The extent of operational flexibility in e-flow provision is a major factor in determining the potential variability of flow regimes. This has implications for setting e-flow regimes and for the capacity of managers to respond to flow requirements in an adaptive manner. In the ACT, the capacity to manipulate these factors varies by reach and these are detailed in the reach tables below. As a summary, releases in water supply catchments have some degree of flexibility, but within the constraints of being managed primarily for water supply. Below non-water supply impoundments (i.e. lower Molonglo River downstream of LBG), flexibility is severely restricted by infrastructure constraints and management goals of the impoundment. Further, operational flexibility is limited in catchments where e-flows are protected by abstraction limits rather than releases from impoundments.

Where flexibility around the e-flow guidelines is required as part of a response to a specific issue, such as fish spawning season, it may be desirable to hold off flows and carry the balance over to a later period. A process for evaluating the ecological merits of such proposals should be built into the formalised adaptive management system recommended above.

OTHER CONSTRAINTS ON E-FLOW PROVISION

A limitation to the establishment of e-flows in the ACT is Tantangara Dam on the Murrumbidgee River headwaters, upstream of the ACT. It is currently operated as a working storage reservoir for the Snowy Hydro Scheme and environmental flows are not a priority management goal. At the Tantangara Dam wall, about 99% of inflows are diverted out of the Murrumbidgee River valley (Snowy Scientific Committee 2010). Environmental flow releases occur based on rules that refer to inflows from the preceding year. It is likely that the volume of water flowing in the Murrumbidgee River through the ACT is reduced from natural flows and the data are currently not available to establish the natural flow regime. The current operational arrangement for Tantangara Dam and the links to NSW and ACT environmental flows might benefit from re-examination when the Basin Plan is reviewed.

Icon Water are able to ensure releases from Tantangara Dam for the purposes of water supply in the ACT, but purchasing water for e-flows is likely to be an expensive exercise.

The reduced flows from upstream and lack of knowledge of the natural flow regime affect the calculation of protected flows in the ACT reaches of the Murrumbidgee River. The reduced flows could have conceivably affected long-lived riparian vegetation along the river, which may not be able to be redressed by the current EFG. Instead, the revised EFG need to be flexible to take advantage of any increase in released volumes possibly by incorporating variation in flows. Given the impact that Tantangara Dam has likely had on the aquatic ecosystems of the ACT, it may be appropriate to note this in Section 2 of the EFG, “Determination of the Environmental Flows”.

RECOMMENDATIONS FOR OBJECTIVES, FLOWS AND INDICATORS

WATER SUPPLY ECOSYSTEMS

The water supply catchments of the ACT are subject to the potentially competing demands of environmental and consumptive purposes. Ensuring an adequate supply of water for domestic consumption is essential, and protecting the habitat of threatened aquatic species is also vital. The EFG are designed to balance these needs, with specified flows meeting the "*minimal requirement for healthy aquatic ecosystems*" (ACT Government 2013).

The Cotter and Queanbeyan Rivers are regulated to supply water to the Australian Capital Territory (ACT) and Queanbeyan. The ecological objectives for these systems are targeted at protecting threatened species, maintaining a healthy ecosystem and preventing degradation of riverine habitat condition.

Particular environmental flow rules for Water Supply Ecosystems are specified for drought periods (Table 4: Appendix 2). A period of water supply drought is defined in the EFG as "*occurring when the water supply utility initiates temporary water restrictions*", noting that restrictions must be approved by the Environment Protection Authority.

The primary management goals of different reaches were considered when identifying Priority Environmental Assets (PEAs) and Priority Ecosystem Functions (PEFs). Riverine sections of the Cotter River system were defined as PEAs and PEFs, but not the reservoirs. The water supply reservoirs on the Cotter River are constructed ecosystems, managed for the purposes of water supply. Some have attributes that may imply eligibility for identification as a PEA (e.g. threatened species habitat) or PEF (e.g. drought refuge). However, managing the reservoirs for ecological values potentially conflicts with their primary purpose of water supply. Instead, it is recommended that the reservoirs of the Cotter River system continue to be managed to meet the broad objective of maintaining a healthy aquatic ecosystem.

Fundamental to identifying the PEAs and PEFs in the ACT Long Term Watering Plan is that they are environmental assets or functions *that can be managed with environmental water*. Many of the ACT's important freshwater assets are located in conservation areas and cannot be managed with environmental water, beyond limiting extractions.

The Cotter River is identified in the Basin-wide environmental Watering Strategy (BWS) as an important environmental asset for native fish. A number of fish species present in the Cotter River are also identified in the BWS as key species. As a result, consideration of BWS outcomes is incorporated into the following tables. As with the identification of PEAs and PEFs, only those ecosystem components that can be managed with environmental water are considered. For further detail on our approach to incorporating BWS outcomes see 'Future of environmental flow guidelines'.

REACHES UPSTREAM OF IMPOUNDMENTS

UPSTREAM OF CORIN, INCLUDING UNREGULATED TRIBUTARIES

Information	The reaches upstream of Corin Reservoir are unregulated and have a natural flow regime and high conservation value. These reaches occur within the ACT's conservation estate.
Ecological and other values	- Near-pristine natural ecosystems including some highly valued bogs/wetlands such as Ginini Flats wetland complex - High biodiversity values (including aquatic and riparian vegetation, frogs, small-bodied fish, reptiles, birds, spiny crays and other aquatic invertebrates)
PEA/PEF[1]	All wetland systems and unregulated tributaries meet at least two criteria for identification as a PEA under MDB Plan Schedule 8. *"Criterion 2: The water-dependent ecosystem is natural or near-natural, rare or unique"* *"Criterion 5: The water-dependent ecosystem supports … significant biodiversity"*.
BWS[1]	Cotter River is identified as an important environmental asset for native fish for: - Presence of threatened species; and - A site of other significance Presence of significant water-dependent vegetation
Flow requirement	*2013 EFG flows:* - No interruption to natural flows to achieve both conservation and water supply outcomes.[1] *Flow recommendations:* - No change to current EFG. Continue to maintain natural flow regime and water quality to maintain ecological values

Objectives	Proposed indicators	Monitoring
2013 EFG objectives: To maintain healthy aquatic ecosystems in all natural ecosystems *No additional objectives identified*	None identified. See note[2]	See note[2]

Justification and notes

1. Note that environmental water can only be managed in these reaches by limiting/prohibiting extraction.
2. In the absence of options to actively manage e-flows for particular outcomes in this reach, indicators are of limited use. Instead, this reach may be monitored to establish reference condition.

REACHES UPSTREAM OF GOOGONG RESERVOIR

Information	The ACT has no statutory responsibility for management of the Googong Reservoir catchment (the Googong, Tinderry and Burra subcatchments) to ensure compliance with the *Seat of Government Acceptance Act 1909,* the ACT considers that any abstraction of natural flows should not be greater than that necessary to support best practice traditional grazing enterprises.
Ecological and other values	- Near-pristine natural ecosystems - High biodiversity values (including aquatic and riparian vegetation, frogs, small-bodied fish, reptiles, birds, spiny crays and other aquatic invertebrates)
PEA/PEF	NSW reaches, not within ACT jurisdiction.
BWS	NSW reaches, not within ACT jurisdiction.
Flow requirement	*2013 EFG flows:* - No interruption to inflows except that necessary for stock and domestic purposes (as provided by the *Water Resources Act 1998*) and that already provided for at the time these guidelines are listed.[1] *Flow recommendations:* - No change to current requirements.

Objectives	**Proposed indicators**	**Monitoring**
2013 EFG objectives: To maintain healthy aquatic ecosystems in all natural ecosystems *No additional objectives identified*	None identified. See note[2]	See note[2]

Justification and notes

1. Note that environmental water can only be managed in these reaches by limiting/prohibiting extraction
2. In the absence of options to actively manage e-flows for particular outcomes in this reach, indicators are of limited use. Instead, this reach may be monitored to establish reference condition.

CORIN RESERVOIR

Information	Corin reservoir is primarily managed for water supply outcomes (though releases occur to comply with e-flow requirements downstream).
Ecological and other values	- Water supply *Potential values (currently data deficient):* - Waterbirds - Drought refuge - Recruitment opportunity for Two-spined Blackfish
PEA/PEF	Does not meet the criteria for identification as a PEA or PEF under MDB Plan Schedules 8 and 9
BWS	Presence of BWS key fish species (Two-spined Blackfish)[2]
Flow requirement	*2013 EFG flows:* - No interruption to natural flows to achieve both conservation and water supply outcomes *Flow recommendations:* - Existing guideline relates to adjacent riverine sections and should be removed. - Proposed flow guideline: reservoirs should be managed primarily for water supply, but complementary ecological benefits (such as drought refuge or refuge for an endangered species) should be sought within the bounds of operational restrictions.

Operational flexibility

The water level in Corin Reservoir is a function of inflow, urban water usage and e-flow requirements downstream. In a scenario of high water usage and low inflow, there is the potential for a relatively fast drop in water level. This is considered outside the control of Icon Water.

Objectives	Proposed indicators	Monitoring
2013 EFG objectives: To maintain healthy aquatic ecosystems	None identified. See notes[1,2]	See notes[1,2]
Additional objectives: To maintain populations of Two-spined Blackfish	1 fish per net night[3]	Bi-ennial. 10 fyke net nights

Knowledge gaps

- Baseline information regarding waterbird composition and abundance in this reach. (Priority B)
- How significantly do flow releases affect water levels in Corin Reservoir? (Priority B)
- Potential impacts of fluctuating water levels on Two-spined Blackfish recruitment and growth (Priority B)

Justification and notes

1. There is limited capacity to manage water levels for ecological outcomes in Corin Reservoir. Thus, indicators are not included, except for Two-spined Blackfish, which is a BWS-listed species.
2. Cormorants are present in Cotter River reaches, but their presence is discouraged due to their predation on Macquarie Perch (a threatened species) in Cotter Reservoir. Additionally, environmental flows are unlikely to influence waterbirds in this reach.
3. The indicator is targeted at detection of the population. There is no robust method for reliable detection of young of the year, thus a related indicator is not appropriate.

GOOGONG RESERVOIR

Information	Googong Reservoir is primarily managed for water supply outcomes (though releases occur to comply with e-flow requirements downstream).
Ecological and other values	- Water supply - Recreation - Fish community free of carp - Water quality
PEA/PEF	Does not meet the criteria for identification as a PEA or PEF under MDB Plan Schedules 8 and 9
BWS	Does not meet criteria for consideration[1]
Flow requirement	*2013 EFG flows:* - No interruption to natural flows to achieve both conservation and water supply outcomes *Flow recommendations:* - Existing guideline relates to adjacent riverine sections and should be removed. - Proposed flow guideline: reservoirs should be managed primarily for water supply, but complementary ecological benefits (such as drought refuge or refuge for an endangered species) should be sought within the bounds of operational restrictions

Objectives	Proposed indicators	Monitoring
2013 EFG objectives: To maintain healthy aquatic ecosystems *No additional objectives identified*[1]	None identified. See notes[2]	See notes[2]

Justification and notes

1. While there are BWS key species present in Googong Reservoir, they are not self-sustaining populations and their on-going persistence is a result of stocking rather than water management
2. There is limited capacity to manage e-flows for ecological outcomes in Googong Reservoir. Thus, indicators are not included.

REACHES BETWEEN IMPOUNDMENTS

CORIN DAM TO BENDORA RESERVOIR, BENDORA DAM TO COTTER RESERVOIR

Information	The reaches between impoundments on the Cotter system are located within the conservation estate and the only impact is to the flow regime through the use of water to supply the ACT's water. Note that the reservoirs are treated as separate reaches.
Ecological and other values	*Corin to Bendora:* - Diversity of fauna (including reptiles, platypus, water rats, frogs, fish, invertebrates) - Intact riparian and aquatic vegetation - Water delivery to water supply reservoirs *Bendora to Cotter:* - Diversity of fauna (including reptiles, platypus, water rats, long-necked tortoise, frogs, fish, invertebrates) - Intact riparian and aquatic vegetation - Water delivery to water supply reservoirs *Potential values (currently data deficient):* - Waterbirds
PEA/PEF	These reaches meet at least one criterion for identification as a PEA under MDB Plan Schedule 8 because of the biodiversity of fauna: *"Criterion 5: The water-dependent ecosystem supports, or with environmental watering is capable of supporting, significant biodiversity"*
BWS	Cotter River is identified as an important environmental asset for native fish for: - Presence of threatened species; and - A site of other significance Presence of BWS key fish species (Two-spined Blackfish, Macquarie Perch) Presence of significant water-dependent vegetation
Flow requirement	*2013 EFG flows:* Base flows: 75% of the 80th percentile or inflows whichever is less Riffle maintenance flow: 150 ML/day for three consecutive days, every two months Pool maintenance flow: >550ML/day for two consecutive days between mid July and mid October Drought rules (stage 1): Base flows: an average of 40 ML/day, or 75% of the 80th percentile or natural inflow whichever is the lesser volume. Riffle maintenance flow: 150 ML/day for three consecutive days, every two months Pool maintenance flow: >550ML/day for two consecutive days between mid July and mid October Drought rules (stage 2): Base flows: an average of 20 ML/day, with license requirements ensuring a scheme of variable low flow releases around the average of the daily base flow. Riffle maintenance flow: 150 ML/day for three consecutive days, every two months Pool maintenance flow: >550ML/day for two consecutive days between mid July and mid October *Flow recommendations[1]:* - In lieu of scientific evidence suggesting adverse impacts of current flow requirements, guidelines should be retained. Maintain natural temperature regime, leaving minimum requirements as per 2013 EFG - It is recommended that weekly variation in flows be reduced (from 50% to 25%) during Macquarie Perch breeding season (October – December inclusive, Bendora Dam to Cotter Reservoir). - Special purpose flows may be necessary to facilitate Macquarie Perch spawning in the Bendora Dam to Cotter Reservoir reach

<table>
<tr><th colspan="3">Operational flexibility</th></tr>
<tr><td colspan="3">Release valves at both Corin and Bendora dams are manually controlled, requiring operators to travel to the dams (via roads potentially closed due to snow and other weather conditions). These factors make step-up or step-down of flows difficult in practice, at least on a more frequent basis than weekly. Automation would be beneficial but would involve large capital expense.
Corin to Bendora
Ideally, riffle maintenance flows should not occur if temperature of released water is too low for fish breeding. For fish outcomes, the quality of the water released is potentially more influential than quantity. Icon Water endeavour to match water quality to that of the natural inflow where this is practical within the constraints of the infrastructure and the primary water supply objective.
Bendora to Cotter
Abstraction at Bendora Dam occurs at water supply level only (offtake height is dependent on water quality suitable for treatment plant). Timing and volume needs to be flexible for water supply.
The release valve at Bendora Dam can be operated at up to 375 ML/day (the safe operating capacity of the pipe), however the recommended maximum operating capacity is 250 ML/day (to minimise erosion of the bank opposite the outlet).
There is flexibility in timing of e-flow releases to allow for requirements of Macquarie Perch breeding. This is adequately managed through an adaptive management process relating to the Cotter Reservoir Fish Management Plan (implemented by Icon Water). As in above reach, temperature of flows is important.</td></tr>
<tr><th>Objectives[2]</th><th>Proposed indicators</th><th>Monitoring</th></tr>
<tr><td>2013 EFG objectives:
To maintain populations of Two-spined Blackfish (both reaches)</td><td>Young of the year and year 1+ age classes (<120 mm) comprise >30% of the monitoring catch; AND

catch is >2 fish for 75% samples (30 m section) in each reach across 2 sampling years[3]</td><td>Annual sampling. EFTAG to further consider details – e.g. timing, sites and effort.</td></tr>
<tr><td>To maintain populations of Macquarie Perch (Bendora Dam to Cotter Reservoir)</td><td>Recruitment detected at 75% of sites[4]. Minimum capture of 1 Macquarie Perch (< 150 mm) per net night[5].</td><td>Annual sampling of 12 net nights per site, 5 sites between Bendora Dam and Cotter Reservoir[6].</td></tr>
<tr><td>To maintain healthy aquatic ecosystems (both reaches)</td><td>- Macroinvertebrate assemblage (AUSRIVAS Band A)
- Non-dominance (<20% cover) of filamentous algae in riffles[7]
- Temperature, turbidity and DO mimic natural inflows
- Instream macrophyte cover <20%[8]</td><td>Maintain current monitoring and reporting</td></tr>
<tr><td>To prevent degradation of riverine habitat through sediment deposition (both reaches)</td><td>Sediment deposition is limited to <20% of total depth of pools at base flow</td><td>Currently not monitored or reported[9]. Five yearly monitoring and reporting recommended.</td></tr>
<tr><th colspan="3">Knowledge gaps</th></tr>
<tr><td colspan="3">- Riparian/macrophyte – flow relationships. Ability of e-flows to prevent encroachment in these reaches (B)
- Riparian and macrophyte baseline condition in these reaches (B)
- There are considerable knowledge gaps in reaches downstream of Corin Dam, particularly around effects of reversed seasonality (e.g. on Two-spined Blackfish). If periods of low flow are possible (e.g. Jan – April) it is not clear what this would achieve on various time scales (B)
- Water level in Bendora Reservoir that leads to stranding of Two-spined Blackfish eggs (B)</td></tr>
</table>

Justification and notes
1. See section on 'Calculating Environmental Flow Requirements' for detail on flow calculations. 2. The 2013 EFG refer to an objective for Cotter River Frog, however, genetic analyses suggest it is a colour morph of *Litoria nudidigitus*, a widely distributed species of frog (W. Osborne, Pers Comm 2017). We recommend that objectives specific to the Cotter River Frog are removed from the EFG. 3. There has been considerable debate around the detail of this indicator, during the workshops and in subsequent feedback. Additionally, a concurrent review of the Two-spined Blackfish monitoring program did not make independent recommendations for biological indicators (Hale and Treadwell 2017). This suggests a lack of evidence to inform indicator parameters. As a result, EFTAG may wish to further revise the indicator as part of the revised EFG. Indicator could be adjusted according to catch at reference sites. The proposed indicator is based on means obtained from reference sites (see Appendix 1); they are reasonably conservative because of large standard deviation from the mean. The sample criterion (75% across 2 years) is selected to account for there only being 1 site in the Corin to Bendora reach and large standard deviation from catch mean. Without this measure, the indicator threshold would often be triggered as a result of limited sampling (rather than ecological factors). 4. The Macquarie Perch population is expanding upstream, but is currently small in this reach. Fyke nets are inappropriate for sampling the adult population, so instead the proposed indicator targets population recruitment. Adult population is somewhat inferred by recruitment. 5. Considerable variation in catch size means a presence/absence indicator is most appropriate in lieu of increased sampling. 6. Annual sampling is appropriate because of expanding distribution. Monitoring details are consistent with current sampling. 7. The 2013 EFG refer to non-dominance of filamentous algae 95% of the time, without clarification of temporal component. It is recommended that the "95% of the time" is removed and that it is stipulated in monitoring requirements that if filamentous algae is found to constitute >20% cover that more intensive sampling takes place. 8. It is assumed that flows of the magnitudes to prevent encroachment predominantly occur naturally in these reaches (in part because of limitations on dam release infrastructure). There is a knowledge gap around ability of e-flows to prevent encroachment in these reaches. 9. The greatest risk of sediment deposition in the pools of the Cotter River occurred following the 2003 fires during the drought. Rainfall had mobilised sediment from the burnt catchment to the river and there were not sufficient in-stream flows to transport the sediment through the system. Monitoring of pools was undertaken in the years immediately following the fires. The catchment has subsequently stabilised but we lack information about the volumes of sediment stored in pools, the extent or consequences of infilling, and the effectiveness of the pool maintenance flows. The 2012 and 2016 floods were observed to have worked the river channels and pools and some morphological changes had taken place. It is recommended that monitoring of the pools be undertaken once within each EFG period to determine the effectiveness of the flow regimes at maintaining pool depths. There is an opportunity to record observations of pool sediments when fish monitoring is undertaken (qualitative data) more frequently and would provide a useful input to the adaptive management process.

BENDORA AND COTTER RESERVOIRS

Information	Bendora and Cotter reservoirs are primarily managed for water supply outcomes (though releases occur to comply with e-flow requirements downstream).
Ecological and other values	- Fish (Two-spined Blackfish, Trout Cod, Macquarie Perch) - Waterbirds - Water supply *Potential values (currently data deficient):* - Drought refuge
PEA/PEF	Does not meet the criteria for identification as a PEA or PEF under MDB Plan Schedules 8 and 9
BWS	Presence of BWS key fish species (Two-spined Blackfish, Macquarie Perch, Trout Cod)
Flow requirement	*2013 EFG flows:* See flow requirements for adjacent riverine reaches, these define inputs. *Flow recommendations:* - Proposed flow guideline: reservoirs should be managed primarily for water supply, but complementary ecological benefits (such as drought refuge or refuge for an endangered species) should be sought within the bounds of operational restrictions - Water level in Cotter Reservoir is partly determined according to the *Enlarged Cotter Dam Fish Management Plan* and informed by EFTAG.

Operational flexibility

Bendora Reservoir

Water level is primarily a function of water supply needs. The reservoir water level is kept relatively stable (approx. 775 m) and while it can change because of maintenance and access requirements, there is minimal chance of it becoming so low as to have a major ecological impact. However, the rate of change in water level may be significant. For example, there is a risk of Two-spined Blackfish eggs being stranded if there is a rapid fall in water level during breeding season. As a result, reduction in water level should be avoided in this period (mid-November), as far as practicable considering the primary function of the reservoir.

Cotter Reservoir

Large releases are now required in the enlarged Cotter Reservoir before water level is substantially effected. The addition of rock reefs has reduced impact of water level fluctuation on fish. The annual Fish Management Plan produced by Icon Water considers how water can be optimally managed for positive fish outcomes.

Objectives[1,2]	Proposed indicators	Monitoring
2013 EFG objectives (for adjacent riverine reaches): To maintain populations of Two-spined Blackfish (Bendora Res.)	Minimum 2 post-juvenile Two-spined Blackfish per net night[1]	Biennial sampling. EFTAG fish group to further consider details – e.g. timing, location, net number.
To maintain populations of Macquarie Perch (Cotter Res.)	Minimum total catch 3 Macquarie Perch per net night, comprised of > 50% individuals <150 mm.[2]	Annual sampling of 60 fyke net nights[3].
To maintain healthy aquatic ecosystems (both reservoirs)	None identified[4,5]	
Additional objectives: To maintain populations of Trout Cod (Bendora Res.)	None identified[6]	

Knowledge gaps

- Baseline information regarding waterbird composition and abundance in these reaches (B).
- Impact of fluctuating water levels on Two-spined Blackfish and Trout Cod recruitment (B).
- Two-spined Blackfish population condition and recruitment considered “good” for Bendora Reservoir (B).
- Location of Trout Cod spawning and what role Bendora Reservoir might play (B).

Justification and notes
1. Mean Two-spined Blackfish per net night in Bendora Res. in sampling since 2001 is 9.27 (±7.3 SD; see Appendix 1). Given the large standard deviation from the mean, it is worth being conservative. Small sample size and large SD mean gives limited power for detecting trend. 2. See Appendix 1 for relevant data. 3. Increased frequency (annual) and intensity (60 nets) of sampling since previous guidelines to be commensurate with the increase in shoreline of the enlarged Cotter Reservoir. 4. There is limited capacity to manage water levels for ecological outcomes in both reservoirs. Thus, indicators are not included, except for populations of threatened fish, where possible. 5. Cormorants are present in Cotter River reaches, but their presence is discouraged due to their predation on Macquarie Perch (a threatened species) in Cotter Reservoir. Additionally, environmental flows are unlikely to influence waterbirds in this reach. 6. Knowledge gaps are too broad to devise meaningful indicators for Trout Cod in Bendora Reservoir.

REACHES DOWNSTREAM OF IMPOUNDMENTS

Information	Downstream of Cotter Dam and downstream of Googong Dam.	
Ecological and other values	*Downstream of Cotter Dam:* - Recreation - Connectivity (Murrumbidgee R. to Paddys R.) - Riparian vegetation (patches in good condition) - Ecosystem function o Major tributary to the Murrumbidgee R. o Sediment transportation o Prevent encroachment o Good water quality to maintain functioning ecosystem	*Downstream of Googong Dam:* - Dilution of flows heading into LBG - Riparian vegetation (patches in good condition) - Vertebrate fauna (platypus, water rats, reptiles) - Irrigation supply
PEA/PEF	Does not meet the criteria for identification as a PEA or PEF under MDB Plan Schedules 8 and 9	
BWS	Cotter River is identified as an important environmental asset for native fish for: - Presence of threatened species; and - A site of other significance Presence of significant water-dependent vegetation	
Flow requirement	*2013 EFG flows:* - Baseflows below Cotter: 15 ML/day - Baseflows below Googong: 10 ML/day or inflow whichever is less - Riffle maintenance flow: 100 ML/day for one day to occur every two months - No pool maintenance flows required. - No specific drought flows are provided *Flow recommendations[1]:* *Downstream of Cotter Dam:* - Incorporate flow variability and seasonal patterns into base flow in a manner consistent with other reaches below impoundments - Base flows: 75% of the 80th percentile (calculated monthly) or inflows whichever is less - Riffle maintenance flows made up of 25% of the 80th percentile (calculated monthly) delivered over 2-3 days every month. - Drought flow provisions to be developed *Downstream of Googong Dam:* - Incorporate flow variability and seasonal patterns into base flow in a manner consistent	

<table>
<tr><td></td><td colspan="2">with other reaches below impoundments
- Base flows: 75% of the 80^{th} percentile or inflows whichever is less
- Riffle maintenance flows made up of 25% of the 80^{th} percentile (calculated monthly) delivered over 2-3 days every month.
- Drought flow provisions to be developed</td></tr>
<tr><td colspan="3">Operational flexibility</td></tr>
<tr><td colspan="3">Downstream of Googong
There is potential to increase the volume of releases at Googong Dam, which are currently at static low flow levels. This may increase releases from Lake Burley Griffin to the lower Molonglo River.
The benefits of increasing e-flows would need to be considered carefully. For example, fish in this reach are from stocked populations and unlikely to respond to increases in e-flows.</td></tr>
<tr><td>Objectives[2]</td><td>Proposed indicators</td><td>Monitoring</td></tr>
<tr><td>2013 EFG objectives:
To maintain healthy aquatic ecosystems below Cotter Dam</td><td>- Macroinvertebrate assemblage (AUSRIVAS Band A)
- Non-dominance (<20% cover) of filamentous algae in riffles[3]
- Temperature, turbidity and DO mimic natural inflows</td><td>Maintain current monitoring and reporting[3]</td></tr>
<tr><td>To maintain healthy aquatic ecosystems below Googong Dam</td><td>- Macroinvertebrate assemblage (AUSRIVAS Band A)
- Non-dominance (<20% cover) of filamentous algae in riffles[3]
- Temperature, turbidity and DO mimic natural inflows</td><td>Maintain current monitoring and reporting[3]</td></tr>
<tr><td>Additional objectives:
To maintain riparian vegetation values below Cotter Dam</td><td>Extent and condition of riparian vegetation is maintained or improved</td><td>Vegetation condition and extent monitoring (5 yearly)</td></tr>
<tr><td>To maintain connectivity for fish populations/habitats below Cotter Dam</td><td>None identified[2,4]</td><td></td></tr>
<tr><td colspan="3">Knowledge gap</td></tr>
<tr><td colspan="3">- Seasonal patterns for both reaches – a requirement for determining base flows (A)
- Flows required to allow fishway below Cotter Dam to operate effectively and if releases from Cotter Dam are required to meet these flows (or is flow from Paddy's River sufficient?) (B)
- Providing higher flows downstream of Googong Dam has downstream consequences for Lake Burley Griffin and potentially the Molonglo River downstream of Lake Burley Griffin. The consequence of any increased flows to Lake Burley Griffin (see later table) for water quality need to be resolved before the recommendation can be implemented (A)</td></tr>
<tr><td colspan="3">Justification and notes</td></tr>
<tr><td colspan="3">1. See section on 'Calculating Environmental Flow Requirements' for justification
2. The 2013 EFG contain fish-specific objectives below Cotter Dam, it is recommended that these objectives be removed. While some BWS key fish species exist below Cotter Dam, these are not self-recruiting populations. Flows should be targeted at supporting their survival through healthy aquatic ecosystems.
3. The 2013 EFG refer to non-dominance of filamentous algae 95% of the time, without clarification of temporal component. It is recommended that the "95% of the time" is removed and that it is stipulated in monitoring requirements that if filamentous algae is found to constitute >20% cover that more intensive sampling takes place.
4. There is a fishway in this reach, which dominates level of connectivity for fish (rather than e-flows). It is included here to align with BWS requirements regarding connectivity, but given limited response to e-flow, we do not recommend including it as an objective in the revised EFG.</td></tr>
</table>

NATURAL ECOSYSTEMS

Natural Ecosystems are those that persist in a state similar to pre-European settlement condition. In the ACT, natural aquatic ecosystems include waterbodies within Namadgi National Park (outside of the Cotter River Catchment) and those within Tidbinbilla Nature Reserve.

ALL REACHES

Information	The reaches Natural Ecosystems are unregulated, have a natural flow regime and high conservation value.
Ecological and other values	- Near-pristine natural ecosystems including some highly valued bogs/wetlands - High biodiversity values (including aquatic and riparian vegetation, frogs, small-bodied fish, reptiles, birds, spiny crays and other aquatic invertebrates)
PEA/PEF	All reaches meet at least two criteria for identification as a PEA under MDB Plan Schedule 8: *"Criterion 2: The water-dependent ecosystem is natural or near-natural, rare or unique"* *"Criterion 5: The water-dependent ecosystem supports … significant biodiversity"*
BWS	Does not meet criteria for consideration[1]
Flow requirement	*2013 EFG flows:* Baseflows are to be protected: Baseflow is defined as the modelled natural 80th percentile of stream flow. Abstractions of surface water may never exceed the flow rate. Abstraction of groundwater is limited to 10% of the recharge rate to protect base flow. Abstractions should allow natural flow variability to be maintained. Flooding flows, particularly channel maintenance flows, are to be protected by restricting abstraction in water management areas to 10% of the flow volume above the 80th percentile. The discharge most critical at determining the width, depth and meander frequency of channels is the 1.5 to 2.5 year annual recurrence interval flood event. *Flow recommendations:* No change to current requirements (abstraction limits already in place). Continue to maintain natural flow regime and water quality to maintain an intact riparian zone/in-stream macrophytes

Objectives	Proposed indicators	Monitoring
2013 EFG objectives: To maintain healthy aquatic ecosystems	None identified. See note[1]	
To prevent degradation of riverine habitat through sediment deposition		
Additional objectives: To maintain high biodiversity values		
To maintain riparian zone and in-stream macrophytes		

Justification and notes

1. In the absence of options to actively manage e-flows for particular outcomes in this reach, indicators are of limited use. Instead, this reach may be monitored to establish reference condition for other reaches. The proposed objectives could be considered for future EFG reviews, however for now they can be folded under the broad objective of maintaining aquatic ecosystems.

MODIFIED ECOSYSTEMS

The Modified Ecosystems of the ACT are those that have been significantly altered by catchment activities, including changing land use and modifications to the natural flow regime.

Rivers, lakes and streams in the Modified Ecosystem category include those water bodies outside Namadgi National Park, Tidbinbilla Nature Reserve and the Canberra urban area. For the purposes of the EFG Lake Burley Griffin, the Molonglo River, and the Queanbeyan River above Googong Reservoir are also considered Modified Ecosystems. These ecosystems have been modified by catchment activities including landscape change, and modifications to the natural flow regime.

The Guidelines seek to maintain Modified Ecosystems in as natural a state as possible through management of flows and abstraction. To achieve these management goals four groups of Modified Ecosystems have been identified:

- Murrumbidgee River;
- Lake Burley Griffin;
- Wetlands in modified ecosystems; and
- other reaches including the Molonglo, Naas and Gudgenby (unless located in National Park, in which they are defined as Natural Ecosystems) and reaches in NSW over which the Commonwealth has paramount rights to the water other than those in the Queanbeyan River catchment.

MURRUMBIDGEE RIVER	
Information	The environmental flow rules implemented in the NSW section of the Murrumbidgee upstream of the ACT are defined in the Snowy Water Inquiry Outcomes Implementation Deed (SWIOID 2002), and defined annually based on inflows in the preceding year (NSW DPI 2017). Environmental flows from NSW upstream are currently not protected within NSW and are likely to pass through the ACT unaffected by activity in the ACT because they are not targeted or accounted for in ACT planning.
Ecological and other values	- Riparian vegetation - Habitat complexity and geomorphic value (wetlands, bedrock, gorges) - Murray Cod (native), Trout Cod (likely to be translocated) - Other fauna (including a diversity of invertebrates, shield shrimp, raptors, reptiles) - Recreation - Water supply - Plant dispersal
PEA/PEF	The presence of threatened species (Murray Cod and Trout Cod) means the Murrumbidgee River meets at least one criterion for identification as a PEA under MDB Plan Schedule 8: *"Criterion 4: Water-dependent ecosystems that support Commonwealth, State or Territory listed threatened species or communities"*
BWS	Upland Murrumbidgee main channel is identified as an important environmental asset for native fish for: - Key movement corridors, threatened species, and a site of other significance Presence of BWS key fish species (Murray Cod)[9] Presence of significant water-dependent vegetation Presence of waterbirds
Flow requirement	*2013 EFG flows:* Baseflows: 80th percentile of stream flow November to May inclusive; 90th percentile of stream flow June to October inclusive

	In addition, abstractions of surface water may never exceed the flow rate. Abstraction of groundwater is limited to 10% of the recharge rate to protect baseflow. Flooding flows, particularly channel maintenance flows, are protected by restricting abstraction activities to ensure that abstraction does not affect the frequency of channel maintenance events. The discharge most critical at determining the width, depth and meander frequency of channels is the 1.5 to 2.5 year annual recurrence interval flood event. A restriction of abstraction to flows below that threshold or a restriction on the rate of abstraction that can occur during those events, will ensure that channel maintenance flows occur at appropriate frequencies. *Flow recommendations:* - No change to existing protected flows, though the timing of abstractions could be stipulated where ecologically important[1] - Murrumbidgee to Cotter and Murrumbidgee to Googong have restrictions on extractions, it was recommended these remain - Environmental flow releases downstream of Tantangara are protected from extraction through the ACT

Objectives	Proposed indicators	Monitoring
2013 EFG objectives: To maintain healthy aquatic ecosystems in terms of biota	- Macroinvertebrate assemblage (AUSRIVAS Band A) - Non-dominance (<20% cover) of filamentous algae in riffles[2]	Continue existing monitoring and reporting[2]
To prevent degradation of riverine habitat through sediment deposition	None identified[3]	
Additional objectives: To maintain extent of water dependent fringing and in-channel native vegetation	None identified[4]	
To enhance native fish community, including Murray Cod and Murray Cray	Recruitment of Murray Cod detected at 75% sites in reach across 2 sampling years[6,7] Murray River Crayfish detected[7]	EFTAG fish group to consider details, including timing, techniques and sites
To maintain diversity and increase abundance of waterbirds.	None identified[4,5]	
To maintain habitat complexity and geomorphic values	None identified[4]	

Knowledge gap

- Fish requirements for connectivity in the Murrumbidgee River. Promoting connectivity for fish is an objective of the BWS (B).
- A number of native fish recruitment: flow relationships are unknown (B).
- How the riparian vegetation along the Murrumbidgee River corridor (and particularly the long lived riparian species) are responding to the effects of Tantangara Dam (B).

Justification and notes

1. Extraction in Murrumbidgee River can occur under drought conditions. This may occur increasingly often under future climates. This is not clearly stated in EFG, but is in Icon Water's *Licence to Take Water* (WU67). It is recommended that the links between the EFG and other documents be clarified and made explicit.
2. The 2013 EFG refer to non-dominance of filamentous algae 95% of the time, without clarification of temporal component. It is recommended that the "95% of the time" is removed and that it is stipulated in monitoring requirements that if filamentous algae is found to constitute >20% cover that more

intensive sampling takes place. 3. Sedimentation of the pools in the Murrumbidgee River is a function of historical land use activities and is unable to be influenced by the management of flows. Monitoring is therefore not relevant to EFG. 4. Under current flow releases from Tantangara Dam there is limited capacity to influence this proposed objective. It is assumed that there will be no changes to releases from Tantangara Dam in the next five years. Such scenarios expose the vulnerability of ACT ecosystems to extractions upstream, over which the ACT has little or no control. While this geomorphology objective is not recommended for the present EFG revision, it could be reconsidered during future reviews. 5. There is an absence of baseline data for waterbirds in this system, thus meaningful indicators could not be formulated. 6. The site criterion (75% across 2 years) is selected to account for methodological issues. Without this measure, the indicator threshold would potentially be triggered as a result of sampling issues (as opposed to an ecological issue). 7. The proposed indicator targets population recruitment on account of methodological issues with sampling adult population. Adult presence is somewhat inferred by recruitment. 8. Detection probability using existing methods is low for Murray River Crayfish. While presence/absence detection is achievable, population estimates are unreliable. 9. The BWS recommends ACT reaches of the Murrumbidgee River as candidate sites for the establishment of additional populations of Silver Perch. Silver Perch are functionally extinct within the ACT and the only way to establish additional populations in the ACT is to undertake a stocking program. This is outside the scope of the EFG.

OTHER ACT REACHES INCLUDING MOLONGLO, NAAS AND GUDGENBY RIVERS

Information	Rivers, lakes and streams in the Modified Ecosystem category include those water bodies outside Namadgi National Park, Tidbinbilla Nature Reserve and the Canberra urban area. The Molonglo River, and the Queanbeyan River above Googong Reservoir are also considered Modified Ecosystems. These ecosystems have been modified by catchment activities including landscape change, and modifications to the natural flow regime
Ecological and other values	*All lakes:* - Drought refuge *Jerrabomberra Wetlands:* - DIWA listed (since 1990s) for its waterbirds and geomorphological features - Biodiversity values (including macrophytes, turtles, platypus, dragonflies) *Molonglo River downstream of LBG:* - Riparian vegetation (patches in good condition) - Platypus and other vertebrate fauna - Recreation Note that other values of this reach are recognised in the Molonglo Corridor Management Plan.
PEA/PEF	The high biodiversity values of Jerrabomberra Wetlands meet at least one criterion for identification as a PEA under MDB Plan Schedule 8: *"Criterion 5: The water-dependent ecosystem supports … significant biodiversity"*
BWS	Presence of BWS key fish species (Murray Cod) Presence of significant water-dependent vegetation Presence of waterbirds
Flow requirement	*2013 EFG flows:* Baseflows are to be protected: Baseflow is defined as the modelled natural 80th percentile of stream flow Abstractions of surface water may never exceed the flow rate. Abstraction of groundwater is limited to 10% of the recharge rate to protect base flow Flooding flows, particularly channel maintenance flows, are to be protected by restricting

	abstraction in water management areas to 10% of the flow volume above the 80th percentile. The discharge most critical at determining the width, depth and meander frequency of channels is the 1.5 to 2.5 year annual recurrence interval flood event. *Flow recommendations:* *Jerrabomberra Wetlands*: - Allow periodic drawdown[1] *Molonglo D/S LBG:* - Maintain natural flow and temperature regime, where possible.[2]

Operational flexibility
The lower Molonglo (downstream of LBG) is the only reach in this category with potential flexibility in flow delivery. This potential and related issues are discussed in the table pertaining to Lake Burley Griffin.

Objectives	**Proposed indicators**	**Monitoring**
2013 EFG objectives: To maintain healthy aquatic ecosystems in terms of biota	- Macroinvertebrate assemblage (AUSRIVAS Band A) - Non-dominance (<20% cover) of filamentous algae in riffles[3]	Continue existing monitoring and reporting[3]
To prevent degradation of riverine habitat through sediment deposition	None identified[4]	
To maintain and improve functional assemblages of macrophytes in modified lakes, ponds and wetlands[5]	None identified[6]	
Additional recommended objectives: To maintain and improve riparian vegetation in Molonglo R. D/S of LBG	None identified[6]	
To maintain and improve populations of platypus and other vertebrate fauna in Molonglo R. D/S of LBG	None identified[6]	
Enhance native fish community (including BWS key species) in Molonglo R. U/S and D/S of LBG	U/S of LBG: Murray Cod present and recruitment detected at 75% of sites across 2 years[7] D/S of LBG: None identified[6]	EFTAG fish group to consider details, including timing, techniques and sites

Knowledge gaps
- Limitations imposed by thermal pollution on fish population in Molonglo River downstream of LBG (B) - Response of fish populations to increased flows in Molonglo River downstream of LBG (A) - Baseline macrophyte assemblages in Modified Ecosystems (A)
Justification and notes
1. Note that there is no capacity for actively managing flows in Jerrabomberra Wetlands. 2. Note there is limited capacity for top releases from LBG 3. The 2013 EFG refer to non-dominance of filamentous algae 95% of the time, without clarification of temporal component. It is recommended that the "95% of the time" is removed and that it is stipulated in monitoring requirements that if filamentous algae is found to constitute >20% cover that more intensive sampling takes place 4. Sedimentation of the pools in Modified Ecosystems is a function of historical land use activities and is unable to be influenced by the management of flows. Monitoring is therefore not relevant to EFG. 5. Amended from reference to "urban lakes and ponds" in 2013 EFG 6. Knowledge gaps are too broad to devise meaningful indicators for macrophytes in Modified Ecosystems. Additionally, there is limited potential to actively manage flows for in Modified Ecosystems (also see table pertaining to management of Lake Burley Griffin). 7. Releases from LBG to lower Molonglo are severely limited by infrastructure restrictions. This is unlikely to change in the next five years. As a result, specific indicators have not been identified for this reach. Objectives are not appropriate here at this time, though future review recommended. 8. For the most part, fish populations in the reach upstream of LBG are non-recruiting. They are typically fish stocked and lost from Googong Reservoir 9. The potential for maintaining waterbird populations at Jerrabomberra Wetlands was considered. This is unlikely to be achieved through e-flows in Jerrabomberra Wetlands. Additionally, any enhancement of waterbird population could threaten operational requirements of the nearby Canberra airport.

LAKE BURLEY GRIFFIN

Information	Lake Burley Griffin is managed according to a hierarchy of lake use values, as listed in the *Lake Burley Griffin Abstraction Guide* (EPA 2014). The primary management goal for Lake Burley Griffin is for recreation.
Ecological and other values	- Recreation - National capital values - Water quality and resources - Tourism and commercial development Note that these values (except specific ecological values) are stipulated and ordered in the *Lake Burley Griffin Abstraction Guide* (EPA 2014). - Ecological o Vertebrate fauna (flying foxes, water rats, platypus) o Macrophytes o Silver gulls (on Spinaker Island) o Diversity of waterbirds - Educational and scientific
PEA/PEF	Does not meet the criteria for identification as a PEA or PEF under MDB Plan Schedules 8 and 9.
BWS	Presence of significant water-dependent vegetation Presence of waterbirds
Flow requirement	*2013 EFG flows:* Baseflows are to be protected: Baseflow is defined as the modelled natural 80th percentile of stream flow. Abstractions of surface water may never exceed the flow rate. Abstraction of groundwater is limited to 10% of the recharge rate to protect base flow Flooding flows, particularly channel maintenance flows, are to be protected by restricting abstraction in water management areas to 10% of the flow volume above the 80th percentile. The discharge most critical at determining the width, depth and meander frequency of channels is the 1.5 to 2.5 year annual recurrence interval flood event. *Flow recommendations:* Allow water level fluctuations of up to 0.6 m below full supply level while continuing to protect waterbird breeding habitat during breeding season (drawdown limited to 0.2 m during July to November inclusively).

Operational flexibility

Water levels in LBG are tightly managed for purposes other than ecological outcomes. The cost of top-releases from Lake Burley Griffin is effectively prohibitive, currently. Licencing requirements also prohibit LBG filling to the point of spilling. While the infrastructure permits bottom-releases, flows are cold, turbid and low in DO. It is not known if such releases are ultimately beneficial for biota. There are some unknowns relating to fish requirements in the downstream reach.
In terms of volume, it was suggested that current outflow from LBG closely mimics natural inflow, with water only retained to compensate for evaporation loss (abstraction close to 0 L, despite existing abstraction licences).
The case for infrastructure alteration (e.g. thermal curtains) would be improved by greater understanding of flow-ecology relationships for the reach downstream of LBG.

Objectives	Proposed indicators	Monitoring
2013 EFG objectives: To maintain healthy aquatic ecosystems in terms of biota	None identified[1]	
To maintain and improve functional assemblages of macrophytes	Presence of emergent macrophytes of sufficient density and diversity to perform beneficial WQ processes and provide habitat for desired fauna. Submerged macrophytes present at density that perform beneficial WQ processes	Littoral zone monitored from aerial photos, examining macrophyte spatial extent over time, species and colour.
Additional objectives: To maintain diversity and	None identified[2]	

abundance of waterbirds		
Knowledge gaps		
- Baseline survey data of waterbird diversity and abundance on Lake Burley Griffin (A)		
Justification and notes		
1. There is limited capacity to manage water levels for ecological outcomes in Lake Burley Griffin. Thus, indicators are not included, except for macrophytes, as per BWS requirements. **2.** Knowledge gaps are too broad to devise meaningful indicators for waterbirds in Lake Burley Griffin.		

WETLANDS

Information	There are some important natural wetlands (such as Horse Park wetland) that are threatened by urban development altering the flow regime to the wetland.
Ecological and other values	No specific values identified
PEA/PEF	Does not meet the criteria for identification as a PEA or PEF under MDB Plan Schedules 8 and 9.
BWS	Presence of significant water-dependent vegetation Presence of waterbirds
Flow requirement	*2013 EFG flows:* Baseflows are to be protected: Baseflow is defined as the modelled natural 80th percentile of stream flow Abstractions of surface water may never exceed the flow rate. Abstraction of groundwater is limited to 10% of the recharge rate to protect base flow Flooding flows, particularly channel maintenance flows, are to be protected by restricting abstraction in water management areas to 10% of the flow volume above the 80th percentile. The discharge most critical at determining the width, depth and meander frequency of channels is the 1.5 to 2.5 year annual recurrence interval flood event. *Flow recommendations:* Natural flow and water level regime remains unchanged in wetlands. In particular, protect wetlands from increased flows from urban areas.

Objectives	Proposed indicators	Monitoring
2013 EFG objectives: To maintain healthy aquatic ecosystems in terms of biota	None identified[1]	
To maintain functional assemblages of macrophytes in wetlands[2] *No additional objectives were identified*	Presence of emergent macrophytes of sufficient density and diversity to perform beneficial WQ processes and provide habitat for desired fauna. Submerged macrophytes present at density that perform beneficial WQ processes	Littoral zone monitored from aerial photos, examining macrophyte spatial extent over time, species and colour.
Knowledge gaps		
- Distribution of wetlands potentially affected by urban development. Recommend mapping of these wetlands for inclusion in EFG (A)		
Justification and notes		
1. Prior to identification of waterbodies in this classification, there is limited value to nominating indicators. As an exception, a general-purpose indicator is proposed for macrophytes, in line with BWS requirements 2. Amendment from reference to urban lakes and ponds		

URBAN ECOSYSTEMS

The waterbodies considered under this category are all those that have developed as a result of urbanisation. It is recommended that the category of ecosystem be changed from 'Created' to 'Urban' ecosystems, removing ambiguity, aligning more neatly with the Territory Plan and reflecting the primary influence on the relevant ecosystems. It is also proposed that Urban Ecosystems then be split into urban streams (naturalised and concrete-lined) and urban standing waters (lakes, ponds and wetlands).

The 2013 EFG cite significant community support for restoring urban streams to a more natural condition. The Guidelines reflect this through recommendations that flows in urban streams be restored to natural flow regimes as far as practicable. In most cases ecological objectives aimed at promoting healthy aquatic ecosystems are not achievable in concrete lined channels. However, such objectives may be appropriate to naturalised channels in urban environments.

Freshwater ecosystems in urban environments are subject to substantial changes in flow regimes driven by large areas of impervious ground within their catchments (Walsh *et al.* 2005). This means that the environmental flow requirements may allow the abstraction of water from these systems to create a more natural flow or water level regime to improve the freshwater ecosystems. This is counter-intuitive to the traditional conceptualisation of environmental flows and could potentially be considered a net reduction in PEW. The reviewers consider that improved ecological outcomes in these systems should be a greater priority than fixed volumes of water. This is particularly pertinent for constructed waterbodies (such as the urban ponds) for which the primary purpose is the attenuation of flows and improvements in water quality to protect downstream ecosystems.

URBAN STREAMS - NATURALISED AND CONCRETE LINED	
Information	All urban streams within the urban area fall into this category, excluding the Molonglo River. Naturalised and concrete lined urban streams should be considered separately, reflecting the differing ecological potential of these systems.
Ecological and other values	- Stormwater function - Transportation of vegetation propagules - Basic ecological function (including connectivity, nutrient transfer, etc.)
PEA/PEF	Does not meet the criteria for identification as a PEA or PEF under MDB Plan Schedules 8 and 9
BWS	Does not meet criteria for consideration
Flow requirement	*2013 EFG flows:* Baseflows are to be protected: Baseflow is defined as the modelled natural 80th percentile of stream flow Abstractions of surface water may never exceed the flow rate. Abstraction of groundwater is limited to 10% of the recharge rate to protect base flow Flooding flows, particularly channel maintenance flows, are to be protected by restricting abstraction in water management areas to 10% of the flow volume above the 80th percentile. The discharge most critical at determining the width, depth and meander frequency of channels is the 1.5 to 2.5 year annual recurrence interval flood event.

	Flow recommendations: *Concrete lined channels:* - Manage flows to reduce runoff volumes, velocities and the transport of pollutants from urban areas to downstream ecosystems.[1] *Naturalised channels:* - Manage flows to reduce runoff volumes, velocities and the transport of pollutants from urban areas to downstream ecosystems.[1] - Protect baseflows where baseflow is defined as the modelled natural 80th percentile of stream flow. Abstractions of surface water may never exceed the flow rate. - Abstraction of groundwater is limited to 10% of recharge to protect base flows. - Protect streams from increased flows caused by urban development.

Objectives	**Proposed indicators**	**Monitoring**
Additional objectives: To prevent degradation of downstream aquatic ecosystems through sediment deposition and high flow rates (all reaches)	Turbidity does not exceed guidelines for freshwater ecosystems 80% of the time	Currently not monitored and reported[2]
To maintain healthy aquatic ecosystems in terms of biota (all reaches)	- Macroinvertebrate assemblage long-term improvement as measured by AUSRIVAS[3] - Non-dominance (<20% cover) of in-stream macrophytes[4]	EFTAG and ACT Government to revise current monitoring program[3]

Justification

1. This measure may require a focus on catchment measures to reduce runoff.
2. It is recommended that monitoring against this objective is considered as part of the review of the ACT water quality monitoring activities.
3. Macroinvertebrate indicator targets of AUSRIVAS Band A may not be achievable in urban streams. A target condition less then Band A may be acceptable within an adaptive management process.
4. Changed from indicator around non-filamentous algae. Macrophytes are a more appropriate measure for naturalised streams

URBAN LAKES, PONDS AND WETLANDS

Information	All lakes, ponds and wetlands within the urban area excluding the Molonglo River fall into this category. Urban lakes, ponds and wetlands are categorised based on the presence of functional process zones: a) Lake – 3 zones/processes b) Pond – 2 zones **c)** Wetlands – 1 zone
Ecological and other values	- Waterbirds and their breeding habitat - Amenity/recreation - Vertebrate fauna - Non-potable water supply - Algae - Vegetation - Water quality
PEA/PEF	Does not meet the criteria for identification as a PEA or PEF under MDB Plan Schedules 8 and 9
BWS	Presence of significant water-dependent vegetation Presence of waterbirds
Flow requirement	*2013 EFG flows:* For urban lakes and ponds that were constructed before the year 2000 the drawdown as a result of abstraction is 0.20m below spillway level. This level of drawdown would result in the lake margins retreating approximately 2 metres in most areas as pond design guidelines require edges to be sloped at approximately 1 in 10 for stability, safety and public health reasons. Historically it is noted that water level variations without abstraction have been greater than 0.20m. Research on Canberra's lakes and ponds indicates that drawdown to 0.60m is the upper limit without the risk of adverse ecological effects increasing significantly. Therefore the drawdown caused by abstraction, of lakes and ponds constructed before 2000 can only exceed 0.20m if the activity is covered by intensive management and monitoring. For minor abstraction activities from lakes and ponds, where management/monitoring programs are uneconomical, a drawdown of 0.20m provides an efficient and safe limit. For urban lakes and ponds constructed after 2000 the maximum drawdown as a result of abstraction is 0.20m below spillway level, or a lower level if it can be demonstrated that a pond has been explicitly designed to fulfil its required water quality and ecological functions under the proposed drawdown regime. As with other guidelines, there will be a need to monitor the effect of this guideline on lake and pond macrophytes and fish populations of stocked lakes over time. *Flow recommendations:* Allow water level fluctuations of up to 0.60 m below full supply level while continuing to protect waterbird breeding habitat during breeding (drawdown limited to 0.2 m during July to November inclusively).[1]

Objectives	**Proposed indicators**	**Monitoring**
2013 EFG objectives: To maintain healthy aquatic ecosystems in terms of biota	None identified[1,2]	
To maintain functional assemblages of macrophytes in urban lakes, ponds and wetlands	- Presence of emergent macrophytes of sufficient density and diversity to perform beneficial WQ processes and provide habitat for desired fauna. - Submerged macrophytes present at density that perform beneficial WQ processes	Littoral zone monitored from aerial photos, examining macrophyte spatial extent over time, species and colour.

To protect waterbird breeding habitat from drawdown during breeding season	None identified	
To maintain populations of fish in urban impoundments where stocking occurs	Fish kills do not occur[3]	Observation
Justification		

1. Workshop 1 participants suggested that drawdown of up to 0.8 m below FSL is unlikely to have a detrimental effect on lake macrophytes. There is potentially an effect on flows in urban creeks downstream of the impoundments. A limit of 0.6 m in autumn has been recommended for urban ponds and wetlands. This is consistent with natural drying patterns in the region and is likely to have benefit for macrophytes and has potential benefit for denitrification. These waterbodies generally refill rapidly with small rainfall events (Stehlik, 2016) and are located within ephemeral drainage lines that would benefit from drying out. There is currently a research project being undertaken by the Institute for Applied Ecology that will inform the effects of water level fluctuations in ponds and wetlands on urban ponds and wetlands.
   A limit of 0.6 m is also suggested for the larger urban lakes, with monitoring of the littoral zone to accompany it. In addition, the effects on the urban creeks downstream of the wetlands should be carefully monitored to ensure that there is not a significant effect on baseflows in these streams, with the target being a more natural streamflow downstream of the urban lakes.
2. Frogs are present in many of these waterbodies, but population health is dominated by land management rather than e-flows. The links between frog abundance and water level are not well established. Urban frog populations are considered under the WSUD code.
3. Macroinvertebrates could be used as an indicator for ecosystem health. Current AUSRIVAS models do not apply to standing waters, but an AUSRIVAS-type model could be constructed for this purpose
4. Monitoring stocked fish for e-flow purposes is not appropriate, however, avoiding draw down to water levels that may induce fish kills will allow maintenance of fish populations.

CALCULATING ENVIRONMENTAL FLOW REQUIREMENTS

The current EFG specify flow releases in relation to percentile flows for reaches between impoundments, reaches below impoundments and the Murrumbidgee River. 75% of the 80th monthly percentile is specified as the baseflow in these reaches. This was set because it was considered that the 80th percentile flow was an appropriate starting point for an environmental flow volume in these rivers. The need to incorporate flow variability (channel maintenance and flushing flows) meant that the baseflow was set at 75% of the 80th percentile and the remaining 25% of the 80th percentile was used to deliver the flow pulses.

The volumes corresponding to the percentile flows are dependent on the time period used for the calculations. It is not clear in the current guidelines which time period should be used other than having a suitable length of record (at least 10 years).

Recommendation:
The time period used to establish environmental flow requirements is specified within the revised EFG.

As part of the review of the EFG, eWater have analysed different time periods to determine the differences in flow volumes. This analysis is provided in Appendix 7. The three time periods considered are:

- 1975 – 1994: This period followed the floods of the early 1970s, the 1980s drought and the wet period of the late 1980s and early 1990s
- 1980 – 2016: This period includes the drought of the early 1980s and the millennium drought as well as the more recent
- 1975 – 2016: This includes both of the above time periods.

None of the time periods analysed match the current environmental flow requirements and some further analysis by eWater indicates that it is not clear which time period was used to establish the current environmental flow requirements. In recommending a time period to be used we note the following:

1. The ecological objectives have generally been met within these reaches over the past 5 years. However, the flows in these reaches have generally exceeded the minimum EFG requirements. We therefore do not know if the ecological objectives would be met if only the minimum EFG requirements were provided. Conversely, we do not know that they would not be met.
2. The Basin Plan requires that the quantity and effectiveness of the PEW is at least maintained.
3. There are considerable reductions in PEW in the reach below Bendora Dam if the 1975-2016 time period is used and also if the 1980-2016 time period is used. There are increases in all other reaches.
4. Small changes in daily flow (± 1-2 ML/day) are unlikely to result in observable changes in the ecology of the system. This is based on work by Florance (2013) in the Cotter catchment where small changes in flows did not result in an observable change in the macroinvertebrate community. It is supported by modelling work by Dyer *et al.* (2013) which indicated that small changes in mean annual flow (as a

consequence of changes in climate) were unlikely to affect the macroinvertebrate and fish community.
5. There is an absence of evidence that would aid in selecting a time period.

We therefore recommend that the longer period of record (1975 – 2016) be used to set the percentile flow volumes in the following reaches:

- Below Corin Dam
- Below Cotter Dam
- Below Googong Dam
- Below Angle Crossing

Because of the magnitude of the difference from the current EFG volumes, it is recommended that the current environmental flow volumes defined within Icon Water's Licence to Take Water remain in place for the reach downstream of Bendora Dam.

Recommendation:
The time period of flow records used to calculate percentile flow volumes be set to 1975-2016, for most reaches. The exception to this is in the reach downstream of Bendora Dam.

FLOW VARIABILITY

Variability in flow is an important characteristic of upland river systems such as the Cotter and upper Murrumbidgee Rivers. Static or constant flows (such as constant low flow) can have a detrimental effect on in-stream biota in the Cotter River system (Norris and Nichols 2011, White *et al.* 2012) and likely in other local streams. Varying flows on a daily basis, where the variability of flows downstream of an impoundment are based on inflows or flow in an adjacent unregulated tributary, is likely to provide the greatest benefit to the river. However, when the volumes available to release as an environmental flow are small, the benefit from (an even smaller) daily fluctuation may be limited and unlikely to be detected. Under such circumstances, there may be greater benefit in designing a hydrograph to achieve certain ecological outcomes. For example, White *et al.* (2012) studied options for varying a very low flow (5 ML/d) in the Cotter River. One of the flow regimes was a cycle of 2 ML/d for 28 days followed by 20 ML/d for either 3 or 4 days, which continued for 5 months. All of the low flows investigated were insufficient to maintain the macroinvertebrate assemblages in reference condition. However, short-term ecological objectives were achieved, with reduced periphyton accumulation and increased habitat availability, and the environmental flows maintained the river's ability to recover (resilience) when higher flows returned.

The current flow rules implemented for the reaches downstream of Corin and Bendora Dams recognises the need for frequent flushes to reduce periphyton and sediment accumulation in riffles. They also recognise the operational constraints that prevent daily flow variation and flows were therefore designed to be constant for most of the month, a flow pulse delivered once a month. This flow regime has been shown to meet the ecological objectives (the river health outcomes desired) and represents a practical approach to flow variability in the Cotter River system.

Recommendation:

In revising the flow requirements downstream of Googong and Cotter Dams, it is recommended that seasonal patterns in flow are included in the baseflow of these rivers and that there is a regular flushing flow to reduce the periphyton and fine sediment accumulation in riffles. The seasonal pattern is incorporated in the recommended 75% of the 80th monthly flow percentile (see above) as baseflow and the flushing flow should be the remaining 25% of the 80th percentile for each month delivered as a flushing flow over a few days.

OTHER RECOMMENDATIONS

1. The two previous reviews of the ACT's EFG are valuable documents that lay out a reasonably clear trail of evidence for the establishment of the present EFG. We recommend that the components of those reviews that provide the scientific basis for e-flow guideline development are incorporated into the appendix of the EFG alongside parts of the present review. In this way, the supporting evidence for the EFG will be carried forward into future reviews and persist as a "living document".

2. There are a number of small inconsistencies in terminology throughout the EFG, for example "Water Supply Ecosystems" are interchangeably referred to as "Water Supply Catchment Ecosystems". Where identified, corrections have been suggested in the draft revised EFG document companion to this report.

3. Numerous small changes to the text have been suggested in the draft revised EFG. These changes are typically minor re-wordings or grammatical changes that may facilitate clarity. Where more substantial changes are suggested, justification is typically provided as a comment.

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APPENDIX 1. TERMS OF REFERENCE FOR 2017 EFG REVIEW

a) ACT hydrology to be revised through a new ACT Source model, currently under development and due May 2017. Current EFG flows are over 10 years old and don't include data from the Millennium drought and following wet years. This data is critical for understanding the resilience of the aquatic ecosystems.
   - Recommendations are required for using either the resultant 80th/90th percentile environmental flows or the current environmental flow guideline quantums.

b) The definition of the 80th %ile flows (ie period of time and method of calculation) should be explained in more detail in the next set of guidelines (Review, update and augment ecological objectives)

c) Performance indicators (eg fish) need changing as the methods are out of date and therefore the targets are becoming irrelevant.

d) Water birds and riparian vegetation targets need to be added, to comply with the MDBA Basin wide Environmental Water Strategy (BWS) where practicable.

e) Note ecological objectives are now available for urban waterways (eg frogs) and can be incorporated.

f) Coordination opportunities with NSW environmental watering, to be identified, developed and documented. Especially coordinating Tantangara Dam environmental releases and protection of those releases within the ACT and protection of ACT releases in downstream NSW;

g) Identify and develop opportunities for working with the Commonwealth Environmental Water office (CEWO).

h) Evaluate and make recommendations for the incorporation of section 2.1.1 EFG 2013 "Advice on changes to the guidelines" following the review of the 2006 EFG by Prof Terry Hillman.

i) Review environmental flow releases from dams with active control eg Lake Burley Griffin (LBG), Googong and Cotter Dams and

j) Consider the following specific issues.
   - Special purpose flows as indicated in the guidelines could reference the drowning of barriers to fish movement as an example of a special purpose flow.
   - A variation to the Icon licence for the provision of flows downstream of Bendora to borrow from high flush events to extend flows to mitigate barriers for Macquarie Perch has been submitted by Icon.
   - A spawning plan is required to be submitted from Icon to the EPA and the Conservator each year.
   - The idea of constructing an accounting arrangement to transfer of volumes from one month to another to enable a greater volume of water to be available to target flows for management of fish spawning was put forward by Icon.
   - Also further development of the variation in baseflows should be considered (currently 2 week +/- 50% variation, which is a coarse approach and was based on operator limitations at the time of introduction of EFGs ;

- Lake level variation for LBG to enhance macrophyte communities and influence fish populations
- Better definitions of the 10% rule (p18), why 75% of 80th percentile (Table 3);
- inclusion of the impacts on fish with pond draw downs (p18);
- fish targets, including adding separate targets per monitoring method and location, as well as references to ACT water quality targets to be added to All reaches (Table 2) especially adding Trout Cod; see c) above
- inclusion of the Murrumbidgee River as a Water Supply Ecosystem (Table 3) and possible inclusion by separate reaches in Table 4 (with pump stations being the reach boundary rather than impoundments) as well as adjustments for drought;
- commentary on Murrumbidgee River flows needed to mix with LMWQCC effluent flows to reduce concentrations of nutrients and salts (5.3.1); and
- consideration of increased monitoring during reduced environmental flow releases during drought periods (6.1.1).
-

k) Icon Water to put temperature probes at: Vanities crossing, downstream of Bendora and Corin dams (but not online telemetered), and at the inflow to Bendora reservoir.

l) Turbidity and EC data to accompany temperature data for compiling and assessing water quality and likely effects on fish populations. Also turbidity data from downstream of Corin Dam means Icon can show if it meets the water quality objectives of the e-flow guidelines. (

m) Consider re-defining pool flow thresholds

n) Consider inclusion into the EFGs of the Commonwealth EIS requirements identified for the Enlarged Cotter Dam and the Murrumbidgee to Googong pipeline;

o) Consider further changes to water levels thresholds for urban ponds and wetlands;

p) Include compliance with EFGs in Licenses to take water;

q) Review monitoring and reporting requirements to ensure progress against meeting objectives and targets can be readily assessed;

r) Consider whether and how climate change should and can be included and make recommendations. See also a) above.

s) Linkage of EFG’s with other aquatic management instruments eg Aquatic and riparian Strategy, Jerrabomberra wetlands management plan.

APPENDIX 2. DETAILS OF ENVIRONMENTAL FLOWS FOR PARTICULAR ECOSYSTEMS

Table 4 Summary of environmental flow requirements for each of the ecosystems categories of the ACT (reproduced from EFG, Table 3; ACT Government 2013).

Flow	Ecosystem category	Reach	Flow requirement
BaseFlows			
	Water Supply Ecosystems	Above Corin Dam	Maintenance of all natural flows.
		Above Googong Dam and any impoundment on the Naas / Gudgenby Rivers	Maintenance of all natural flows except those needed for stock and domestic purposes, and that already provided for at the time these guidelines are listed.
		Below Corin Dam	Maintain 75% of the 80th percentile of the monthly natural inflow, or inflow, whichever is less.
		Below Bendora Dam	Maintain 75% of the 80th percentile of the monthly natural inflow, or inflow, whichever is less.
		Below Cotter Dam	Maintain an average flow of 15 ML /day.
		Below Googong Dam	Maintain an average flow of 10 ML/day or natural inflow which ever is the lesser volume.
		Below any impoundment on the Naas / Gudgenby Rivers	Maintain an average flow of 10 ML/day or natural inflow which ever is the lesser volume.
	Natural Ecosystems	All reaches in Natural Ecosystems	All reaches in natural ecosystems Maintain 80m percentile monthly flow in all months. Abstractions may not exceed flow rate.
	Modified Ecosystems	Murrumbidgee River	Maintain 80th percentile monthly flow November - May, and 90th percentile monthly flow June -October inclusive. Abstractions may not exceed flow rate.
		Other reaches in the ACT in Modified Ecosystems	Maintain 80th percentile monthly flow in all months. Abstractions may not exceed flow rate.
	Created Ecosystems	All reaches in Created Ecosystems	Maintain 80th percentile monthly flow in all months. Abstractions may not exceed flow rate.
Riffle Maintenance Flows			
	Water Supply Ecosystems	Below Corin Dam	Maintain a flow of 150 ML/Day for 3 consecutive days every 2 months
		Below Bendora Dam	Maintain a flow of 150 ML/Day for 3 consecutive days every 2 months
		Below Cotter Dam	Maintain a flow of 100 ML/Day for 1 day every 2 months
		Below Googong Dam	Maintain a flow of 100 ML/Day for 1 day every 2 months
		Below any impoundment on the Naas / Gudgenby Rivers	Maintain a flow of 100 ML/Day for 1 day every 2 months
	Natural Ecosystems	All reaches in Natural Ecosystems	Riffle maintenance flows are not required
	Modified Ecosystems	All reaches in Modified Ecosystems	Riffle maintenance flows are not required
	Created Ecosystems	All reaches in Created Ecosystems	Riffle maintenance flows are not required

Pool Maintenance Flows		
Water Supply Ecosystems	Below Corin Dam	Maintain a flow of >550 ML/day for 2 consecutive days between mid-July and mid-October
	Below Bendora Dam	Maintain a flow of >550 ML/day for 2 consecutive days between mid-July and mid-October
	Below Cotter Dam	Not required
	Below Googong Dam	Not required
	Below any impoundment on the Naas / Gudgenby Rivers	Not required
Channel Maintenance Flows		
Natural Ecosystems	All reaches in Natural Ecosystems	Protect 90% of the volume in events above the 80th percentile from abstraction
Modified Ecosystems	All reaches in the ACT including the Murrumbidgee	Protect 90% of the volume in events above the 80th percentile from abstraction
Created Ecosystems	All reaches in Created Ecosystems	Protect 90% of the volume in events above the 80th percentile from abstraction
Groundwater Abstraction Limits		
Water Supply Ecosystems	All reaches	Groundwater abstraction is limited to 10% of the long term recharge
Natural Ecosystems	All reaches in Natural Ecosystems	Groundwater abstraction is limited to 10% of the long term recharge
Modified Ecosystems	All reaches in the ACT including the Murrumbidgee	Groundwater abstraction is limited to 10% of the long term recharge
Created Ecosystems	All reaches	Groundwater abstraction is limited to 10% of the long term recharge
Impoundment Drawdown Levels		
Water Supply Ecosystems	Cotter Reservoir	An adaptive management program will be used to guide drawdown to protect habitat for Macquarie Perch
	All other water supply impoundments	No limits are placed on drawdown levels
Natural Ecosystems	All natural lakes or ponds	No abstraction is permitted from natural lakes or ponds
	All other impoundments	Drawdown is limited to 0.20m below the spillway[1and2]
Modified Ecosystems	All impoundments	Drawdown is limited to 0.20m below the spillway[1and2]
Created Ecosystems	All impoundments	Drawdown is limited to 0.20m below the spillway[1and2]
Drought Flows for Water Supply Ecosystems Stage 1 restrictions		
Base Flows		
	Above Corin Dam	Maintenance of all natural flows
	Above Googong Dam and any impoundment on the Naas / Gudgenby Rivers	Maintenance of all natural flows except those needed for stock and domestic purposes, and that already provided for at the time these guidelines are listed.
	Below Corin Dam	Maintain a flow of 40 ML/day or 75% of the 80^{th} percentile of the monthly natural inflow, or natural inflow which is the

		lesser volume
	Below Bendora Dam	Maintain a flow of 40 ML/day or 75% of the 80th percentile of the monthly natural inflow, or natural inflow which is the lesser volume
	Below Cotter Dam	Maintain an average flow of 15 ML/day
	Below Googong Dam	Maintain an average flow of 10 ML/day or natural inflow which ever is the lesser volume.
	Below any impoundment on the Naas / Gudgenby Rivers	Maintain an average of 10 ML/day or natural inflow which ever is the lesser volume.
Riffle Maintenance Flows		
	Below Corin Dam	Maintain a flow of 150 ML/Day for 3 consecutive days every 2 months
	Below Bendora Dam	Maintain a flow of 150 ML/Day for 3 consecutive days every 2 months
	Below Cotter Dam	Not required
	Below Googong Dam	Not required
	Below any impoundment on the Naas / Gudgenby Rivers	Not required
Pool Maintenance Flows		
	Below Corin Dam	Maintain a flow of >550 ML/day for 2 consecutive days between mid-July and mid-October
	Below Bendora Dam	Maintain a flow of >550 ML/day for 2 consecutive days between mid-July and mid-October
	Below Cotter Dam	Not required
	Below Googong Dam	Not required
	Below any impoundment on the Naas / Gudgenby Rivers	Not required
Drought Flows for Water Supply Ecosystems Stage 2 restrictions or above		
Base Flows		
	Above Corin Dam	Maintenance of all natural flows
	Above Googong Dam and any impoundment on the Naas / Gudgenby Rivers	Maintenance of all natural flows except those needed for stock and domestic purposes, and that already provided for at the time these guidelines are listed.
	Below Corin Dam	Maintain an average of 20 ML/day
	Below Bendora Dam	Maintain an average of 20 ML/day
	Below Cotter Dam	Maintain an average of 15 ML/day
	Below Googong Dam	Maintain an average of 10 ML/day or inflow which ever is the lesser volume.
	Below any impoundment on the Naas / Gudgenby Rivers	Maintain an average of 10 ML/day or natural inflow which ever is the lesser volume.
Riffle Maintenance Flows		
	Below Corin Dam	Maintain a flow of 150 ML/day for 3

		consecutive days every 2 months
	Below Bendora Dam	Maintain a flow of 150 ML/day for 3 consecutive days every 2 months
	Below Cotter Dam	Not required
	Below Googong Dam	Not required
	Below any impoundment on the Naas / Gudgenby Rivers	Not required
Pool Maintenance Flows		
	Below Corin Dam	Maintain a flow of >550 ML/day for 2 consecutive days between mid-July and mid-October
	Below Bendora Dam	Maintain a flow of >550 ML/day for 2 consecutive days between mid-July and mid-October
	Below Cotter Dam	Not required
	Below Googong Dam	Not required
	Below any impoundment on the Naas / Gudgenby Rivers	Not required

APPENDIX 3. ANALYSIS OF MONITORING DATA (FROM PREPARATORY DOCUMENTS FOR WORKSHOP 2)

WATER SUPPLY ECOSYSTEMS

The water supply catchments of the ACT are subject to the potentially competing demands of environmental and consumptive purposes. Ensuring an adequate supply of water for domestic consumption is essential, and protecting the habitat of threatened aquatic species is also vital. The EFG are designed to balance these needs, with flows specified meeting the "*minimal requirement for healthy aquatic ecosystems*" (ACT Government 2013). Particular environmental flow rules for Water Supply Ecosystems are specified for drought periods (Table 4: Appendix 2).

The Cotter and Queanbeyan Rivers are regulated to supply water to the Australian Capital Territory (ACT) and Queanbeyan. The ecological objectives for these systems are targeted at protecting threatened species, maintaining a healthy ecosystem and preventing degradation of riverine habitat condition.

Threatened and rare species

Corin Dam to Bendora Reservoir

Objective: Maintain populations of Two-spined Blackfish.

Indicators: Young of the year and year 1+ ages classes comprise >40% of the monitoring catch, and >80 fish captured per standard monitoring effort.

Two-spined Blackfish populations are monitored annually to biennially and results are reported to ACT Government. The indicator target has not been fully achieved for this objective for any of the years monitored (Table 5). Although the desired percentage composition of 0+ and 1+ was met in all years, the minimum number of individuals (80) was not. It is possible that environmental flows are not sufficient to achieve this ecological objective. However, given that flows have exceeded targets considerably (Figures 3-6), it is possible that the nominated indicator target may not be achievable for this reach.

Recommendation: given that Two-spined Blackfish monitoring is consistently not meeting indicator targets in Corin Dam to Bendora Reservoir reach,

i) environmental flows are sufficient,
ii) indicator target is achievable,
iii) sampling methods are suitable.

Discussion should also be held around ambiguities around interpretation of what data are appropriate to assess indicator.

Table 5 Number of Two-spined Blackfish captured from backpack electrofishing in two sites combined (one in the Cotter River immediately upstream of Bendora Reservoir and one in Bendora Reservoir between Corin Dam and Bendora Dam between 2012 and 2016.

Year	Total No.	No. of 0+ and 1+	% of 0+ and 1+	Indicator met?	Effort
2012	11	9	82	No*	5 x 30m sections Fyke net Bendora
2013	Did not sample				
2014	56	38	68	No*	5 x 30m sections Fyke net Bendora
2015	Did not sample				
2016	37	24	65	No*	5 x 30m sections Fyke net Bendora

* Although the percentage of 0+ and 1+ was met, the minimum number of individuals (n = 80) was not.

Objective: maintain population numbers and distribution of Cotter River frog.

Indicator: Extant populations are maintained at current levels.

There is no regular systematic monitoring of Cotter River Frog population. Thus, insufficient data exist to adequately measure if indicator has been met.

Monitoring has been potentially prevented by limited vehicular access to this stretch of river. Some minor nomenclature issues have been identified – the Cotter River Frog is listed as *Litoria nudidigitus* in the 2013 EFG and *Litoria phyllochroa* elsewhere (including in ACT and Region Frogwatch identification material (Ginninderra Catchment Group, 2017). This is not believed to have affected monitoring against this indicator.

It is also noted that subsequent to the original inclusion of the Cotter River Frog in the EFG, genetic characterisation confirms it to be *Litoria nudidigitus* and not a new species. The retention in the EFG is likely a legacy issue and it probably should be removed from the EFG.

Recommendation: Remove ecological objective for the Cotter River Frog

Bendora Dam to Cotter Reservoir

Objective: To maintain populations of Macquarie Perch.

Indicators: Young of the year and year 1+ ages classes comprise >30% of the monitoring catch, and >40 fish captured per standard monitoring effort.

Since 2010, the indicator target for maintaining Macquarie perch populations between Bendora Dam and Cotter Reservoir has been met on 5 of 8 occasions (63%; Table 6). Note that in 2016 the percentage composition of 0+ and 1+ individuals was met, but the minimum number of individuals did not meet the indicator target. It must also be noted that the monitoring program in 2016 recommended that fyke netting effort be increased in 2017 because of the increase in shoreline of the enlarged Cotter Reservoir (Broadhurst *et al.* 2016).

The indicator for this objective was not met for three consecutive years (2014 – 2016) despite gill netting indicating that a good adult population still existed (Broadhurst *et al.* 2014; 2015 and 2016). According to Broadhurst *et al.* (2014; 2015 and 2016) the recruitment failure (and thus failure to meet the indicator target) was a result of the filling of the enlarged reservoir and the presence of natural instream barriers which prevented access to suitable spawning habitat. Some small scale management intervention and reservoir water level manipulation was implemented in the spawning season of 2015 to facilitate spawning but this was largely unsuccessful. In mid-2016, all three reservoirs on the Cotter River filled and flow in the Cotter River was managed to promote Macquarie perch spawning, resulting in a successful spawning of Macquarie perch and the indicator target was met. It should be noted that these specially-allocated flows greatly exceeded the environmental flow requirements.

The enlargement of Cotter Reservoir has somewhat complicated the indicator performance, with the new driver of Macquarie perch recruitment being Cotter Reservoir water level and natural barriers to upstream passage. Indeed environment flow requirements for this population now revolve around spawning site maintenance, providing suitable temperature cures for migration, facilitating passage to spawning sites and stability of discharge during spawning season. With this in mind, the indicator appears to still be valid, but evaluations against it must be made in the context of the above considerations.

Consideration for EFG revision: revisit indicator targets for Macquarie Perch populations in light of enlargement of Cotter Reservoir and subsequent impacts on Macquarie Perch recruitment.

Table 6 No of Macquarie perch captured from fyke netting in Cotter Reservoir between 2010 and 2017.

Year	Total	No. of 0+ and 1+	% of 0+ and 1+	Indicator met?	Effort
2010	525	440	84	Yes	12 + 10 fykes
2011	249	215	86	Yes	12 + 10 fykes
2012	105	97	92	Yes	12 + 10 fykes
2013	257	247	96	Yes	12 + 10 fykes
2014	81	15	19	No	12 + 10 fykes
2015	29	3	10	No	12 + 10 fykes
2016	20	12	60	No*	12 + 10 fykes
2017	266	244	94	Yes	3 x 20 fykes

* Although the percentage of 0+ and 1+ was met, the minimum number of individuals (n = 40) was not.

Objective: Maintain populations of Two-spined Blackfish.

Indicators: Young of the year and year 1+ ages classes comprise >40% of the monitoring catch, and >80 fish captured per standard monitoring effort.

Two-spined Blackfish populations are monitored at four sites (Vanitys Crossing, Spur Hole, Pipeline Crossing and Burkes Ck. Crossing) annually to biennially and results are reported to ACT Government. The indicator for this objective was met on three of five years (Table 7). The two years that did not satisfy the indicator guideline the percentage composition of 0+ and 1+ was met, but the total number of individuals captured did not.

Table 7 Number of Two-spined Blackfish captured from backpack electrofishing in Cotter River (all sites combined) between Bendora Dam and Cotter Reservoir between 2012 and 2016.

Year	Total	No. of 0+ and 1+	% of 0+ and 1+	Indicator met?	Effort
2012	26	23	88	No*	5 x 30m sections
2013	161	88	55	Yes	5 x 30m sections
2014	70	34	49	No*	5 x 30m sections
2015	197	123	62	Yes	5 x 30m sections
2016	171	100	58	Yes	5 x 30m sections

* Although the percentage of 0+ and 1+ was met, the minimum number of individuals (n = 80) was not.

The monitoring of this reach has been altered by the filling of the enlarged Cotter Reservoir. One of the sites included in the original monitoring is no longer sampled as it was inundated during filling. Some additional sites have been included and some removed in this section over the past decade. Additionally, there has been a drift in the standard method from only sampling unbroken water to sampling all water in the 5 x 30m sections. This may alter the suitability of this indicator to inform on ecological objectives. At this stage it is not clear what has driven the low number of two-spined blackfish captured in 2012 and 2014 (population fluctuation or sampling variability), though seeing as it has affected the meeting of the performance indicator in those years, this variation warrants further investigation.

Consideration for EFG revision: revisit indicator and/or sampling methods for Two-spined Blackfish populations in light of enlargement of Cotter Reservoir and subsequent impacts on habitat.

Healthy aquatic biota

Objective: To maintain healthy aquatic ecosystems in terms of biota

Indicators:

1) Macroinvertebrate assemblages are maintained at AUSRIVAS band A level assessed using protocols in the ACT AUSRIVAS sampling and processing manual (http://ausrivas.canberra.edu/au/ausrivas)
2) Non-dominance (<20% cover) of filamentous algae in riffles for 95% of the time. Assessed using standardised collection and processing methods as per Norris *et al*. 2004.

Macroinvertebrate community composition and algae cover are assessed bi-annually at the same fixed sites in water supply catchments (Figure 9). The ecological objectives for environmental flows are for the Cotter and Queanbeyan Rivers to be maintained at an Australian River Assessment System (AUSRIVAS; see Appendix 2 for summary of method) band A grade and to have <20% filamentous algal cover in riffles 95% of the time. Sampling is conducted during autumn and spring of each year, and a comparison is made with the condition of reference sites on the unregulated Goodradigbee River and the Queanbeyan River upstream of Googong Dam (Figure 9). These assessments are supplied in bi-annual reports to Icon Water and satisfy Icon Water's *Licence to Take Water* (WU67), as well as the requirement to provide an assessment of the effects of dam operation. The results of these assessments are summarised in Tables 8 and 9.

Across the period 2012-2016, below dam test sites have been in poorer biological condition than reference sites on the Goodradigbee and Queanbeyan Rivers, based on AUSRIVAS assessment. The Cotter River test site, CM2 below Bendora Dam, is the only site that came close to maintaining the EFG ecological objective of AUSRIVAS Band A throughout the period of interest. It is possible that test sites rarely achieve Band A because of recolonisation issues associated with being located directly below a dam/reservoir. Such a location prevents drift from upstream, precluding recolonization from upstream.

Consideration for EFG revision: review if sites immediately downstream of dam walls are the most suitable to indicate the ecological performance of environmental flows.

Filamentous algae is measured at each site for AUSRIVAS habitat data, but is only reported for test sites and reference main channel sites to be used for the assessing the indicator criteria. Test sites were assessed as meeting the indicator of having less than 20 % filamentous algae cover in riffles on 91 % of sampling occasions compared to that of 89 % for reference sites. By site, three of five sites met the indicator target by having less than 20 % cover on 100 % of occasions. A fourth site (CM2) was close, meeting the requirement on 89 % of occasions. Site CM1 regularly breaches the indicator target. Two of the four reference sites met the indicator criteria on 100 % of occasions, one was very close (met the criteria on 89 % of occasions) and one only met the criteria on 67 % of occasions. It is not possible to accurately retro-analyse filamentous algae cover for other sites as the data is recorded in broad bands, with the indicator (20 %) lying within category 2 (10 – 35 %).

There is no indication of an overall decline or improvement in biological condition at test sites; instead test sites tend to fluctuate in their level of biological impairment. These fluctuations are explored in detail in each report and are typically explained by minor disturbances operating at small temporal and spatial scales. In terms of the suitability of the monitoring program, the fact that the current methods are sufficiently sensitive to detect changes in condition suggests the program has the capacity to usefully assess the outcomes of environmental flow provision. Additionally, all sites have obtained AUSRIVAS Band A and <20% algae cover during the sampling period, indicating that objectives are appropriate and that the selected sites are suitable. With this in mind, it remains possible that sites further downstream of dams may be more appropriate for assessing the ecological performance of environmental flows.

Table 8 AUSRIVAS assessment results for riffle habitats on test sites (sites below dams) and references sites (main channel and tributary) from autumn 2013 to spring 2016 (reproduced from Broadhurst *et al.,* 2016; Levings and Harrison, 2014). Site locations mapped in Figure 9.

	Below dams sites					Reference sites										
	CM1	CM2	CM3	QM2	QM3	CT1	CT2	CT3	QM1	GM1	GM2	GM3	GT1	GT2	GT3
Spring 2016	B (0.84)	A (0.89)	C (0.51)	B (0.72)	B (0.69)	B (0.75)	A (1.07)	A (0.88)	A (1.01)	A (1.04)	A (1.04)	A (0.97)	A (1.13)	A (1.07)	A (0.88)
Autumn 2016	B (0.85)	A (0.94)	A (0.89)	B (0.84)	B (0.69)	X (1.16)	Not sampled	A (0.90)	A (1.04)	B (0.84)	A (0.97)	B (0.74)	A (1.12)	A (0.93)	A (0.97)
Spring 2015	B (0.69)	A (0.89)	B (0.66)	B (0.80)	A (1.07)	A (0.96)	X (1.15)	A (0.96)	A (1.1)	X (1.27)	A (1.04)	X (1.19)	X (0.91)	A (0.98)	A (1.21)
Autumn 2015	B (0.85)	A (0.94)	B (0.67)	C (0.49)	C (0.63)	A (0.93)	B (0.77)	B (0.70)	A (0.97)	B (0.81)	A (1.05)	A (1.12)	X (1.16)	A (1.05)	A (1.05)
Spring 2014	B (0.77)	A (0.97)	B (0.66)	A (0.88)	B (0.84)	A (1.03)	A (1.07)	A (0.96)	A (0.92)	A (1.12)	A (1.11)	A (1.12)	A (1.13)	A (0.98)	A (1.05)
Autumn 2014	A (0.91)	B (0.86)	B (0.66)	B (0.70)	B (0.83)	A (0.96)	A (0.90)	B (0.84)	A (0.97)	A (0.88)	A (1.04)	A (0.97)	X (1.19)	A (1.12)	A (1.05)
Spring 2013	B (0.69)	A (0.89)	A (0.88)	A (0.38)	A (0.92)	X (1.16)	A (1.00)	B (0.74)	A (1.10)	X (1.19)	A (1.11)	X (1.19)	A (1.13)	A (098)	A (1.13)
Autumn 2013	C (0.59)	A (1.12)	C (0.60)	B (0.77)	B (0.77)	A (1.08)	Not sampled	B (0.70)	A (0.97)	A (0.89)	A (0.89)	B (0.81)	A (1.01)	B (086)	A (1.05)

Table 9 Filamentous algae (categorised on percent cover) in the riffle habitat at below dams sites and reference sites, from autumn 2013 to spring 2016 (reproduced from Broadhurst *et al.,*2016; Levings and Harrison, 2014). Filamentous algae observations greater than the environmental flow ecological indicator target of <20% cover are shaded orange. Site locations mapped in Figure 9.

	Site	Aut-13	Spr-13	Aut-14	Spr-14	Aut-15	Spr-15	Aut-16	Spr-16	Aut-17
Test sites	CM1	<10	80	<10	25	10	20	10	<10	20
	CM2	<10	20	<10	10	<10	<10	<10	<10	<10
	CM3	<10	<10	<10	10	<10	15	<10	<10	<10
	QM2	<10	<10	<10	10	<10	10	<10	<10	15
	QM3	<10	<10	<10	10	<10	<10	10	<10	<10
Reference sites	GM1	15	<10	<10	<10	0	<10	<10	<10	<10
	GM2	<10	<10	<10	<10	<10	<10	<10	20	<10
	GM3	<10	15	<10	<10	10	10	10	<10	10
	QM1	<10	<10	<10	10	10	40	25	<10	20

RiverIne habitat condition

Objective: To prevent degradation of riverine habitat through sediment deposition.

Indicator: Sediment deposition is limited to <20% of total depth of pools measured at base flow using techniques as per Ecowise Environmental 2005**.**

Sediment deposition in Water Supply Ecosystems has not been the subject of any monitoring programs since the commencement of the 2013 EFG. It is thus difficult to assess the relevant ecological objective in light of nominated indicator variables. Removal of sediment deposits is addressed in the EFG through the prescription of riffle maintenance and pool maintenance flows in Water Supply Ecosystems, and the EFG state "*The effect of the riffle maintenance flows on the identified ecological objectives and indicators will continue to be monitored and assessed*." (ACT Government 2013). The specified flows were established based on research conducted by the CRC for Freshwater Ecology in the early 2000's. Riffle maintenance flows are likely to assist the removal of deposited sediments (Harrison 2010); it would be beneficial to monitor this relationship.

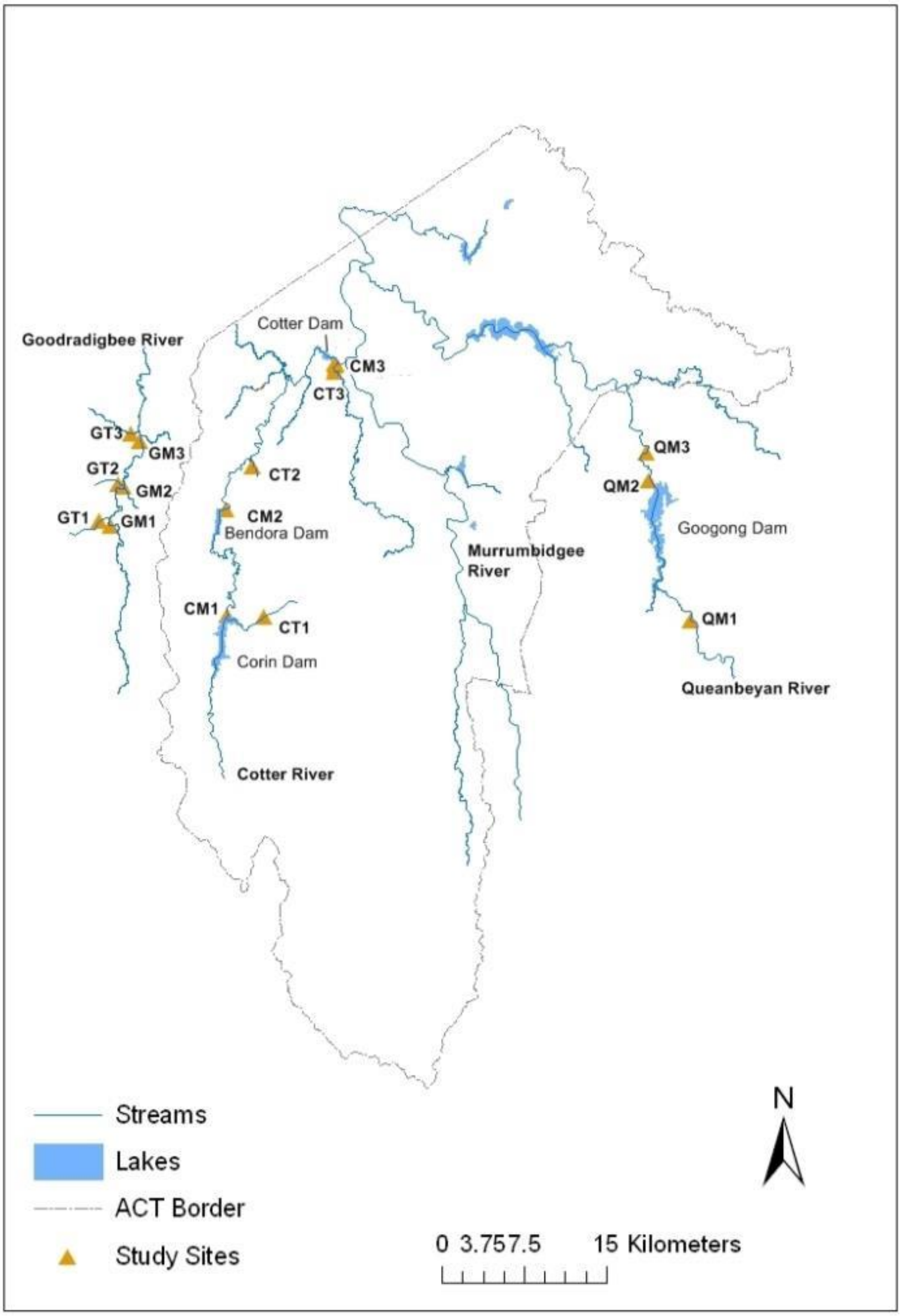

Figure 8 The location of sites on the Cotter, Goodradigbee, and Queanbeyan Rivers and tributaries for the below dams assessment program. CM1 = Below Corin Dam, CM2 = Below Bendora Dam, CM3 = Below Cotter Dam, QM2 = immediately below Googong Dam, QM3 = Queanbeyan River at Wickerslack Lane, CT1 = Kangaroo Ck, CT2 = Burkes Ck, CT3 = Paddy River, QM1 = Queanbeyan River upstream of Googong Reservoir, GM1 – GM3 = Goodradigbee River main channel sites, GT1 – GT3 – Goodradigbee River tributary sites.

NATURAL ECOSYSTEMS

Natural Ecosystems are those that persist in a state similar to pre-European settlement condition. In the ACT, natural aquatic ecosystems include waterbodies within Namadgi National Park (outside of the Cotter River Catchment) and those within Tidbinbilla Nature Reserve. Conservation is the primary management goal in Natural Ecosystems and thus the ecological objectives in the 2013 EFG are to maintain a healthy ecosystem and prevent degradation of riverine habitat condition

Healthy aquatic biota

Objective: To maintain healthy aquatic ecosystems in terms of biota

Indicators:

1) Macroinvertebrate assemblages are maintained at AUSRIVAS band A level assessed using protocols in the ACT AUSRIVAS sampling and processing manual (http://ausrivas.canberra.edu/au/ausrivas)
2) Non-dominance (<20% cover) of filamentous algae in riffles for 95% of the time. Assessed using standardised collection and processing methods as per Norris *et al*. 2004.

Neither indicator is assessed at any sites outside of the Cotter Catchment via systematic monitoring.

Riverine habitat condition

Objective: To prevent degradation of riverine habitat through sediment deposition.

Indicator: Sediment deposition is limited to <20% of total depth of pools measured at base flow using techniques as per Ecowise Environmental 2005**.**

Sediment deposition in Water Supply Ecosystems has not been the subject of any monitoring programs since the commencement of the 2013 EFG. It is thus not possible to assess the relevant ecological objective in light of nominated indicator variables.

MODIFIED ECOSYSTEMS

The Modified Ecosystems of the ACT are those that have been significantly altered by catchment activities, including changing land use and modifications to the natural flow regime. The EFG are designed to mitigate such changes by managing flows and water abstraction in order to maintain Modified Ecosystems in as natural a state as possible.

Waterbodies outside of Namadgi National Park, Tidbinbilla Nature Reserve and the Canberra urban area are considered in the Modified Ecosystem category. For the purposes of the EFG, Lake Burley Griffin, the Molonglo River, and the Queanbeyan River above Googong Reservoir are also considered Modified Ecosystems. The ecological objectives for this system are targeted at maintaining a healthy ecosystem, preventing degradation of riverine habitat condition and maintaining a functional assemblage of macrophytes in urban lakes and ponds.

Healthy aquatic biota

Objective: To maintain healthy aquatic ecosystems in terms of biota

Indicators:

1) Macroinvertebrate assemblgaes are maintained at AUSRIVAS band A level assessed using protocols in the ACT AUSRIVAS sampling and processing manual (http://ausrivas.canberra.edu/au/ausrivas)
2) Non-dominance (<20% cover) of filamentous algae in riffles for 95% of the time. Assessed using standardised collection and processing methods as per Norris *et al*. 2004.

Macroinvertebrate community composition is assessed bi-annually at the same fixed sites in Modified Ecosystems (Figure 10). Four test sites are located in rural areas and another three are reference sites. The ecological objectives for environmental flows are for the test sites to be maintained at an Australian River Assessment System (AUSRIVAS; see Appendix 2 for summary of method) band A grade and to have <20% filamentous algal cover in riffles 95% of the time. Assessments of macroinvertebrate assemblage are supplied in bi-annual reports to the ACT Government's Environment, Planning and Sustainable Development Directorate. The results of these assessments since 2013 are summarised in Table 10.

Reference sites regularly achieved Band A during the evaluation period, however test sites rarely met this target. In general, rural sites were somewhat biologically impaired, likely reflecting the impacts of adjacent land use.

The sites used for AUSRIVAS calculations are sampled using the edge habitat model. While filamentous algae is measured in the edge habitat (categorical data only) it is not assessed in riffles (which are not present at many of the assessed sites). No other record could be obtained for the regular quantified monitoring of filamentous algae.

Table 10 AUSRIVAS band and Observed/Expected taxa score for each Modified Ecosystem site from autumn 2013 to spring 2016 (reproduced from Broadhurst *et al.,* 2017). Sites locations mapped in Figure 10. 010 = Paddy River, 015 = Tidbinbilla River, 040 = Murrumbidgee River at Angle Crossing, 020 Gudgenby River, 053 = Murrumbidgee River at Halls Crossing, 242 = Molonglo River and 246 = Jerrabomberra.

	Reference sites			Test sites			
	010	015	040	020	053	242	246
Autumn 2017	A (0.89)	A (0.90)	B (0.80)	A (0.86)	A (0.89)	B (0.76)	B (0.70)
Spring 2016	A (1.03)	B (0.80)	A (0.89)	A (1.08)	A (0.89)	B (0.78)	C (0.55)
Autumn 2016	B (0.76)	A (1.1)	A (0.89)	A (0.86)	B (0.64)	B (0.51)	B (0.64)
Spring 2015	A (0.87)	A (0.89)	A (0.89)	A (0.97)	B (0.78)	A (0.89)	B (0.78)
Autumn 2015	B (0.70)	B (0.68)	A (0.86)	A (0.93)	A (0.83)	A (0.83)	B (0.64)
Spring 2014	X (1.18)	X (1.19)	A (0.89)	B (0.82)	B (0.78)	A (0.89)	B (0.78)
Autumn 2014	B (0.69)	A (0.94)	B (0.71)	A (1.01)	B (0.64)	B (0.57)	B (0.64)
Spring 2013	A (1.08)	A (1.01)	B (0.78)	X (1.20)	A (0.89)	B (0.82)	A (0.94)
Autumn 2013	A (0.90)	B (0.80)	A (0.87)	A (0.89)	B (0.62)	B (0.57)	A (0.83)
% band A	56	56	67	78	44	33	22

Riverine habitat condition

Objective: To prevent degradation of riverine habitat through sediment deposition.

Indicator: Sediment deposition is limited to <20% of total depth of pools measured at base flow using techniques as per Ecowise Environmental 2005**.**

Sediment deposition in Modified Ecosystems has not been the subject of any monitoring programs since the commencement of the 2013 EFG. It is thus difficult to assess the relevant ecological objective in light of nominated indicator variables.

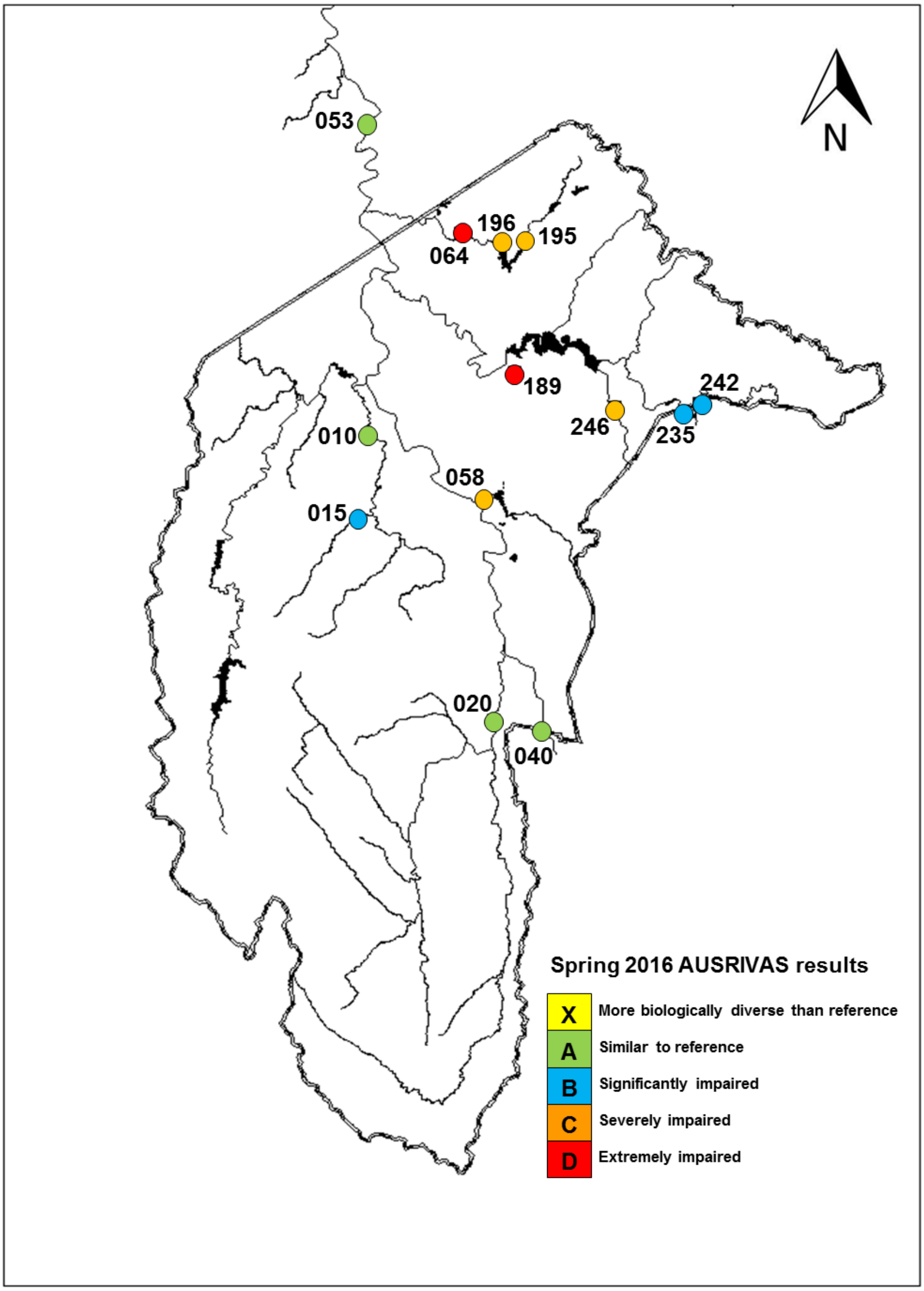

Figure 9 Location of test and references sites for macroinvertebrate surveys in Modified and Created Ecosystems in ACT region. Sites are classified as rural (20,53,242,246), urban (58,64,189,195,196,235) or reference (10,15,40). AUSRIVAS results are displayed for the latest reporting season, spring 2016 (reproduced from Broadhurst *et al.* 2017). 010 = Paddy River, 015 = Tidbinbilla River, 040 = Murrumbidgee River at Angle Crossing, 020 Gudgenby River, 053 = Murrumbidgee River at Halls Crossing, 058 = Tuggeranong Ck, 064, 195 and 196 Ginninderra Ck at Latham, Baldwin Dr and Downstream lake Ginninderra, respectively, 189 = Yarralumla Ck, 235 = Queanbeyan River, 242 = Molonglo River and 246 = Jerrabomberra.

Functional macrophyte assemblage

Objective: To maintain functional assemblages of macrophytes in urban lakes and ponds.

Indicators: Presence of emergent macrophytes in density and diversity that perform beneficial water quality processes and provide habitat for desired fauna. Submerged macrophytes present and at densities that perform beneficial water quality processes.

The only urban lake and pond in this category is Lake Burley Griffin. Emergent and submerged macrophytes have not been systematically monitored within Lake Burley Griffin during the period of the 2013 EFG. It is thus not possible to assess the relevant ecological objective in light of nominated indicator variables.

> **Consideration for EFG revision:** revisit if objective is appropriate for Lake Burley Griffin. This is closely tied to the need to revise categorisation of waterbodies as Modified or Created Ecosystems.

CREATED ECOSYSTEMS

All streams, lakes and ponds within the urban areas of the ACT (excluding the Molonglo River) are categorised as Created Ecosystems. The 2013 EFG cite significant community support for restoring urban streams to a more natural condition. The Guidelines reflect this through recommendations that flows in urban streams be restored to natural flow regimes as far as practicable. The ecological objectives for this system are targeted at maintaining a healthy ecosystem, preventing degradation of riverine habitat condition and maintaining a functional assemblage of macrophytes in urban lakes and ponds.

Healthy aquatic biota

Objective: To maintain healthy aquatic ecosystems in terms of biota

Indicators:

1) Macroinvertebrate assemblages are maintained at AUSRIVAS band A level assessed using protocols in the ACT AUSRIVAS sampling and processing manual (http://ausrivas.canberra.edu/au/ausrivas)
2) Non-dominance (<20% cover) of filamentous algae in riffles for 95% of the time. Assessed using standardised collection and processing methods as per Norris *et al*. 2004.

Macroinvertebrate community composition is assessed bi-annually at the same fixed sites in Modified Ecosystems (Figure 10). Six test sites are in urban areas and another three are reference sites. The ecological objectives for environmental flows are for the test sites to be maintained at an Australian River Assessment System (AUSRIVAS; see Appendix 2 for summary of method) band A grade and to have <20% filamentous algal cover in riffles 95% of the time. Assessments of macroinvertebrate assemblage are supplied in bi-annual reports to the ACT Government's Environment, Planning and Sustainable Development Directorate. The results of these assessments since 2013 are summarised in Table 11.

Reference sites regularly achieved Band A during the evaluation period, however test sites rarely met this target. In general, urban sites were severely biologically impaired. Some heavily urbanised sites were regularly assessed as band C or D. This likely reflects the legacy of contaminant inputs to waterbodies in these locations. Impaired communities in these locations may have low resistance to disturbance, and a limited to capacity to regenerate.

Consideration for EFG revision: given how heavily impacted urban sites are, revisit if macroinvertebrate indicator target is appropriate in Created Ecosystems.

The sites used for AUSRIVAS calculations are sampled using the edge habitat model. Whilst filamentous algae is measured in the edge habitat (categorical data only) it is not assessed in riffles (which are not present at many of the assessed sites). No other record could be obtained for the regular quantified monitoring of filamentous algae.

Table 11 AUSRIVAS band and Observed/Expected taxa score for each Created Ecosystem site from autumn 2013 to spring 2016 (reproduced from Broadhurst *et al.,* 2017). Sites locations mapped in Figure 10. 010 = Paddy River, 015 = Tidbinbilla River, 040 = Murrumbidgee River at Angle Crossing, 058 = Tuggeranong Ck, 064, 195 and 196 Ginninderra Ck at Latham, Baldwin Dr and Downstream lake Ginninderra, respectively, 189 = Yarralumla Ck, 235 = Queanbeyan River.

	Reference sites			Test sites					
	010	015	040	058	064	189	195	196	235
Autumn 2017	A (0.89)	A (0.90)	B (0.80)	B (0.69)	C (0.45)	C (0.45)	B (0.57)	B (0.57)	B (0.60)
Spring 2016	A (1.03)	B (0.80)	A (0.89)	C (0.47)	D (0.33)	D (0.23)	C (0.55)	C (0.35)	B (0.66)
Autumn 2016	B (0.76)	A (1.1)	A (0.89)	B (0.53)	B (0.57)	B (0.7)	B (0.64)	B (0.64)	B (0.6)
Spring 2015	A (0.87)	A (0.89)	A (0.89)	C (0.58)	B (0.66)	C (0.35)	B (0.77)	C (0.58)	C (0.55)
Autumn 2015	B (0.70)	B (0.68)	A (0.86)	B (0.60)	B (0.57)	B (0.54)	B (0.73)	B (0.70)	B (0.76)
Spring 2014	X (1.18)	X (1.19)	A (0.89)	B (0.66)	C (0.47)	D (0.33)	C (0.55)	B (0.66)	B (0.56)
Autumn 2014	B (0.69)	A (0.94)	B (0.71)	B (0.55)	B (0.68)	C (0.37)	B (0.62)	B (0.69)	B (0.58)
Spring 2013	A (1.08)	A (1.01)	B (0.78)	B (0.78)	C (0.55)	C (0.47)	B (0.66)	C (0.55)	A (0.89)
Autumn 2013	A (0.90)	B (0.80)	A (0.87)	B (0.51)	A (1.01)	B (0.64)	B (0.64)	B (0.53)	B (0.69)
% band A	56	56	67	0	11	0	0	0	11

Riverine habitat condition

Objective: To prevent degradation of riverine habitat through sediment deposition.

Indicator: Sediment deposition is limited to <20% of total depth of pools measured at base flow using techniques as per Ecowise Environmental 2005**.**

Sediment deposition in Water Supply Ecosystems has not been the subject of any monitoring programs since the commencement of the 2013 EFG. It is thus not possible to assess the relevant ecological objective in light of nominated indicator variables.

Funcational macrophyte assemblage

Objective: To maintain functional assemblages of macrophytes in urban lakes and ponds.

Indicators: Presence of emergent macrophytes in density and diversity that perform beneficial water quality processes and provide habitat for desired fauna. Submerged macrophytes present and at densities that perform beneficial water quality processes.

Emergent and submerged macrophytes are not monitored systematically within the urban lakes and ponds. Drawdown is generally within the range that is expected to support the maintenance of functional assemblages of macrophytes within urban lakes and ponds (a key indicator variable) and it is likely that in the larger lakes and ponds the current approach to limiting abstraction is meeting the objectives. However, the paucity of lake and pond level monitoring means it is not possible to evaluate the outcomes from the majority of the smaller lakes and ponds for which abstraction licences have been granted.

Macrophyte data were collected in 2010 from Lake Ginninderra, Point Hut Pond and Upper Stranger Pond by the University of Canberra (Fiona Dyer, IAE, unpublished data), with repeat surveys undertaken in 2012 at Lake Ginninderra and Point Hut Pond (Nathalie Budarick, student, unpublished data). While these data are limited (spatially and temporally), they suggest that water level variation influences the distribution and density of the emergent vegetation along the littoral zone of the lakes. The data also suggest that the water level regimes antecedent to the two sampling dates had not been sufficiently different to cause shifts in the patterns of emergent vegetation at the two lakes. Water levels had been generally within 0.2 m or less of full supply level between 2010 and 2012, but there had been some significant periods of drawdown of up to 0.6 m prior to the 2010 sampling. To our knowledge, no subsequent surveys of lake vegetation have been undertaken.

APPENDIX 4. AUSRIVAS SUMMARY

AUSRIVAS (AUStralian RIVer Assessment System) predicts the macroinvertebrate fauna expected to occur at a site with specific environmental characteristics, in the absence of environmental stress. The fauna observed (O) at a site can then be compared to fauna expected (E), with the deviation between the two providing an indication of biological condition (Coysh *et al*. 2000; http://ausrivas.ewater.com.au). A site displaying no biological impairment should have an O/E ratio close to one. The O/E ratio will decrease as the macroinvertebrate assemblage and richness are adversely affected.

The AUSRIVAS predictive model used to assess the biological condition of sites was the ACT autumn or spring riffle model, as appropriate to the sampling season. The AUSRIVAS software and Users Manual (Coysh *et al.* 2000) is available online at: http://ausrivas.ewater.com.au . The ACT autumn riffle model uses a set of 12 habitat variables to predict the macroinvertebrate fauna expected to occur at each site in the absence of disturbance.

AUSRIVAS allocates test site O/E taxa scores to category bands that represent a range in biological conditions to aid interpretation. AUSRIVAS uses five bands, designated X, A, B, C, and D (Table 12). The derivation of model bandwidths is based on the distribution of O/E scores of the reference sites used to create each AUSRIVAS model (Coysh *et al.* 2000, http://ausrivas.ewater.com.au).

Table 12 ACT autumn and spring riffle AUSRIVAS model band descriptions, band width and interpretation.

Band	Band description	Band width	Interpretation
X	More biologically diverse than reference	**>1.12** (autumn) **>1.14** (spring)	More taxa found than expected. Potential biodiversity hot-spot. Possible mild organic enrichment.
A	Similar to Reference	**0.88-1.12** (autumn) **0.86-1.14** (spring)	Water quality and/or habitat condition roughly equivalent to reference sites.
B	Significantly Impaired	**0.64-0.87** (autumn) **0.57-0.85** (spring)	Potential impact either on water quality or habitat quality or both, resulting in loss of taxa.
C	Severely Impaired	**0.40-0.63** (autumn) **0.28-0.56** (spring)	Loss of macroinvertebrate biodiversity due to substantial impacts on water and/or habitat quality.
D	Extremely Impaired	**0-0.39** (autumn) **0-0.27** (spring)	Extremely poor water and/or habitat quality. Highly degraded.

APPENDIX 5. ABSTRACTION LICENCES FOR URBAN LAKES AND PONDS

Table 13 Water abstraction licences for urban lakes and ponds of the ACT

Waterbody	Licenced Abstraction Volume (ML)	Number of Licences
Coombs Pond 2	6.5	1
Crace Community Recreation Irrigated Park (CRIP)	5	1
Dickson stormwater harvesting and control pond	50	1
Exhibition Park in Canberra (EPIC)	15	1
Flemington Pond Standpipe	10	1
Flemington Road Pond 2	463	2
Forde Pond	6	1
Goodwin Aged Care Services Water Quality Pond	4	1
Gungahlin College	13	2
Gungahlin Lakes Golf Course (Bores)	160	2
Gungahlin Pond	1	1
Gunghalin Lake (upstream section)	229	1
Horse Park Drive Water Quality Control Pond	1.5	1
Lake Burley Griffin	2616	15
Lake Burley Griffin / West Basin	1	1
Lake Ginninderra	65	3
Lake Tuggeranong	55	5
Lyneham Pond (Randwick Road)	3	1
Molonglo River	1324.5	6
National Arboretum Canberra, Bore 1	10	1
National Arboretum Canberra, Bore 2	56	1
National Arboretum Canberra, Dam 1 (Front)	30	1
National Arboretum Canberra, Dam 2 (Back) and Molonglo River	100	2
Norgrove Park	13	1
North Weston Ponds	1.5	1
Point Hut Pond	35.5	2
Stromlo Forest Park	67	2
Stromlo Forest Park	67	2
The Valley Ponds	10	1
The Valley Ponds Standpipe	10	1
West Belconnen Pond	1.5	1

APPENDIX 6. IDENTIFICATION OF PRIORITY ENVIRONMENTAL ASSETS AND PRIORITY ECOSYSTEM FUNCTIONS

The following text is an extract from Chapter 8 of the the Basin Plan

8.49 Method for identifying environmental assets and their environmental watering requirements

(1) An environmental asset that requires environmental watering, and its environmental watering requirements, must be identified having regard to the information on the environmental assets and ecosystem functions database, using the following method:

(a) identify any environmental asset that meets one or more of the assessment indicators for any of the 5 criteria specified in the table in Schedule 8; and

(b) identify the environmental assets that can be managed with environmental water (***priority environmental assets***); and

(c) for priority environmental assets, identify ecological objectives that are consistent with the criteria used to identify those assets; and

Example: If the environmental asset falls within the assessment indicator for Criterion 1 because it is a declared Ramsar wetland, the objectives must be directed towards maintaining the ecological character of the wetland.

(d) identify ecological targets to achieve those objectives; and

(e) in accordance with section 8.51 determine the environmental watering requirements needed to meet the targets in order to achieve the objectives.

(2) This method may be applied in a flexible manner, having regard to the particular circumstances.

Example: If new information came to light, the step in paragraph (1)(e) could be re-applied without needing to re-apply the entire method.

8.50 Method for identifying ecosystem functions that require environmental watering and their environmental watering requirements

(1) An ecosystem function that requires environmental watering to sustain it, and its environmental watering requirements, must be identified having regard to the information on the environmental assets and ecosystem functions database, using the following method:

(a) identify any ecosystem function that meets one or more of the assessment indicators for any of the 4 criteria specified in the table in Schedule 9; and

(b) identify the ecosystem functions that can be managed with environmental water (***priority ecosystem functions***); and

(c) for priority ecosystem functions, identify ecological objectives that are consistent with the criteria used to identify those ecosystem functions; and

(d) identify ecological targets to achieve those objectives; and

(e) in accordance with section 8.51, determine the environmental watering requirements needed to meet the targets in order to achieve the objectives.

(2) This method may be applied in a flexible manner, having regard to the particular circumstances.

Example: If new information came to light, the step in paragraph (1)(e) could be re-applied without needing to re-apply the entire method.

Schedule 8—Criteria for identifying an environmental asset

Note: See section 8.49

Item	Criteria
Criterion 1: The water-dependent ecosystem is formally recognised in international agreements or, with environmental watering, is capable of supporting species listed in those agreements	
1	Assessment indicator: A water-dependent ecosystem is an environmental asset that requires environmental watering if it is: (a) a declared Ramsar wetland; or (b) with environmental watering, capable of supporting a species listed in or under the JAMBA, CAMBA, ROKAMBA or the Bonn Convention.
Criterion 2: The water-dependent ecosystem is natural or near-natural, rare or unique	
2	Assessment indicator: A water-dependent ecosystem is an environmental asset that requires environmental watering if it: (a) represents a natural or near-natural example of a particular type of water-dependent ecosystem as evidenced by a relative lack of post-1788 human induced hydrologic disturbance or adverse impacts on ecological character; or (b) represents the only example of a particular type of water-dependent ecosystem in the Murray-Darling Basin; or (c) represents a rare example of a particular type of water-dependent ecosystem in the Murray-Darling Basin.
Criterion 3: The water-dependent ecosystem provides vital habitat	
3	Assessment indicator: A water-dependent ecosystem is an environmental asset that requires environmental watering if it: (a) provides vital habitat, including: (i) a refugium for native water-dependent biota during dry spells and drought; or (ii) pathways for the dispersal, migration and movements of native water-dependent biota; or (iii) important feeding, breeding and nursery sites for native water-dependent biota; or (b) is essential for maintaining, and preventing declines of, native water-dependent biota.
Criterion 4: Water-dependent ecosystems that support Commonwealth, State or Territory listed threatened species or communities	
4	Assessment indicator: A water-dependent ecosystem is an environmental asset that requires environmental watering if it: (a) supports a listed threatened ecological community or listed threatened species; or Note: See the definitions of ***listed threatened ecological community*** and ***listed threatened species*** in section 1.07. (b) supports water-dependent ecosystems treated as threatened or endangered (however described) under State or Territory law; or (c) supports one or more native water-dependent species treated as threatened or endangered (however described) under State or Territory law.
Criterion 5: The water-dependent ecosystem supports, or with environmental watering is capable of supporting, significant biodiversity	
5	Assessment indicator: A water-dependent ecosystem is an environmental asset that requires environmental watering if it supports, or with environmental watering is capable of supporting, significant biological diversity. This includes a water-dependent ecosystem that: (a) supports, or with environmental watering is capable of supporting, significant numbers of individuals of native water-dependent species; or (b) supports, or with environmental watering is capable of supporting, significant levels of native biodiversity at

	the genus or family taxonomic level, or at the ecological community level.

Schedule 9—Criteria for identifying an ecosystem function

Note: See section 8.50.

Item	Criteria
Criterion 1: The ecosystem function supports the creation and maintenance of vital habitats and populations	
1	Assessment indicator: An ecosystem function requires environmental watering to sustain it if it provides vital habitat, including: (a) a refugium for native water-dependent biota during dry periods and drought; or (b) pathways for the dispersal, migration and movement of native water-dependent biota; or (c) a diversity of important feeding, breeding and nursery sites for native water-dependent biota; or (d) a diversity of aquatic environments including pools, riffle and run environments; or (e) a vital habitat that is essential for preventing the decline of native water-dependent biota.
Criterion 2: The ecosystem function supports the transportation and dilution of nutrients, organic matter and sediment	
2	Assessment indicator: An ecosystem function requires environmental watering to sustain it if it provides for the transportation and dilution of nutrients, organic matter and sediment, including: (a) pathways for the dispersal and movement of organic and inorganic sediment, delivery to downstream reaches and to the ocean, and to and from the floodplain; or (b) the dilution of carbon and nutrients from the floodplain to the river systems.
Criterion 3: The ecosystem function provides connections along a watercourse (longitudinal connections)	
3	Assessment indicator: An ecosystem function requires environmental watering to sustain it if it provides connections along a watercourse or to the ocean, including longitudinal connections: (a) for dispersal and re-colonisation of native water-dependent communities; or (b) for migration to fulfil requirements of life-history stages; or (c) for in-stream primary production.
Criterion 4: The ecosystem function provides connections across floodplains, adjacent wetlands and billabongs (lateral connections)	
4	Assessment indicator: An ecosystem function requires environmental watering to sustain it if it provides connections across floodplains, adjacent wetlands and billabongs, including: (a) lateral connections for foraging, migration and re-colonisation of native water-dependent species and communities; or (b) lateral connections for off-stream primary production.

APPENDIX 7. HYDROLOGICAL ANALYSIS - EWATER SOLUTIONS

See below.

Hydrological Analysis for Review of ACT Environmental Flow Guidelines

Technical Report

14 September 2017, v1.1

DOCUMENT CONTROL SHEET

Author: Darryl Lindner UC Innovation Centre, Building 22 University Drive South Bruce, ACT, 2617, Australia T: +61 2 6201 5168 F: +61 2 6201 5038 E: contact@ewater.org.au ABN 47 115 422 903 www.ewater.org.au	**Document:**	Hydrological Analysis for ACT Environmental Flows Review_v1.1.docx
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Australian Government
Department of Industry, Innovation, Science, Research and Tertiary Education
Department of Sustainability, Environment, Water, Population and Communities
National Water Commission

For more information:

UC Innovation Centre, Building 22
University Drive South
Bruce, ACT, 2617, Australia
T: 1300 5 WATER (1300 592 937)
T: +61 2 6201 5168 (outside Australia)
E: contact@ewater.org.au
www.ewater.org.au

Contents

1 Summary

Environmental flow requirements for the sites located at below Corin, Bendora and Googong Dams and below Angle Crossing calculated from 1975 to 1994 daily data are listed in Table 1, environmental flow requirements calculated from 1980 to 2016 data are listed in Table 2, and environmental flow requirements calculated from data covering the entire period 1975 – 2016 are presented in Table 3. The current requirements are listed in Table 12.

When the environmental flow requirement is calculated using 1975 to 1994 daily data, the average monthly environmental flow requirement is increased at all locations apart from Bendora Dam. However, when using 1980 to 2016 data for calculations the average monthly environmental flow requirement is increased at the Corin Dam, Cotter Dam and Googong Dam sites and decreased at Bendora Dam and Angle Crossing. Using the entire period of analysis, 1974 to 2016, results in the average monthly flow requirements increasing at all locations apart from Bendora Dam. Monthly changes from the current environmental flow requirements are summarised for each location in Table 4, green indicates an increase, orange indicates a decrease and blue indicates no change in the required environmental flow.

The downstream Googong Dam environmental flow requirement is currently set at 10ML/day, this is a constraint of the minimum flow volume that can be released from Googong Dam. The current environmental flow from the base of the new Cotter Dam is determined by the flow in the Murrumbidgee River measured at the Mt. MacDonald stream gauge. Currently when the flow in the Murrumbidgee River is greater than 80ML/day the required environmental flow below the Cotter Dam is 40ML/day. When the Murrumbidgee River flow is less than 80ML/day, but greater than 20 ML/day, the environmental flow below the Cotter Dam is to be equal to half that of the gauged reading, and if the Murrumbidgee River flow is less than 20ML/day then the required flow is to be provided by discharges from the Cotter Dam at the rate of 15ML/day. The 75% of the 80th percentile calculated natural flow for below Cotter and Googong Dams has been provided for comparison against the current required environmental flow below these dams.

Table 1 Monthly Environmental Flow Requirements Calculated from 1975 – 1994 data

Location	Environmental Flow Rule	Required Environmental Flow (ML/Day)											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Below Corin Dam	75% of the 80th percentile flow	24	14	11	15	25	34	42	67	111	81	47	34
Below Bendora Dam	75% of the 80th percentile flow	31	18	14	19	33	44	55	88	146	106	62	45
Below Cotter Dam	75% of the 80th percentile flow	45	26	20	27	47	63	78	125	208	151	89	46
Below Googong Dam	75% of the 80th percentile flow	21	15.2	13	21	33	38	40	54	47	42	16	17
Below - Angle Crossing	80th Percentile	43	25	24	54	106						153	52
	90th Percentile						100	144	143	161	130		

Table 2 Monthly Environmental Flow Requirements Calculated from 1980 – 2016 data

Location	Environmental Flow Rule	Required Environmental Flow (ML/Day)											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Below Corin Dam	75% of the 80th percentile flow	17	13	11	13	15	24	45	65	98	64	47	31
Below Bendora Dam	75% of the 80th percentile flow	22	18	14	18	20	32	59	85	129	84	61	40
Below Cotter Dam	75% of the 80th percentile flow	31	25	20	25	29	46	85	121	184	119	87	57
Below Googong Dam	75% of the 80th percentile flow	6	7	8	9	12	18	23	22	19	14	11	10
Below - Angle Crossing	80th Percentile	26	20	16	31	43						158	60
	90th Percentile						61	78	101	158	119		

Table 3 Monthly Environmental Flow Requirements Calculated from 1975 – 2016 data

Location	Environmental Flow Rule	Required Environmental Flow (ML/Day)											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Below Corin Dam	75% of the 80th percentile flow	19	14	11	14	16	27	44	63	101	66	47	28
Below Bendora Dam	75% of the 80th percentile flow	24	18	15	18	21	35	58	83	133	87	62	37
Below Cotter Dam	75% of the 80th percentile flow	35	26	21	26	30	50	83	119	189	124	89	52
Below Googong Dam	75% of the 80th percentile flow	7	9	9	10	13	19	25	24	21	17	16	12
Below - Angle Crossing	80th Percentile	30	23	20	33	46						153	54
	90th Percentile						64	87	123	173	126		

Table 4 Change from Current Environmental Flow Requirement (Green = Increase, Orange = Decrease, Blue = No Change)

	1975 to 1994 Data					1980 to 2016 Data					1975 to 2016 Data				
	Corin	Bendora	Cotter	Googong	Angle Crossing	Corin	Bendora	Cotter	Googong	Angle Crossing	Corin	Bendora	Cotter	Googong	Angle Crossing
January	Green	Green	Green	Green	Green	Green	Orange	Orange	Orange	Orange	Green	Green	Orange	Orange	Orange
February	Green	Green	Orange	Green	Green	Green	Green	Orange	Orange	Orange	Green	Green	Orange	Orange	Green
March	Orange	Orange	Orange	Green	Green	Orange	Orange	Orange	Orange	Orange	Green	Orange	Orange	Orange	Green
April	Orange	Orange	Orange	Green	Green	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Green	Orange
May	Green	Green	Green	Green	Green	Orange	Orange	Orange	Green	Orange	Orange	Orange	Orange	Green	Orange
June	Green	Orange	Green	Green	Green	Orange	Orange	Green	Green	Orange	Orange	Orange	Green	Green	Orange
July	Orange	Orange	Green	Green	Green	Green	Orange	Green	Green	Orange	Orange	Orange	Green	Green	Green
August	Green	Orange	Green	Green	Green	Green	Orange	Green	Green	Green	Green	Orange	Green	Green	Green
September	Green	Green	Green	Green	Orange	Green	Orange	Green	Green	Orange	Green	Orange	Green	Green	Green
October	Green	Green	Green	Green	Green	Orange	Orange	Green	Green	Orange	Green	Orange	Green	Green	Orange
November	Green	Orange	Green	Green	Green	Green	Orange	Green	Green	Green	Green	Orange	Green	Green	Green
December	Green	Green	Green	Green	Orange	Green	Orange	Green	Orange	Green	Green	Orange	Green	Green	Green
Monthly Ave.	Green	Orange	Green	Green	Green	Green	Orange	Green	Green	Orange	Green	Orange	Green	Green	Green

2 Observed Data

2.1 Data Sources

All daily streamflow, water storage, and climate data were sourced from the Bureau of Meteorology website (Table 5). Data for the Stromlo to Googong Bulk Transfer, Murrumbidgee River to Googong Dam transfers, water supplied from Bendora Dam to Stromlo Water Treatment Plant and Googong Dam to the Googong Water Treatment Plant were provided by ICON Water. Daily evaporation depths was sourced from the Bureau of Meteorology Landscape Water Balance Database (bom.gov.au/water/landscape) for the Corin, Bendora, Cotter and Googong Dam sites.

Table 5 Locations and corresponding data sources used in this assessment

Gauge Number*	Location	River/Tributary	Data Provider	Source
410033	Mittagang Crossing	Murrumbidgee	NSW DPI Water	BoM.gov.au/waterdata
410050	Billilingra	Murrumbidgee	NSW DPI Water	BoM.gov.au/waterdata
410719	Above Bendora	Cotter	Icon Water	BoM.gov.au/waterdata
410730	Gingera	Cotter	Icon Water	BoM.gov.au/waterdata
410734	Tinderry	Queanbeyan	Icon Water	BoM.gov.au/waterdata
410747	Below Bendora	Cotter	Icon Water	BoM.gov.au/waterdata
410752	Below Corin	Cotter	Icon Water	BoM.gov.au/waterdata
410761	Below Lobbs Hole	Murrumbidgee	ACT Environment	BoM.gov.au/waterdata
410781	U/S Googong	Queanbeyan	Icon Water	BoM.gov.au/waterdata
41001702	U/S Angle Crossing	Murrumbidgee	Icon Water	BoM.gov.au/waterdata
410774	Burra Road	Burra	Icon Water	BoM.gov.au/waterdata
410717	Bendora Dam	Cotter	Icon Water	BoM.gov.au/waterdata
410742	Corin Dam	Cotter	Icon Water	BoM.gov.au/waterdata
410748	Googong Dam	Queanbeyan	Icon Water	BoM.gov.au/waterdata
070317	Corin Dam	Cotter		bom.gov.au/climate/data/
070322	Corin Forest	Cotter		bom.gov.au/climate/data/
070241	Honeysuckle Creek	Cotter		bom.gov.au/climate/data/
070206	Orroral	Cotter		bom.gov.au/climate/data/
070349	Mt. Ginnini	Cotter		bom.gov.au/climate/data/
070310	Tidbinbilla	Cotter		bom.gov.au/climate/data/
070083	Tharwa	Cotter		bom.gov.au/climate/data/
070316	Bendora Dam	Cotter		bom.gov.au/climate/data/
070347	Googong	Queanbeyan		bom.gov.au/climate/data/
070072	Queanbeyan Bowling Club	Queanbeyan		bom.gov.au/climate/data/

*Gauges beginning with 4 are streamflow, and beginning with 0 are rainfall.

2.2 Infilling missing data

2.2.1 Streamflow Data

Missing stream flow data was infilled using a linear regression of the monthly total streamflow from the nearest gauging station.

Table 6 summarises the missing data and the locations used to infill missing records. Regression equations for the infilling of the streamflow data plots are presented in the Appendix. The period from May 1968 to December 2016 has been used for developing the regressions between streamflow sites.

Table 6 Missing Streamflow data summary

Gauge Number	Location	% Missing Data (May 1968 to December 2016)	Opened	Closed	Filled from (Ordered by Preference)
410050	Billilingra	0.3	12/02/1939	~	-
410719	Above Bendora	92.6	06/11/1962	26/01/1972	Gingera
410730	Gingera	0	02/07/1963	~	-
410734	Tinderry	0.31	01/08/1966	~	-
410747	Below Bendora	21.6	21/12/1975	~	Gingera
410752	Below Corin	13.3	22/08/1974	~	Gingera
410761	Below Lobbs Hole	13.8	11/11/1974	~	-
410781	U/S Googong	44.2	01/02/1990	~	Tinderry
41001702	U/S Angle Crossing	84.4	23/02/2013	~	Lobbs Hole, Billilingra

Rainfall Data

Rainfall data were used for mass balance calculations of inflows at storage sites.
Correlation between the monthly Corin Dam rainfall station and nearby rainfall stations which have an appropriate amount of overlapping data was used to determine the most suitable sites to use for infilling and extending the Corin Dam rainfall data. The percentage of missing daily rainfall data for each site used is summarised in Table 7. The period from May 1968 to December 2016 has been used for developing the linear regression between rainfall stations listed in Table 8.

Table 7 Percentage of missing rainfall data at each site between May 1969 and August 2017

Gauge Number	Location	% Missing Data (May 1968 to December 2016)	Opened	Closed
070317	Corin Dam	25.9	01/01/1968	01/09/2004
070322	Corin Forest	63.1	01/01/1986	01/01/2013
070241	Honeysuckle Creek	72.4	01/01/1967	31/12/1981
070206	Orroral	64.8	01/01/1967	31/12/1985
070349	Mt. Ginnini	76.0	17/06/2004	~
070310	Tidbinbilla	13.8	01/01/1974	14/03/2013
070083	Tharwa	12.7	01/01/1938	~
070316	Bendora Dam	19.1	01/01/1966	~
070347	Googong (Fernleigh)	84.3	01/03/2004	~
070072	Queanbeyan Bowling Club	7.6	01/01/1870	~

Table 8 Rainfall stations used for filling missing records.

Site	Corin Dam	Honeysuckle Creek	Orroral
January	Tidbinbilla		
February	Corin Forest, Tidbinbilla		
March	Corin Forest, Honeysuckle Ck.	Tidbinbilla	
April	Honeysuckle Ck.	Tidbinbilla	
May	Orroral		Tharwa
June	Honeysuckle Ck.	Tidbinbilla	
July	Honeysuckle Ck.	Tidbinbilla	
August	Honeysuckle Ck., Orroral	Tidbinbilla	
September	Corin Forest, Mt. Ginnini, Tidbinbilla		
October	Honeysuckle Ck., Tharwa	Tidbinbilla	
November	Tidbinbilla		
December	Honeysuckle Ck.	Tidbinbilla	

Monthly linear regression between the Corin Dam and Bendora Dam rainfall stations was used for infilling missing rainfall data at the Bendora Dam site, and Queanbeyan Bowling Club was used to infill the Googong (Fernleigh) site.

These data were used to test a water balance approach for estimating natural flows. The water balance approach was not adopted.

2.2.2 Extending Evaporation Data

Daily evaporation estimates for the period 2005 to 2017 were extended back to 1975 using the daily average total evaporation, determined from the 2005 to 2017 period.

These data were used to test a water balance approach for estimating natural flows. The water balance approach was not adopted.

2.3 Storage Surface Area Estimation

Calculation of the volume of water lost or gained from water storages due to evaporation and rainfall is dependent upon the surface area of the water body. Storage surface area has been estimated using a trapezoidal method per the equation below. The decreasing length of the water body has been assumed to be linear and the storage slope angle has been assumed to remain static as the storage level decreases. The storage slope angle parameters α and β for each water storage (Corin, Bendora, Cotter and Googong Dams) were determined using Solver within Excel. The maximum length and width of the water bodies were determined from satellite imagery.

$S = (l \times (w - h \times (1/\tan \alpha + 1/\tan \beta))) \times 0.0001$

Where:

S = Surface Area (Ha)

l = Length of Water Body (m)

h = Maximum Depth of Water (m)

w = Maximum Width of Water (m)

α = Storage slope angle of side 1

β = Storage slope angle of side 2

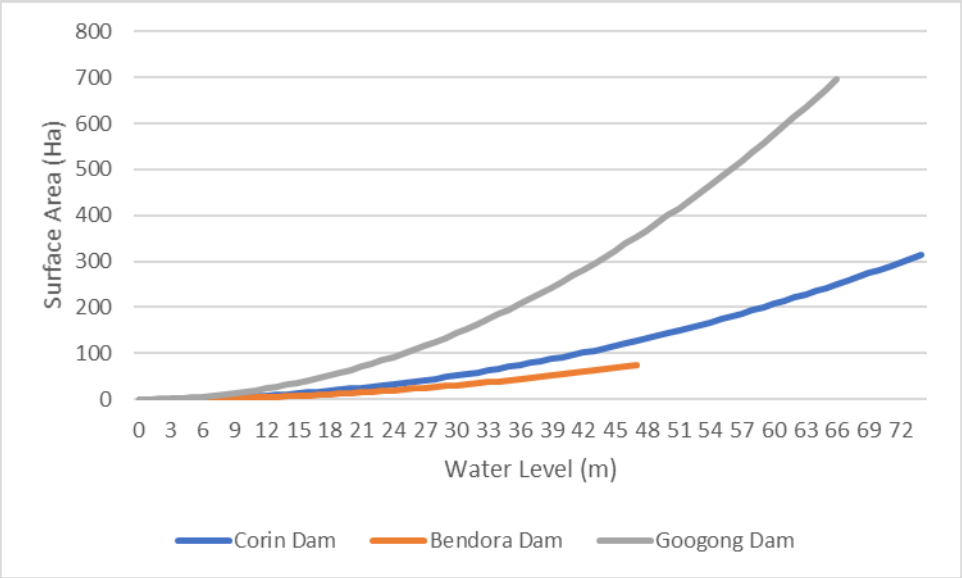

Figure 1 Estimated Water Storage Surface Areas

3 Natural Flow Calculations

3.1 Corin Dam

Two approaches were tried for estimating natural flows at Corin Dam:

I. scaling daily flows measured upstream of the dam at Gingera with the ratio of monthly mass balance calculated inflow at Corin to monthly Gingera flow, and,

II. applying the area runoff relationship used in the 2013 ACT Environmental Flow Guidelines[1].

The first method was not reliable for low flows, with the mass balance resulting in many negative calculated inflows, especially in the drier months. The second method could produce large errors in high flow months.

For the purposes of this study the second method was used, as it gave more reliable results for lower flow periods, which is the flow regime of interest to the study.

The method for calculating the monthly natural flow at Corin Dam by mass balance is:

$Q_{Cn} = S_{t+1} - S_t + E_{net} + Q_o$

Where:

Q_{Cn} = Natural Streamflow at Corin Dam (ML/month)

S_t = Start of month Storage volume (ML)

S_{t+1} = End of month Storage volume (ML)

E_{net} = Corin Dam net evaporation volume (ML/month)

Q_o = Observed Corin Dam Outflow (ML/Month)

The daily estimated natural flow was determined by applying the Gingera (upstream of Corin) daily flow pattern to the monthly natural flow.

The area runoff relationship described in the 2013 ACT Environmental Flow Guidelines is:

$Flow_{req} = Flow_{gauge} \times (A_{req}/A_{gauge})^{0.7}$

Where $Flow_{req}$ is flow at the required point, $Flow_{gauge}$ is flow at the gauging station, A_{req} is the catchment area above the required point, and A_{gauge} is the catchment area above the gauging station.

This was applied to the daily gauged Gingera flows. The area coefficient is shown in Table 9.

[1] Water Resources Environmental Flow Guidelines 2013. Disallowable Instrument DI2013-44,

3.2 Bendora Dam

The two approaches tried for Corin Dam were also tried for Bendora natural inflow calculation. The Bendora Dam monthly natural streamflow calculation is:

$Q_{Bn} = S_{t+1} - S_t + E_{net} + Q_o + Q_s - Q_{Co} + Q_{Cn}$

Where:

Q_{Bn} = Bendora natural inflow (ML/month)

S_t = Start of month storage volume (ML)

S_{t+1} = End of month storage volume (ML)

E_{net} = Bendora Dam net evaporation volume (ML/month)

Q_o = Observed Bendora Dam outflow (ML/Month)

Q_s = Bendora Dam supply to Stromlo Water Treatment Plant (ML/month)

Q_{Co} = Observed Corin Dam outflow (ML/Month)

Q_{Cn} = Calculated natural streamflow at Corin Dam (ML/month)

As with Corin the natural flows calculated by mass balance were not considered reliable for low flows, so the area ratio method was applied to the daily gauged Gingera flows to obtain the estimated natural inflows to Bendora. The area coefficient is shown in Table 9.

3.3 Cotter Dam

As with Corin and Bendora the natural flows calculated by mass balance were not considered reliable in the low flow range, so the area ratio method was applied to the daily gauged Gingera flows to obtain the estimated natural inflows to Cotter. The area coefficient is shown in Table 9.

3.4 Googong Dam

The monthly natural streamflow downstream of Googong Dam was estimated by applying a mass balance equation at the Wickerslack stream gauge below Googong.

$Q_{Gn} = S_{t+1} - S_t + E_{net} + Q_W + Q_{Gs} - Q_{M2G} - Q_{C2G}$

Where:

Q_{Gn} = Natural Streamflow below Googong Dam (ML/month)

S_t = Start of month Storage volume (ML)

S_{t+1} = End of month Storage volume (ML)

E_{net} = Googong Dam net evaporation volume (ML/month)

Q_W = Observed streamflow at Wickerslack stream gauge (ML/month)

G_s = Googong Dam supply to Googong Water Treatment Plant (ML/month)

Q_{M2G} = Murrumbidgee to Googong transfer (ML/month)

Q_{C2G} = Cotter to Googong transfer (ML/month)

The daily natural flow was determined by applying the daily pattern from the gauge upstream of Googong to the monthly natural flow. As with the Cotter storages there was doubt as to the veracity of the low flow results, with for example the 80 percentile daily natural flow for February being estimated as 0.5 Ml/d.

Natural flows used for this assessment were therefore estimated using the area ratio method applied to flows recorded or estimated for the Queanbeyan River upstream of Googong. Missing flows were estimated using the method described in section 2.2.1. The area coefficient is shown in Table 9.

Table 9 Stream Flow Area Coefficients

Location	Reference Gauge	Area Coefficients
Corin Dam	Gingera, 410730	1.34
Bendora Dam	Gingera, 410730	1.754
Cotter Dam	Gingera, 410730	2.502
Googong Dam	Queanbeyan River upstream of Googong 410781	1.191

3.5 Murrumbidgee River at Angle Crossing

The natural daily flow at Angle Crossing is the infilled measured flow at the upstream Angle Crossing stream gauge. This stream gauge has a very short period of record (November 2010 to July 2017). To extend the record a regression of the total monthly streamflow was developed between the Upstream Angle Crossing stream gauge and the closest site which covered the period of interest. The Lobb's Hole stream gauge was used for the period November 1974 to November 2010 and the Billilingara stream gauge for August to November 1974. Monthly coefficients are summarized in Table 10, and regression plots with statistics are provided in the Appendix. Coefficients derived from the monthly total flow were applied to the daily observed stream flow where required to infill missing data at the Angle Crossing site.

Infilling Equation.

IF Q_A is null, then

$$Q_A = Q_{LH} \times Q_{LHi}$$

IF both Q_A and Q_{LH} are null, then

$$Q_A = Q_B \times Q_{Bi}$$

Where:

Q_A = Stream flow at Angle Crossing (ML/Day)

Q_{LH} = Stream flow at Lobb's Hole (ML/Day)

Q_B = Stream flow at Billilingra (ML/Day)

Q_{LHi} = Lobb's Hole to Angle Crossing coefficient for month i

Q_{Bi} = Billilingra to Angle Crossing coefficient for month i

Table 10: Coefficients for extending flow at Angle Crossing

	Billilingra (Q_{Bi})	Below Lobbs Hole (Q_{LHi})
January	1.123	0.907
February	1.317	0.904
March	1.373	0.861
April	1.176	0.887
May	0.942	0.821
June	1.465	0.950
July	1.177	0.970
August	1.195	0.921
September	1.269	0.863
October	1.158	0.857
November	1.171	0.894
December	1.218	0.851

4 Environmental Flow Requirements

4.1 Current Environmental Flows Guidelines

The current environmental flow guidelines were established in 2013 (Table 11). It has been assumed that these guidelines form the basis for re-assessment of the environmental flow requirements taking into account additional data. The comparison of the current environmental flow requirement for each month (Table 12) with the revised environmental flow requirements derived from the 1975 to 1994 streamflow (Table 13) data indicates that the environmental flow requirements are predominantly increased. Comparison of the existing requirements against the revised requirements derived from 1980 to 2016 streamflow data (Table 14) indicates that the environmental flow requirements are predominantly decreased (Table 16). The calculated values of the environmental flow requirements are highly dependent on the period of record of (estimated) historical data used for the analysis, and is also dependent on the method used to estimate natural flows at each site.

Table 11 Current ACT Environmental Flow Guidelines[2]

Location	Flow Type	Ecosystem Category	Flow Requirement
Below Corin Dam	Base Flow	Modified Ecosystem	Maintain 75% of the 80th percentile of the monthly natural inflow, or inflow, whichever is less
	Riffle Maintenance	Modified Ecosystem	Maintain a flow of 150 ML/Day for 3 consecutive days every 2 months
	Pool Maintenance	Modified Ecosystem	Maintain a flow of >550 ML/Day for 3 consecutive days between mid-July and mid-October
	Channel Maintenance	All reaches of the Murrumbidgee River	Protect 90% of the volume in events above the 80th percentile from abstraction
Below Bendora Dam	Base Flow	Modified Ecosystem	Maintain 75% of the 80th percentile of the monthly natural inflow, or inflow, whichever is less
	Riffle Maintenance	Modified Ecosystem	Maintain a flow of 150 ML/Day for 3 consecutive days every 2 months
	Pool Maintenance	Modified Ecosystem	Maintain a flow of >550 ML/Day for 3 consecutive days between mid-July and mid-October
	Channel Maintenance	All reaches of the Murrumbidgee River	Protect 90% of the volume in events above the 80th percentile from abstraction
Below Googong Dam	Base Flow	Modified Ecosystem	Maintain a flow of 10 ML/Day, or inflow, whichever is less
	Riffle Maintenance	Modified Ecosystem	Maintain a flow of 100 ML/Day for 1day every 2 months
	Pool Maintenance	Modified Ecosystem	Not required
	Channel Maintenance	All reaches of the Murrumbidgee River	Protect 90% of the volume in events above the 80th percentile from abstraction
Angle Crossing	Base Flow	Modified Ecosystem	Maintain 80th percentile monthly flow November – May Maintain 90th percentile monthly flow June – October inclusive Abstractions may not exceed flow rate
	Riffle Maintenance	Modified Ecosystem	Not required
	Pool Maintenance	Modified Ecosystem	Not required
	Channel Maintenance	All reaches of the Murrumbidgee River	Protect 90% of the volume in events above the 80th percentile from abstraction

[2] Water Resources Environmental Flow Guidelines 2013, ACT Parliamentary Council

4.2 Current and Revised Environmental Flows Requirements

Table 12 Current Environmental Flow Requirements[3]

Location	Environmental Flow Rule	Required Environmental Flow (ML/Day)											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Below Corin Dam	Minimum of 75% of the 80th percentile flow, or inflow	15	10	11	15	19	28	45	62	92	64	43	26
Below Bendora Dam	Minimum of 75% of the 80th percentile flow, or inflow	23	16	19	24	31	45	71	97	144	100	67	41
Below Cotter Dam	When Murrumbidgee > 80ML/d	40	40	40	40	40	40	40	40	40	40	40	40
	When Murrumbidgee < 80ML/d, but > 20ML/d	Gauged flow at Mt McDonald											
	When Murrumbidgee < 20ML/d	15	15	15	15	15	15	15	15	15	15	15	15
Below Googong Dam	Minimum of 10 ML/Day, or inflow	10	10	10	10	10	10	10	10	10	10	10	10
Below Angle Crossing	80th Percentile	33	22	16	35	55						130	53
	90th Percentile						65	79	99	169	128		

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Table 13 Monthly Environmental Flow Requirements Calculated from 1975 – 1994 data

Location	Environmental Flow Rule	Required Environmental Flow (ML/Day)											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Below Corin Dam	75% of the 80th percentile flow	24	14	11	15	25	34	42	67	111	81	47	34
Below Bendora Dam	75% of the 80th percentile flow	31	18	14	19	33	44	55	88	146	106	62	45
Below Cotter Dam	75% of the 80th percentile flow	45	26	20	27	47	63	78	125	208	151	89	46
Below Googong Dam	75% of the 80th percentile flow	21	15.2	13	21	33	38	40	54	47	42	16	17
Below - Angle Crossing	80th Percentile	43	25	24	54	106						153	52
	90th Percentile						100	144	143	161	130		

[3] Australian Capital Territory – License to Take Water Under the Water Resources Act 2007, License No. WU67

Table 14 Monthly Environmental Flow Requirements Calculated from 1980 – 2016 data

Location	Environmental Flow Rule	Required Environmental Flow (ML/Day)											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Below Corin Dam	75% of the 80th percentile flow	17	13	11	13	15	24	45	65	98	64	47	31
Below Bendora Dam	75% of the 80th percentile flow	22	18	14	18	20	32	59	85	129	84	61	40
Below Cotter Dam	75% of the 80th percentile flow	31	25	20	25	29	46	85	121	184	119	87	57
Below Googong Dam	75% of the 80th percentile flow	6	7	8	9	12	18	23	22	19	14	11	10
Below - Angle Crossing	80th Percentile	26	20	16	31	43						158	60
	90th Percentile						61	78	101	158	119		

Table 15 Monthly Environmental Flow Requirements Calculated from 1975 – 2016 data

Location	Environmental Flow Rule	Required Environmental Flow (ML/Day)											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Below Corin Dam	75% of the 80th percentile flow	19	14	11	14	16	27	44	63	101	66	47	28
Below Bendora Dam	75% of the 80th percentile flow	24	18	15	18	21	35	58	83	133	87	62	37
Below Cotter Dam	75% of the 80th percentile flow	35	26	21	26	30	50	83	119	189	124	89	52
Below Googong Dam	75% of the 80th percentile flow	7	9	9	10	13	19	25	24	21	17	16	12
Below - Angle Crossing	80th Percentile	30	23	20	33	46						153	54
	90th Percentile						64	87	123	173	126		

Table 16 Change from Current Environmental Flow Requirement (Green = Increase, Orange = Decrease, Blue = No Change)

	1975 to 1994 Data					1980 to 2016 Data					1975 to 2016 Data				
	Corin	Bendora	Cotter	Googong	Angle Crossing	Corin	Bendora	Cotter	Googong	Angle Crossing	Corin	Bendora	Cotter	Googong	Angle Crossing
January	Green	Green	Green	Green	Green	Green	Orange	Orange	Orange	Orange	Green	Green	Orange	Orange	Orange
February	Green	Green	Orange	Green	Green	Green	Green	Orange	Orange	Orange	Green	Green	Orange	Orange	Green
March	Orange	Orange	Orange	Green	Green	Orange	Orange	Orange	Orange	Orange	Green	Orange	Orange	Orange	Green
April	Orange	Orange	Orange	Green	Green	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Green	Orange
May	Green	Green	Green	Green	Green	Orange	Orange	Orange	Green	Orange	Orange	Orange	Orange	Green	Orange
June	Green	Orange	Green	Green	Green	Orange	Orange	Green	Green	Orange	Orange	Orange	Green	Green	Orange
July	Orange	Orange	Green	Green	Green	Green	Orange	Green	Green	Orange	Orange	Orange	Green	Green	Green
August	Green	Orange	Green	Green	Green	Green	Orange	Green	Green	Green	Green	Orange	Green	Green	Green
September	Green	Green	Green	Green	Orange	Green	Orange	Green	Green	Orange	Green	Orange	Green	Green	Green
October	Green	Green	Green	Green	Green	Orange	Orange	Green	Green	Orange	Green	Orange	Green	Green	Orange
November	Green	Orange	Green	Green	Green	Green	Orange	Green	Green	Green	Green	Orange	Green	Green	Green
December	Green	Green	Green	Green	Orange	Green	Orange	Green	Orange	Green	Green	Orange	Green	Green	Green
Monthly Ave.	Green	Orange	Green	Green	Green	Green	Orange	Green	Green	Orange	Green	Orange	Green	Green	Green

4.3 Environmental Flows Requirements Adjusted for Climate Change

Calculated natural flow at each site was modified by applying climate scaling factors for wet, medium and dry future climate scenarios derived from Figure 8-3, ACTEW Future Climate Update report[4]. Generally, a wetter climate scenario (Table 18 and Table 21) results in the calculated natural flow at all sites increasing above the historic natural 80^{th} percentile flow, and therefore the required environmental flow is also increased. For the medium (Table 19 and Table 22) and dry (Table 20 and Table 23) climate scenarios, the scaled 75% of the 80^{th} percentile natural flow is lower than 75% of the historic natural 80^{th} percentile flows.

Table 17 Climate Coefficients

	Climate Coefficients		
	Wet	Medium	Dry
80%ile	1.167	0.961	0.879
90%ile	1.162	0.963	0.874

Climate Adjusted Environmental Flow Requirements – Calculated from 1975-1994 Data

Table 18 Wet Climate Scenario Environmental Flow Requirements – 1975 to 1994 Data

Location	Environmental Flow Rule Applied	Wet Climate Scenario Required Environmental Flow (ML/Day)											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Below Corin Dam	75% of the 80^{th} percentile flow	28	16	12	17	30	39	49	78	130	94	55	40
Below Bendora Dam	75% of the 80^{th} percentile flow	37	21	16	22	39	52	64	102	170	123	72	53
Below Cotter Dam	75% of the 80^{th} percentile flow	52	30	23	32	55	74	91	146	243	176	103	53
Below Googong Dam	75% of the 80^{th} percentile flow	24	18	15	25	38	44	47	63	54	49	19	20
Below - Angle Crossing	80^{th} Percentile	50	29	28	63	124						178	61
	90^{th} Percentile						117	167	166	187	151		

[4] ACTEW Water, ACTEW Future Climate Update, 2014, Canberra

Table 19 Medium Climate Scenario Environmental Flow Requirements – 1975 to 1994 Data

Location	Environmental Flow Rule Applied	Medium Climate Scenario Required Environmental Flow (ML/Day)											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Below Corin Dam	75% of the 80th percentile flow	23	13	10	14	24	32	40	64	107	77	45	33
Below Bendora Dam	75% of the 80th percentile flow	30	17	13	18	32	42	53	84	140	102	60	43
Below Cotter Dam	75% of the 80th percentile flow	43	25	19	26	46	61	75	120	200	145	85	44
Below Googong Dam	75% of the 80th percentile flow	20	15	12	20	32	36	38	52	45	40	15	16
Below - Angle Crossing	80th Percentile	42	24	23	52	102						147	50
	90th Percentile						97	138	138	155	125		

Table 20 Dry Climate Scenario Environmental Flow Requirements – 1975 to 1994 Data

Location	Environmental Flow Rule Applied	Dry Climate Scenario Required Environmental Flow (ML/Day)											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Below Corin Dam	75% of the 80th percentile flow	21	12	9	13	22	30	37	59	98	71	42	30
Below Bendora Dam	75% of the 80th percentile flow	28	16	12	17	29	39	48	77	128	93	54	40
Below Cotter Dam	75% of the 80th percentile flow, or inflow	39	23	17	24	42	55	69	110	183	132	78	40
Below Googong Dam	75% of the 80th percentile flow	18	13	11	19	29	33	35	47	41	37	14	15
Below - Angle Crossing	80th Percentile	38	22	21	47	93						134	46
	90th Percentile						88	125	125	141	113		

Climate Adjusted Environmental Flow Requirements – Calculated from 1980-2016 Data

Table 21 Wet Climate Scenario Environmental Flow Requirements – 1980 to 2016 Data

Location	Environmental Flow Rule Applied	Wet Climate Scenario Required Environmental Flow (ML/Day)											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Below Corin Dam	75% of the 80th percentile flow	20	16	13	16	18	29	53	76	115	74	54	36
Below Bendora Dam	Min 75% of the 80th percentile flow	26	21	17	21	23	37	69	99	151	98	71	47
Below Cotter Dam	75% of the 80th percentile flow	37	29	24	29	34	53	99	141	215	139	102	67
Below Googong Dam	75% of the 80th percentile flow	7	0	10	11	14	21	27	25	22	16	13	12
Below - Angle Crossing	80th Percentile	31	23	19	36	50						185	70
	90th Percentile						71	91	118	184	139		

Table 22 Medium Climate Scenario Environmental Flow Requirements – 1980 to 2016 Data

Location	Environmental Flow Rule Applied	Medium Climate Scenario Required Environmental Flow (ML/Day)											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Below Corin Dam	75% of the 80th percentile flow	16	13	10	13	15	23	43	62	95	61	45	29
Below Bendora Dam	75% of the 80th percentile flow	21	17	14	17	19	31	57	82	124	80	59	38
Below Cotter Dam	75% of the 80th percentile flow	30	24	20	24	28	44	81	116	177	115	84	55
Below Googong Dam	75% of the 80th percentile flow	6	0	8	9	12	17	22	21	18	13	10	10
Below - Angle Crossing	80th Percentile	25	19	15	30	41						152	57
	90th Percentile						59	76	98	152	115		

Table 23 Dry Climate Scenario Environmental Flow Requirements – 1980 to 2016 Data

Location	Environmental Flow Rule Applied	Dry Climate Scenario Required Environmental Flow (ML/Day)											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Below Corin Dam	75% of the 80th percentile flow	15	12	10	12	13	21	40	57	86	56	41	27
Below Bendora Dam	75% of the 80th percentile flow	19	15	13	15	18	28	52	74	113	73	54	35
Below Cotter Dam	75% of the 80th percentile flow	28	22	18	22	25	40	74	106	162	105	77	50
Below Googong Dam	75% of the 80th percentile flow	5	0	7	8	11	16	20	19	17	12	9	9
Below - Angle Crossing	80th Percentile	23	17	14	27	38						139	53
	90th Percentile						53	69	89	138	104		

Climate Adjusted Environmental Flow Requirements – Calculated from 1975-2016 Data

Table 24 Wet Climate Scenario Environmental Flow Requirements – 1975 to 2016 Data

Location	Environmental Flow Rule Applied	Wet Climate Scenario Required Environmental Flow (ML/Day)											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Below Corin Dam	75% of the 80th percentile flow	22	16	13	16	19	31	52	74	118	78	55	33
Below Bendora Dam	Min 75% of the 80th percentile flow	29	21	18	21	24	41	68	97	155	102	72	43
Below Cotter Dam	75% of the 80th percentile flow	41	30	25	30	35	58	97	139	221	145	103	61
Below Googong Dam	75% of the 80th percentile flow	9	11	11	12	15	22	29	28	24	19	19	14
Below - Angle Crossing	80th Percentile	36	27	23	39	53						178	63
	90th Percentile						74	101	143	201	146		

Table 25 Medium Climate Scenario Environmental Flow Requirements – 1975 to 2016 Data

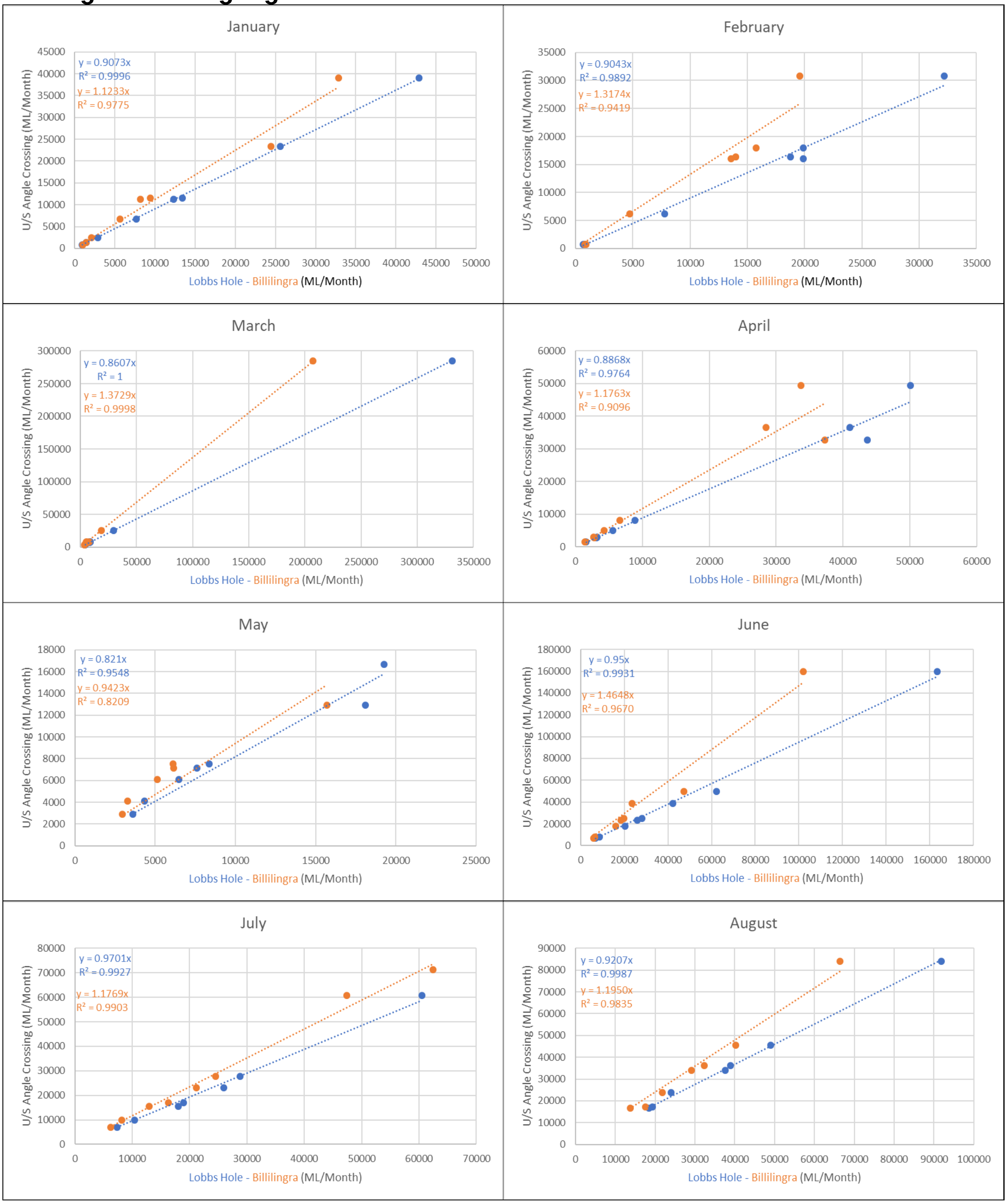
Location	Environmental Flow Rule Applied	Medium Climate Scenario Required Environmental Flow (ML/Day)											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Below Corin Dam	75% of the 80th percentile flow	18	13	11	13	15	25	43	61	97	64	45	27
Below Bendora Dam	75% of the 80th percentile flow	24	17	14	17	20	33	56	80	127	84	60	35
Below Cotter Dam	75% of the 80th percentile flow	34	25	21	25	29	48	80	114	182	119	85	50
Below Googong Dam	75% of the 80th percentile flow	7	9	9	10	13	18	24	23	20	16	15	12
Below - Angle Crossing	80th Percentile	29	22	19	32	44						147	52
	90th Percentile						61	84	118	166	121		

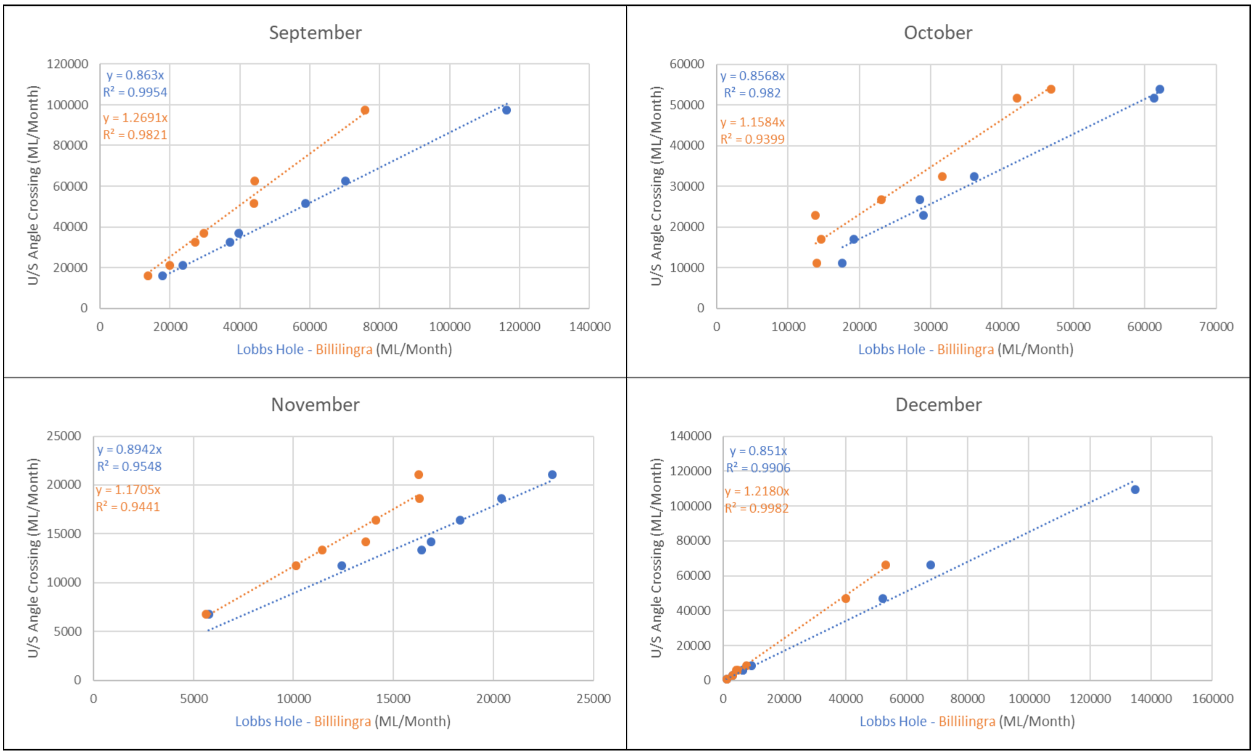
Table 26 Dry Climate Scenario Environmental Flow Requirements – 1975 to 2016 Data

Location	Environmental Flow Rule Applied	Dry Climate Scenario Required Environmental Flow (ML/Day)											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Below Corin Dam	75% of the 80th percentile flow	15	12	10	12	13	21	40	57	86	56	41	27
Below Bendora Dam	75% of the 80th percentile flow	19	15	13	15	18	28	52	74	113	73	54	35
Below Cotter Dam	75% of the 80th percentile flow	28	22	18	22	25	40	74	106	162	105	77	50
Below Googong Dam	75% of the 80th percentile flow	5	6	7	8	11	16	20	19	17	12	9	9
Below - Angle Crossing	80th Percentile	23	17	14	27	38						139	53
	90th Percentile						53	69	89	138	104		

Appendix

Upstream Angle Crossing stream gauge regression with Lobbs Hole and, Billilingra stream gauge




September
y = 0.863x
R² = 0.9954
y = 1.2691x
R² = 0.9821
U/S Angle Crossing (ML/Month)
Lobbs Hole - Billilingra (ML/Month)
October
y = 0.8568x
R² = 0.982
y = 1.1584x
R² = 0.9399
U/S Angle Crossing (ML/Month)
Lobbs Hole - Billilingra (ML/Month)
November
y = 0.8942x
R² = 0.9548
y = 1.1705x
R² = 0.9441
U/S Angle Crossing (ML/Month)
Lobbs Hole - Billilingra (ML/Month)
December
y = 0.851x
R² = 0.9906
y = 1.2180x
R² = 0.9982
U/S Angle Crossing (ML/Month)
Lobbs Hole - Billilingra (ML/Month)

eWater Solutions ABN 47 115 422 903

UC Innovation Centre, Building 22
University Drive South
Bruce ACT 2617
T: +61 2 6201 5168
E: contact@ewater.org.au
www.ewater.org.au