

Water Resources Environmental Flow Guidelines 2019 (No 2)

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made under the

Water Resources Act 2007, s 12 (Environmental flow guidelines)

1 Name of instrument

This instrument is the *Water Resources Environmental Flow Guidelines 2019 (No 2)*.

2 Commencement

This instrument commences on the day after its notification day.

3 Determination of environmental flow guidelines

I approve the environmental flow guidelines in schedule 1.

4 Revocation

This instrument revokes the *Water Resources Environmental Flow Guidelines 2019* (DI2019-37).

Mick Gentleman MLA
Minister for the Environment and Heritage
24 July 2019

Schedule 1

(see cl 3)

ACT WATER RESOURCES Environmental Flow Guidelines - 2019

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EXECUTIVE SUMMARY

The Environmental Flow Guidelines are an instrument under the *Water Resources Act 2007* that set out the flow requirements needed to maintain aquatic ecosystems. The Guidelines have been developed using the most up-to-date scientific information available, and will be used with Water Resource Management regulatory instruments under the Water Resources Act, the Water Available From Areas Determination and Water Management Areas Determination, to manage ACT water resources.

Environmental flows, for the purposes of the Water Resources Act, are specified in Table 3 of Section 5 for each ecosystem category and each specific reach. The Environmental Flow Guidelines apply to all rivers, streams, lakes and ponds in the ACT. The 2019 Environmental Flow Guidelines replace the 2013 Environmental Flow Guidelines.

Purpose of environmental flows

Environmental flows describe the quantity and timing of water required to sustain freshwater ecosystems.

We rely on our waterways for a range of functions including biodiversity and conservation, irrigation and domestic water supply. Waterways need to be healthy to provide these functions. The natural flows in ACT streams are highly variable. Rivers and streams naturally have periods of both very low and very high flows. Flows in our streams also vary seasonally with the higher flows usually occurring in the spring months. The Guidelines identify the components of flow from this variable flow regime necessary to maintain stream health. One way to do this is to specify environmental flows that mimic the flows that would occur naturally. In more heavily used systems such as water supply catchments, it may be necessary to protect specific components of the flow regime to keep aquatic ecosystems healthy. In highly modified ecosystems, the environmental flows needed to ensure critical processes occur and provide habitat may be very different to the natural flow regime that occurred before development.

Components of environmental flows

To account for natural variability, the Guidelines include protection of particular components of the natural flow. These are:

- base flow
- small floods (riffle maintenance flows)
- larger floods (pool or channel maintenance flows)
- special purpose flows
- impoundment drawdown level.

The base flow—the flow component contributed mostly by groundwater—is the minimal volume of water that the stream needs to support the fish, plants, insects, and protect water quality. The volume of the base flow is determined for each month for each stretch of stream or river.

The purpose of the small and larger floods—termed riffle, pool, and channel maintenance flows—is to move out sediment deposits and maintain channel form. The movement of sediment is important for maintaining healthy aquatic ecosystems. Riffles are the shallow fast flowing sections of the river. The riffle maintenance flows scour out fine sediment that accumulates in riffles, damaging these habitats for fish, water plants and other aquatic life.

The pool and channel maintenance flows scour sediment from pools and ensure the river maintains its natural channel form.

Special purpose flows are flows designed for a particular ecological need, for example the flow needed to encourage breeding of a species of fish, or to protect habitat of a frog species. The Guidelines make provision for special purpose flows should they be identified. However no special purpose flows are currently specified in the Guidelines.

Impoundment drawdown levels are the levels that a reservoir, lake or pond needs to be kept within so that impacts on macrophytes, sediment processes and water quality do not result in adverse changes to the state of the ecosystem. Static impoundment levels can result in a limited fragile ecosystem dominated by a few species of flora and fauna even though the biomass can be high. Excessive fluctuations in impoundment levels can result in a denuded barren water body that supports little biomass and low biodiversity.

How environmental flows are provided

In the ACT environmental flows are provided in one of two ways: either by releases or spills from dams or by restricting the volume of water that can be abstracted from a water management area. In the ACT the volume of water available for abstraction within each water management area is limited to the volume remaining after environmental flow volumes have been provided. Abstraction rules are also applied to ensure that licensed abstractors do not impact on waterways during critical flow events such as very low flows, flooding flows or cause excessive drawdown levels. The ACT only abstracts up to about 10% of available flows on average, with the remaining 90% effectively environmental flows. In addition, only the water supply dams significantly modify flows in downstream river reaches.

Ecological objectives for environmental flows

Setting ecological objectives for waterways allows specific ecological values to be protected by components of the environmental flow regime. In addition, ecological objectives can be used to assess the effectiveness of environmental flows, and the information used to refine the Guidelines.

The ecological objectives and indicators of these objectives identified in the Guidelines are based on the Territory Plan, ACT legislation, Commonwealth threatened species legislation, ACT Government policies and knowledge gained from research.

As an example, an ecological objective for the Cotter River reach between Bendora Dam and Cotter Reservoir is to maintain populations of the endangered fish species Macquarie Perch. An indicator of success in meeting this objective is that recruitment of Macquarie Perch is detected at greater than 75% of monitoring sites in the reach.

Environmental flows in water supply catchments

In the water supply catchments a balance between environmental needs and consumptive needs has to be made in the Guidelines to ensure there is adequate supply of water for domestic consumption. At the same time, there is a requirement to maintain the health of the rivers and, in particular, to protect the two endangered fish species that live in the Cotter River. The environmental flows that are recommended for the water supply catchments are based on the extensive information about environmental flows in the Cotter River.

Flows specified for these catchments are the minimal requirement for healthy aquatic ecosystems, while ensuring both water supply and conservation objectives can be met. This approach is appropriate for these catchments as the intensive monitoring of the system allows adaptive management to be implemented if adverse effects are detected.

Special rules for drought periods have also been specified for these catchments. The Guidelines recognise that during dry times, when the urban population faces water restrictions, it is appropriate that environmental flows also be reduced.

Environmental flows in urban catchments

Urbanisation has caused considerable modification to the streams flowing through urban areas. The increase in impervious surfaces, including roads, roofs and car parks, has caused a higher rate of run-off than occurred naturally. In addition urban watering has led to many urban streams now having unnatural permanent flow. Increased flows in urban streams can stress aquatic ecosystems. For urban streams, the Guidelines identify the natural base flow and channel maintenance flow that should be protected, and recommends that the additional run-off from urban development be made available for abstraction. This serves the dual purpose of protecting streams from the effects of frequent short duration high flows, and allows greater use of second-class water in the urban area.

Environmental flows in other catchments

Environmental flow requirements are also set for streams in natural ecosystems, such as those within Namadgi National Park and Tidbinbilla Nature Reserve, and in modified ecosystems in rural ACT. The Guidelines for these systems are designed to protect the base flow and also protect most of the volume of flood flows that are necessary to maintain the channel form. In these catchments limiting the quantity of water that can be abstracted protects environmental flows.

Indigenous water—values and uses

The values and uses of Indigenous water are currently being identified through the ACT Water Resource Plan process. While Indigenous water is different to environmental flows, where it relates to meeting the ecological objectives shown in Table 2 and supporting the environmental flow requirements in Table 3, it will be included in future environmental flow guidelines.

Flow Requirements Summary

Reach	Flows
Corin & Bendora	Base flow = 75% of 80th percentile flow RMF = 150ML and PMF = 550ML
Cotter	Base flow = 15ML/Day RMF = 100ML
Googong	Base flow = October to June -10ML/Day and July to September 15ML/Day RMF = 100ML

Natural & Modified	Base flow = 80th percentile flow RMF & PMF = abstraction will be restricted to a long-term average of 10% of the flow above the 80th percentile flow.
Murrumbidgee	Base flow = Maintain 80th percentile monthly flow November – May, and 90th percentile monthly flow June –October inclusive. RMF = Protect a minimum of 195 ML/d natural flow for a period of 1 day, once every 30 days. ⁶
Urban	Maintain 80th percentile modelled natural monthly flow
Urban lakes and ponds	Drawdowns of 0.2m to 0.6m
Groundwater	Groundwater abstraction is limited to 10% of the long term recharge

1 INTRODUCTION

1.1 Background

Increasing demands for the allocation of water for off-stream uses has resulted in substantial changes in the streamflow regimes in many streams across Australia. These changes in streamflow have contributed to major impacts on aquatic habitats and ecology. In some Australian streams, allocation of water for off-stream uses can exceed total flow resulting in patterns of flow that reflect the rights of water users rather than the requirements of the streams and their ecological processes. Consumptive uses are often given priority as water rights, entitlements, and licences have legal and commercial status. With the growing use of market forces as the basis of resource allocation, there is a need to ensure that environmental quality and ecological requirements are not disadvantaged.

Over past decades there has been an acceptance of the need to give explicit recognition to environmental flow needs through the establishment of water specifically for the environment. Similarly, it is accepted that there is a relationship between surface and ground water and that ground water abstraction will impact on base flows of surface streams.

Many aquatic ecosystems in the ACT are modified as a result of changes in land use, changes to river channels and floodplains, streamflow diversion, discharges to streams, introduction of flora and fauna, and recreational fishing. Some of these systems, particularly urban lakes and streams—categorised as urban ecosystems—are highly valued in their own right. Other aquatic ecosystems are in a condition close to that prior to European settlement.

Depending on the condition of a stream and the environmental values specified for that stream, the planning and management issues in respect to environmental flows vary from:

- managing streamflow diversion and discharges so as to maintain the current status of the aquatic ecosystems to
- managing streamflow diversion and discharges so as to restore aquatic ecosystems to a standard to meet the community's environmental values.

It should be recognised that the guidelines for environmental flows in this document are based upon the best scientific knowledge available at the time they were drafted. The determination of environmental flows is an active research field and this document will be refined and amended as the knowledge base grows.

1.2 Purpose of the guidelines

These Guidelines are a statutory instrument to be used when determining volumes in the Water Resource Plan and in the regulation of water abstraction. Environmental flows, for the purposes of the Water Resources Act, with respect to each ecosystem category and specific reaches within are specified in Table 3 of Section 5.

1.3 National responsibilities

The Intergovernmental Agreement on the Environment (1992) sets out clear guidance on land use decision and approval processes to ensure development is ecologically sustainable. The National Strategy for Ecologically Sustainable Development (1992) sets the goal of Ecologically Sustainable Development (ESD) as ‘development that improves the total quality of life, both now and in the future, in a way that maintains the ecological processes on which life depends’. When applied to ecosystems this core objective is expressed as ‘protection of biological diversity and the maintenance of essential ecological processes and life support systems’. These guidelines have been prepared with these principles in mind.

In line with the ESD precautionary principle, the Guidelines are conservative and may need to be reassessed in light of further knowledge and experience. In water supply catchments a smaller safety margin is accepted on the basis of our better understanding of such streams, and in recognition of the importance of the water supply function of these catchments.

The ACT is also party to the 1994 and 1995 Competition Policy and related reforms agreements. These include the COAG agreement on the strategic framework for the efficient and sustainable reform of the Australian water industry. Amongst other things, this requires the setting of environmental flow requirements based on the best available scientific advice. The 2004 National Water Initiative confirms this requirement.

1.3.1 Murray Darling Basin Plan

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. The establishment of 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, the ACT is required to develop a 10 year Water Resource Plan (WRP). 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, MDBA, 2014a). Thus, the revised EFG will be central to the ACT’s WRP and have been prepared with these requirements in mind.

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):

- Protect and restore water-dependent ecosystems.
- Protect and restore the ecosystem functions of water-dependent ecosystems.

- 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, water birds and native fish.

With respect to fish, the BWS identifies the following requirements:

- Increase populations of Macquarie Perch in at least two of six sites, one of which is the Cotter River (Table 8 and the Cotter River is also a site of significance in Appendix 7).
- Increase populations of Silver Perch in at least two of seven sites, one of which is in reaches of the Murrumbidgee River (Table 8).

Expected outcomes for native fish (pp45- 46)

The BWS outcomes are reliant on other factors such as land management, and not just by environmental flows.

Under the Basin Plan Basin States are required to prepare a long-term watering plan for its water resource plan area (in the case of the ACT, the ACT itself). The LTWP sets out the environmental watering requirements needed to meet ecological objectives and targets, in particular for identified priority environmental assets (PEAs) and priority ecosystem functions (PEFs). PEAs and PEFs are assets and functions that by definition require watering. This is in keeping with the environmental objectives of the Basin 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; as water cannot be delivered to this asset, the way of managing water at this site is by preventing extraction.

1.4 Statutory basis for environmental flows in the ACT

1.4.1 Water Resources Act

The preparation of environmental flow guidelines is a requirement of the [Water Resources Act 2007](#) (the Act). This Act has the objectives of:

- ensuring the use and management of water resources to sustain the physical, economic and social wellbeing of the people of the Territory, while protecting the ecosystems that depend on those resources
- protecting waterways and aquifers from damage and, where possible, reversing damage that has already occurred
- ensuring water resources are able to meet the reasonably foreseeable needs of future generations.

To achieve these objectives the Act requires that Environmental Flow Guidelines be prepared to set out the flows necessary to maintain aquatic ecosystems in ACT waterways. The Act also requires the determination of areas (Water Management Areas) for managing the water resources of the ACT and requires that the amount of water available for taking from each area is determined. The Act further provides that the Environment Protection Authority may license the taking of both surface and groundwater from areas as provided for by the water available from areas determination and the Guidelines.

1.4.2 Territory Plan

Implementation of the Act needs to be consistent with the Territory Plan. Three types of water use catchments are identified in the Territory Plan (Section 11.8 Water use and catchment general code); ‘conservation’, ‘water supply’, and ‘drainage and open space’. These uses have been designated as the primary uses for the waterbodies within these types of catchment.

Within each of these catchments, secondary use values are also specified and include provision of recreational amenity, supply of potable or second class water, provision of aquatic habitat, and remediation of low quality urban stormwater (Section 11.8 of the Plan). Where several secondary uses are specified for a water body, that water body is to be managed to achieve the use with the most stringent requirements, so that other uses are not compromised by relaxation of standards.

Under the general principles and policies, the Territory Plan requires that planning be guided by the principles of ecological sustainability and exclude catchment land and water uses which impact on the sustainability of identified environmental or water use values.

It is therefore necessary that appropriate flows be provided to protect the environmental and use values of ACT waterbodies.

The Territory Plan explicitly requires that environmental flows be maintained to ensure that the stream flow and quality of discharges from all catchments protect environmental values of downstream waters. Four policies are elaborated to achieve this objective:

- Land use and management practice shall be cognisant of streamflow and water quality impacts downstream.
- Stream-flow diversions shall be restricted to authorised diversions.
- Lake and reservoir releases shall be consistent with the protection of downstream ecology and water uses.
- Groundwater abstraction shall be consistent with authorised abstraction.

Implementing these policies necessitates defining quantitative environmental flow guidelines for all streams, rivers, lakes and aquifers in the ACT and the control of abstraction of the volumes not required by the environment.

1.4.3 Supporting legislation and strategies

The objectives of the Territory Plan and the Act are supported and complemented by the provisions and strategies contained in the [Environment Protection Act 1997](#), the [Nature Conservation Act 2014](#) and the ACT Nature Conservation Strategy 2013–23. The Environment Protection Act provides capacity for compliance and enforcement by the Environment Protection Authority as well as water quality and chemical use standards. The Nature Conservation Act and ACT Nature Conservation Strategy support the conservation of native

species, communities and habitats essential to the protection of the wellbeing of aquatic species.

The Guidelines will also be complemented by the ACT Aquatic and Riparian Conservation Strategy and related action plans. The strategy guides conservation and recovery of aquatic and riparian species in water systems.

1.4.4 National waters

These Guidelines include environmental flows for the Molonglo River downstream of Scrivener Dam and drawdown limits for Lake Burley Griffin. Lake Burley Griffin remains under the control of the Australian Government and is managed by the National Capital Authority.

Environmental flows for Lake Burley Griffin are recommended given the ACT's responsibility to protect ACT water resources upstream of Lake Burley Griffin including the Jerrabomberra Wetlands and the Molonglo River, as well as the Molonglo River downstream of Lake Burley Griffin. The National Capital Authority recognised the need for environmental flows from Scrivener Dam in their management practices. The Guidelines therefore specify environmental flows for all waterways lying within the ACT. Following the enacting of Commonwealth legislation, the Environment Protection Authority regulates water use from Lake Burley Griffin. Lake Burley Griffin also has its own management plan administered by the National Capital Authority.

1.4.5 Paramount rights to Queanbeyan and Molonglo waters

By the Agreement between the Commonwealth and NSW for the surrender of territory by NSW for the Seat of Government, the Commonwealth gained paramount rights to the waters of the Queanbeyan and Molonglo Rivers and their tributaries (in NSW) for all the purposes of the Territory (see [*Seat of Government Acceptance Act 1909 \(Cwlth\)*](#)). The Commonwealth has developed the waters of the Queanbeyan River for the purposes of urban water supply for the ACT through the construction of the Googong Dam. Through the Commonwealth [*Canberra Water Supply \(Googong Dam\) Act 1974*](#), the Territory Executive exercises the rights to the waters of the Googong Dam Area and this includes any necessary releases from the Googong Dam. The Canberra Water Supply (Googong Dam) Act also requires that environmental needs be taken into account in water resources management.

While the only NSW waters yet developed for ACT urban water supply are those entering Googong Reservoir, the remaining waters over which the Commonwealth has paramount rights (that is, the Molonglo River upstream of the ACT and Jerrabomberra Creek upstream of the ACT) are important for other ACT purposes, including the protection of aquatic ecosystems in the ACT.

Without appropriate environmental flows entering the ACT from the Molonglo River and Jerrabomberra Creek the ACT may not be able to ensure appropriate environmental flows in these waterways in the ACT and further downstream in NSW. The determination and maintenance of flow requirements in these waters to protect environmental values is the responsibility of NSW. The current NSW rules for taking water from river reaches upstream and downstream of the ACT are contained in the 'Water sharing plan for the Murrumbidgee unregulated and alluvial water sources 2012'.

Part 8 Division 2 of the NSW plan specifies the flow at which take can commence, which is approximately equal to the 95th percentile for the Murrumbidgee and Queanbeyan Rivers

and the 80th percentile for the Molonglo River. To ensure protection of the Commonwealth's paramount rights to these waters under the Seat of Government Acceptance Act for the purposes of the Territory, it is expected that water use be limited to that necessary to support stock and domestic purposes for traditional grazing enterprises and associated long established rural villages (or equivalent use). Part 5 Division 2 of the NSW water sharing plan specifies the flows available for stock and domestic rights in the relevant catchments. This is expected to ensure that adequate environmental flows into the ACT are maintained. There are currently no water requirements for native title rights in this NSW water sharing plan.

In this context, these Guidelines only specify the environmental flows in NSW immediately downstream of Googong Dam as these flows are under the direct control of the ACT through regulation of releases.

The ACT ensures that environmental flow requirements in the rivers it has responsibility for are met by flows under the control of the ACT, principally water running off ACT land.

1.5 Review of the guidelines

Actual flows and their effect on stream structure and ecology will be the subject of an ongoing monitoring and evaluation program. Recommendations for monitoring and evaluation are provided in Section 6 Monitoring and Assessment. The program will be used to evaluate the effectiveness of the Guidelines. The first guidelines were published in 1999 and were reviewed after five years. The changes to the original guidelines focussed mainly on the setting of environmental objectives and adjustments to the flows in water supply catchments. Changes to the 2006 Guidelines provided a framework for accommodating climate change and aspects relating to updated water supply infrastructure. Further recommendations from reviews conducted in 2010 and 2017 have been incorporated into the Guidelines. The scientific basis for these recommendations and amendments has been appended to the Guidelines.

The Guidelines will be reviewed after a further five years of operation to determine if the ecological objectives specified are the most appropriate, and the environmental flows required achieve those objectives. The review may be conducted earlier if evidence indicates it is warranted.

2 DETERMINATION OF ENVIRONMENTAL FLOWS

2.1 Basis for determination of environmental flows

The concept of environmental flow is based on the recognition that aquatic ecosystems are adapted to natural flow conditions and modification of the flow regime will impact on the ecosystem. Additionally, the geomorphological structure of streams is largely determined by the flow regime, with flow-on effects on stream biota through changes to substrate type and available habitat. Flow regime refers not only to the quantity of water but also to the variability of flow and incidence of flood and low flow events. For long term viability of some ecosystems there may be a need for periods of low flow.

In practice it may be difficult to determine the effect of an 'environmental flow' component in isolation from other factors such as water quality. The environmental flows have been determined by relating the Territory Plan requirements to protect specific aquatic ecosystems with the scientific basis for sustaining significant ecosystems or species.

2.2 Adaptive management

Adaptive management is the systematic process of continually improving management policies and practices by learning from the outcomes of an experimental approach to operational programs (Peat et al. 2017).

As a method for guiding and improving environmental management, it has been adopted in many environmental water management systems in Australia such as the Murray–Darling Basin Authority. The principles of adaptive management have been embedded in the ACT’s Environmental Flow Guidelines, with environmental flows management integrated with ecological objectives, monitoring and reporting requirements.

The flow regimes specified within the Guidelines have been developed within an adaptive management cycle (Peat, 2007), with investment in monitoring, assessment and research to fill knowledge gaps and thereby improve the overall management of flow regimes and management of aquatic ecosystems and river health. This process has been applied over time in the ACT in the review and revision of the ACT’s Guidelines.

The focus has been on balancing the needs of the water users with the requirements of the freshwater ecosystems. This has resulted in the refinement of the defined flow requirements and recommended flow regimes.

Strategies for further improving environmental flow implementation within an adaptive management framework include the regular production and review of monitoring reports as part of a documented process. Information from monitoring reports and other experimental flow releases and related research can then be used as the basis for making informed flow management decisions. The assessment of the impact of climate change is a critical factor in this work. In addition, a technical advisory group is used to assist on particular environmental flow issues. Information and research findings can also be shared across water users and the community and can facilitate social learning. Adaptive management will be an important component of the ACT’s environmental watering requirements under the Basin Plan.

In the ACT, legislative instruments and planning documents determine environmental water management, as described in Section 1.4. A key document is the Water Use and Catchment General Code (2009), a code under the Territory Plan which is also a legislative instrument. The purpose of the code is to identify waters in the ACT in terms of the permitted water uses and environmental values, and to identify the water quality and stream flow criteria related to the full protection of these values and uses. For example, the code specifies approaches to protect stream flows in water supply catchments.

It should be noted that in the ACT there are specific links between the requirements set under the Guidelines and licence conditions set for water abstraction. Where a licence condition is to vary from the Guidelines then the change is facilitated by an adaptive management process of acquiring the necessary information to justify the variance.

2.3 Economic and social issues

The primary purpose of environmental flows is to maintain aquatic ecosystems; however, the social and economic consequences of the Guidelines are also taken into account through two approaches. First, the Guidelines recognise that there are different social and economic factors associated with the three types of water use catchments identified in the Territory Plan:

- Conservation
- Water supply
- Drainage and open space

The Territory Plan policies for these catchments identify different social and economic values and priorities for these catchments. The Guidelines take account of these priorities in setting environmental flow requirements. For example, in water supply catchments, the primary value is domestic water supply and, in recognition of this, a smaller margin for protection of aquatic ecosystems has been adopted to provide greater volumes of water for domestic supply. In conservation catchments the priority is on protection of natural resources and conservative environmental flow guidelines have been set with those values in mind.

These Guidelines recognise that the economic and social importance of water can vary over time, particularly during periods of drought. The Guidelines accommodate this factor by changes to the environmental flow requirements during times of drought, balanced against the continuing need to also protect aquatic ecosystems during such critical periods.

Provision of environmental flows and protection of aquatic ecosystems and threatened species is a requirement under both ACT and national legislation, and is an obligation under national agreements to which the ACT is a party. Given these fundamental obligations, the social and economic issues identified through public submissions received during the consultation process and workshops with relevant subject experts, have been taken into account in developing the Guidelines.

2.4 Water quality issues

Both water quality and water quantity characteristics have effects on ecosystems and, in some areas, are strongly interrelated. Although these Guidelines focus on water quantity and flow regimes, water quality issues factor in the discussions.

For example, water quality problems may arise when water is released from impoundments to meet downstream environmental flow requirements if water is released from the lower layers of deep, stratified reservoirs where the water can have a much lower temperature and oxygen content than surface waters. If this bottom water is released to meet environmental flow requirements, its quality may compromise its value for the maintenance of aquatic ecosystems. For example, many native fish species use water temperature, day length and flow as cues for reproduction; the temperature of water released to meet an environmental flow requirement may severely disrupt spawning, migrations and reproductive activity. In catchments where reservoir releases are made to meet environmental flow requirements, the water quality of the release is to match as closely as possible to that of the water flowing into the reservoir.

Water quality in the ACT is more fully defined and regulated by interrelationship between the Territory Plan Water Use and Catchment General Code (see the [Planning and Development Act 2007](#)) and the Environment Protection Act. Policies, objectives and values are defined in the catchment code and the concentrations of water quality parameters to support them are listed in the *Environment Protection Regulation 2005*. Where gaps are identified in relation to water quality than the National Water Quality framework is used.

As land use and management dominates many impacts on rivers, there can be a limit to what environmental flows can achieve by themselves. Hence, it is critical to continue to focus on water quality to support a healthy aquatic ecosystem.

2.5 Impoundment release structures

Most dams in the ACT were built before the importance of environmental flows was identified and may not be best suited to meet the operational requirements of the environmental flows specified in these Guidelines. In particular, this relates to the temperature and flow variations to mimic natural conditions. Ideally, the water released from a reservoir for environmental purposes should match as closely as possible the temperature of the water entering the reservoir or lake.

2.5.1 Water supply dams

The major water storage structures—Corin, Bendora, Cotter and Googong dams—all have the capacity to release water from a variety of depths and so inflow and release water temperature can be matched. In practice, the depth from which water is drawn for environmental flow releases is often determined by the quality requirements for water supply, which are not always the same as the temperature requirements to protect downstream aquatic ecosystems.

The current adaptive management process will continue to ensure that infrastructure will be managed to meet the Guidelines as closely as possible.

2.5.2 Urban lakes

The Guidelines do not require environmental flow releases from ACT urban lakes and ponds. These waterbodies only have the capacity to release water by overtopping or discharge through a valve at the base of the dam. Water in the bottom of these reservoirs is often of low quality and its release would potentially compromise downstream aquatic ecosystems. However, any reductions in streamflow downstream and caused by the urban dams tend to have been compensated by the increased run-off from the urbanised area. Consequently, the flows in urban streams downstream of impoundments in the ACT generally have been at or above the specified base flow (the 80th percentile flow), see Figure 7 (Dusting et al, 2017). The urban dams are sized relative to their catchment for purposes of attenuating storm peaks and improving water quality and are full for the most of the time. Medium flow events and large floods entering the lake pass through and on down the river. Flows downstream of the lakes are also augmented by increased flows from downstream urbanised tributaries.

2.5.3 Lake Burley Griffin

Similarly, Scrivener Dam on the Molonglo River, managed by the Commonwealth, currently does not have a multi-level off-take. Releases can only be made through a valve at the base of the dam or by opening the dam gates. Following the passage of the Commonwealth *Australian Capital Territory Water Management Legislation Amendment Act 2013* management of take of Commonwealth water resources (including Lake Burley Griffin) in the ACT has passed to the ACT Government. The National Capital Authority and the ACT Government will together formulate how to meet environmental flow obligations for the ACT and under the Basin Plan, both in Lake Burley Griffin and in the Molonglo River downstream, while ensuring Lake Burley Griffin fulfils its amenity functions for central Canberra. This includes consideration of reviewing operational flexibility to allow surface water releases and assist in meeting other ecological objectives.

2.6 Augmentation of stream flows

Streamflow in the ACT is augmented through various processes that include urban run-off, water transfers and return of treated wastewater to streams, which need to be managed to avoid detrimental changes to aquatic ecosystems.

2.6.1 Urbanisation

In urban areas, the increased stormwater run-off from roofs and roads can increase flow volume unnaturally and change flow variability, particularly in small streams. Urban run-off can also degrade streams if the water is of a poor quality. At the same time, it should be recognised that the community values some urban streams that now flow permanently in contrast to their prior ephemeral but natural condition.

2.6.2 Water transfers

Streams can be used to transfer water between water storages. ACT examples of this are the reach between Corin and Bendora Reservoirs on the Cotter River and a section of Burra Creek that will be used as a conduit for water abstracted from the Murrumbidgee River for storage in Googong Reservoir. Higher more constant flows than natural can alter ecosystem processes and change stream geomorphology.

2.6.3 Waste water discharges

Discharge of treated wastewater is the other process that significantly augments river flows. Through Icon Water, the ACT can divert up to 71GL a year for urban water supply. Of the amount diverted, around 60% is returned to streams as treated effluent. Downstream of the Queanbeyan and Lower Molonglo sewage treatment works on the Molonglo River there is a significant increase in base flows as a result of the return of treated effluent to the river. Augmented flows are not necessarily of benefit to the aquatic ecosystems because natural ecosystems are not adapted to the constant, high base flows that large sewage treatment plants can discharge. In addition, contaminants such as nutrients and salt in the discharged effluent from sewage treatment plants may compromise the value of the returned flows to rivers.

Where streamflow is unnaturally augmented either by stormwater run-off or by sewage treatment discharge, reuse is encouraged within limits, for example, within the sustainable abstraction limit for a sub-catchment, so that stream flows more closely approximate those prior to urbanisation. Streamflow augmented by water transfers should be managed in a manner to minimise adverse effects and maintain the values of the stream.

2.7 Climate change

The water resources of southern and eastern Australia are identified as one of our national resources most vulnerable to climate change (Bates 2010). The impacts of projected climate change in the coming decades are expected to alter the hydrology of ACT streams, which in turn may result in fundamental changes in the stream ecosystems regardless of whether they be in a 'pristine' state or modified by human intervention. 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, Morrongieelo and Balcombe, 2011; ACT Government 2016). Human needs may also change in combination with potential demographic and land-use changes, which may in turn alter the human impact on the ACT's natural water resources. In sum, these changes may affect the efficacy of the current environmental flow program and/or the adequacy of the current monitoring program.

The ACT's Biodiversity Adaptation Pathways Project report discusses environmental flows including deliberate release of cold water to manage climate change effects, 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'.

The work of Dyer et al. (2013) suggests that changes in temperature are likely to have far greater effect on aquatic biota (macroinvertebrates and native fish) than changes to flow regimes.

However, there remains uncertainty around the specific effects of climate change on a reach-to-reach scale in the ACT. The holistic approach adopted in the Guidelines (see Section 3) is 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 and ACT Climate Change Adaptation Strategy and provides a best practice approach to managing freshwater ecosystems in an uncertain and changing climate.

Climate change effects need to be considered for the ongoing monitoring of aquatic ecosystems. Many of the indicators chosen to reflect the achievement of ecological objectives (the performance variables) are based on comparing specific biological observations with the same biological parameters under conditions of zero human hydrological impact—often referred to as 'reference condition'. Reference condition can either be observed, by including control sites from pristine streams (e.g. natural ecosystems) in the monitoring program or modelled using best available information and may be useful for elucidating climate change impacts.

The AUSTRALIAN RIVER Assessment System (AUSRIVAS) using macroinvertebrates uses the reference condition concept to compare natural to human impacted river reaches, but would require consideration for climate change impacts.

Reference sites assessed by AUSRIVAS should be Band A with impacted sites usually being Bands B, C or D. It is reasonable to expect that climate change will affect both reference and impacted sites—possibly differentially—which may result in changes to the 'achievability' of ecological objectives and the measurement of progress towards achieving them. A significant response to climate change at reference sites may result in their having a biological condition outside of Band A. To identify such change, it would be essential to monitor a sub-set of reference sites used in building the AUSRIVAS predictive models. If a shift in the reference condition was observed management may:

- accept the altered condition of the 'reference' sites as the new reference condition and adjust the Ecological Objectives (indicator values) accordingly
- resample the reference sites and modify the predictive models to reflect the post-climate changed situation and retain the current indicator values.

The second option is probably preferable because it acknowledges the reality of climate change but uncouples the flow management response from the response to climate change. It is important to note that there is no need for any of these responses (or to choose a response) unless and until the reference sites score is consistently outside Band A. This is unlikely in the medium future under moderate climate change considering that:

- the sub-set of reference sites currently sampled have remained at or near Band A throughout the recent drought
- the main monitoring indicator (AUSRIVAS macroinvertebrates) operates at Family level which may mask subtle changes in the macroinvertebrate assemblage
- a change of around 9% of total stream flow is not likely to invoke a significant change in AUSRIVAS scores unless it is expressed in substantial changes to some specific aspect of flow (e.g. seasonal pattern, base flow, duration of particular events).

It would be sensible to continue the current AUSRIVAS program while paying particular attention to the performance of reference sites. To improve the sensitivity of this approach further reference sites might be added to the monitoring program.

If however, extreme climate change effects occur and ecosystems were to decline over time, as drought and other impacts overcome their resilience, and particularly if Natural Ecosystems decline (e.g. their macroinvertebrate communities consistently in 'sub-A' AUSRIVAS band), a more fundamental revision of the objectives within the Guidelines is called for. It may be necessary to review the type of aquatic ecosystems we are aiming to support/reinstate through environmental flow management as well as developing new arrangements that share the significantly depleted resource. This is an extreme response and need be considered only if the monitoring results show it is necessary.

The identification of climate change issue for fish performance indicators is another task for the next 5 years.

2.8 Groundwater

2.8.1 ACT aquifers

Aquifers in the ACT fall into two types: aquifers in fractured rock; and aquifers in alluvium. Both types are relatively shallow and groundwater eventually discharges into lower sections of the catchment's waterways. Both aquifer types can support unique groundwater ecosystems; however, at present the ecosystems in the ACT that are recognised as being groundwater dependant are small unregulated streams whose base flow is primarily supplied by localised groundwater discharge.

Aquifers in alluvium generally have a more direct and rapid connection with surface waters whereas with fractured rock aquifers the connection between surface and groundwater may be less direct.

2.8.2 Aquifers and base flow

In general, discharge from fractured rock aquifers will occur at the lower parts of the landscape, and the lower reaches of streams in a sub-catchment will be the ultimate destination for the groundwater flow. Virtually all water that infiltrates to the groundwater system exits into the streams. Existing work on aquifers in the ACT suggest they are relatively shallow, their boundaries are expected to largely match the topography of the

catchments that overlie them, and there is unlikely to be groundwater flow between catchments. Aquifers have low storage and so provide little buffering capacity against a sequence of years with low groundwater recharge. The extraction of groundwater in wet years will have an influence on base flow in succeeding dry years. Abstraction of groundwater from both types of aquifers will ultimately affect surface water flows in streams. Consequently, the importance of joint consideration of surface and groundwater for water management policies in the ACT is clear.

The proportion of flow in the stream contributed by groundwater (base flow), depends on the position in the catchment, and varies according to catchment characteristics. The base flow contribution to streams also varies throughout the year, with base flow contribution greater during winter and spring.

This is a consequence of reduced evapotranspiration in winter and spring and reduced summer recharge. During summer when soil crusts tend to be hydrophobic, higher rainfall intensities generate larger amounts of surface water run-off and less groundwater recharge. Additionally, in dry years stream flow will tend to be dominated by base flow.

In the urban environment the base flow is supplemented by drainage from garden watering and other activities.

As groundwater in both types of aquifers eventually discharges to streams, these Guidelines limit groundwater abstraction to ensure that there is no impact from groundwater abstractions on in-stream aquatic ecosystems.

If groundwater abstractions are too high, the base flow in streams will be significantly reduced. Although in-stream aquatic ecosystems are currently adapted to natural low flow and no flow periods, there is a high risk they will be negatively affected by 'extended' no flow periods. It is assumed that the groundwater abstraction limits would also protect other types of groundwater dependent ecosystems (such as wetlands, floodplains or aquifer and cave ecosystems).

All groundwater referred to in these guidelines is from shallow aquifers, as is all take. There is no known significant connection to the Lachlan Fold Belt aquifer which underlies the ACT as well as a large area of regional NSW.

2.9 Upstream influences

A limitation to the establishment and maintenance of environmental 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 in the upper Murrumbidgee River are limited, as specified in the Snowy Hydro licence.

At the Tantangara Dam wall, about 99% of inflows were previously diverted out of the Murrumbidgee River valley (Snowy Scientific Committee 2010), which was subsequently reduced to about 83% from 2011–12 onwards. Even though environmental flow releases occur, the volume of water flowing through the ACT is reduced from natural condition.

The current operational arrangement for Tantangara Dam might benefit from re-examination when the Basin Plan is reviewed.

The rules and limits on take for the Murrumbidgee River in the ACT ensure that the releases from Tantangara Dam that reach the ACT fully pass through the ACT. However, the reduced flows from upstream restrict the potential benefits from more natural environmental flows in the ACT reaches of the Murrumbidgee River. These Guidelines, by protecting releases from Tantangara Dam, are able to incorporate variation in released flows and to take advantage of any possible future increase in released volumes.

2.10 Types of ecosystems

There have been extensive changes to land use in some parts of the ACT resulting in substantial changes to stream flow and hence ecosystems. Restoration of natural aquatic ecosystems is generally not practical. In recognition of this situation, aquatic ecosystems have been categorised into four broad types, in order to clarify differences in management goals and techniques that can be used to arrive at these goals (Table 1). These ecosystems are based on the water use catchments identified in the Territory Plan.

Different environmental flow requirements have been set for each of the types of ecosystem referred to in Table 1; natural, water supply, modified and urban. These requirements are discussed in detail in Section 3. For the purpose of setting environmental flow requirements major rivers and streams are divided into reaches delineated by major confluences, lakes or reservoirs. This procedure assumes that a degree of homogeneity applies within reaches and acknowledges that there are links between reaches of a river.

Specific environmental flow requirements can then be determined for each reach. This procedure is applied to all river reaches.

Map 1 shows the Territory Plan catchment categories, as well as river reaches that are considered regulated and which have translucent flows (dam outflows which are effectively equal to inflows), from the major dams within the ACT and Googong Dam.

Map 1: Water use catchments

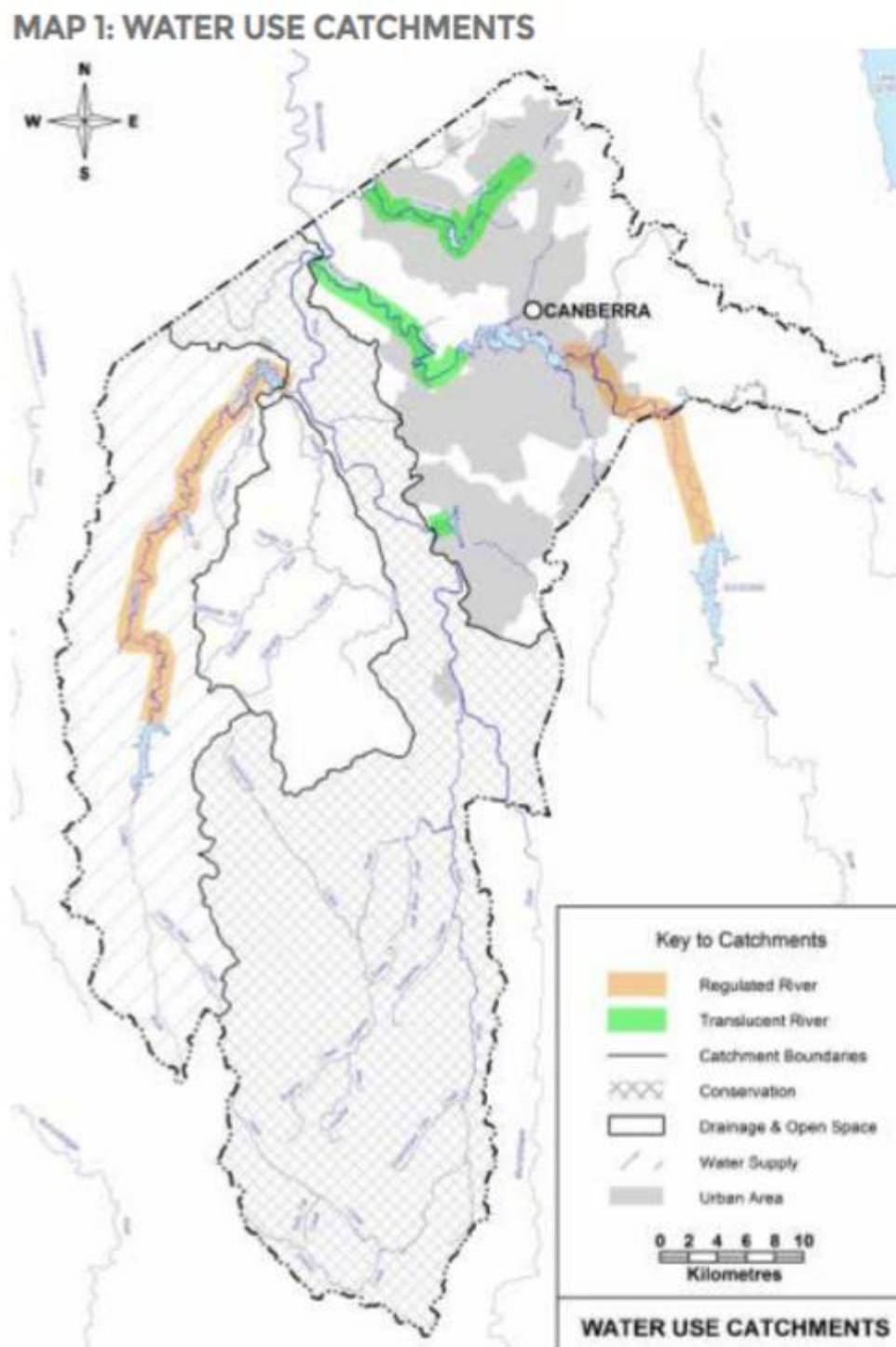


Table 1: Types of aquatic ecosystems and their location

Category of Aquatic Ecosystem ¹	Description	Management Goal	Waterways ² in this Category
Natural ecosystems (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.	Waterways in Namadgi National Park, excepting the Cotter River catchment. Waterbodies in Tidbinbilla Nature Reserve.
Water supply ecosystems (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 ecological values, protection of ecological values associated with the reservoirs, conservation and recreation	Waterways in the Cotter River catchment. The Googong Foreshore. ^{3,4}
Modified ecosystems (Conservation catchments, Drainage and Open Space catchments)	Majority of ecosystems modified by catchment activities (land use change, discharges) or by changes to the flow regime.	Primary goals: range of functions including protection of ecological values, recreation and conservation. Secondary goal: provide water supply.	All Waterways not included in the other three categories. Includes the Paddys, Murrumbidgee and Molonglo rivers, and Lake Burley Griffin. Naas and Gudgenby rivers downstream of Namadgi National Park
Urban ecosystems (Drainage and Open Space catchments and Urban Areas)	Ecosystems in urban lakes, ponds, wetlands and streams that have developed as a result of urbanisation	Range of functions including recreation, conservation, irrigation and stormwater runoff.	Waterways within the urban area, excluding the Molonglo River.

1 The terminology used to describe aquatic ecosystems, for environmental flow purposes, and are shown with the closest water use catchment category listed in the Territory Plan (parentheses).

2 Waterways include all streams, rivers, lakes, ponds, reservoirs, and aquifers.

3 The Queanbeyan River within the Googong Foreshore and the Googong Foreshore are not identified as water supply catchments in the Territory Plan, but are considered water supply ecosystems for the purposes of setting environmental flow guidelines.

4 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. Thus, they are regarded as Natural Ecosystems in Namadgi National Park, and Modified Ecosystems downstream of Namadgi National Park.

3 ENVIRONMENTAL FLOW APPROACH ADOPTED

A range of approaches has been used in Australia to establish environmental flow requirements. These include the holistic approach, the building block methodology, expert panel assessments and the habitat analysis model (reviewed by Arthington 1998). Different approaches have differing strengths and weaknesses, and information requirements. The holistic approach has a number of particular strengths:

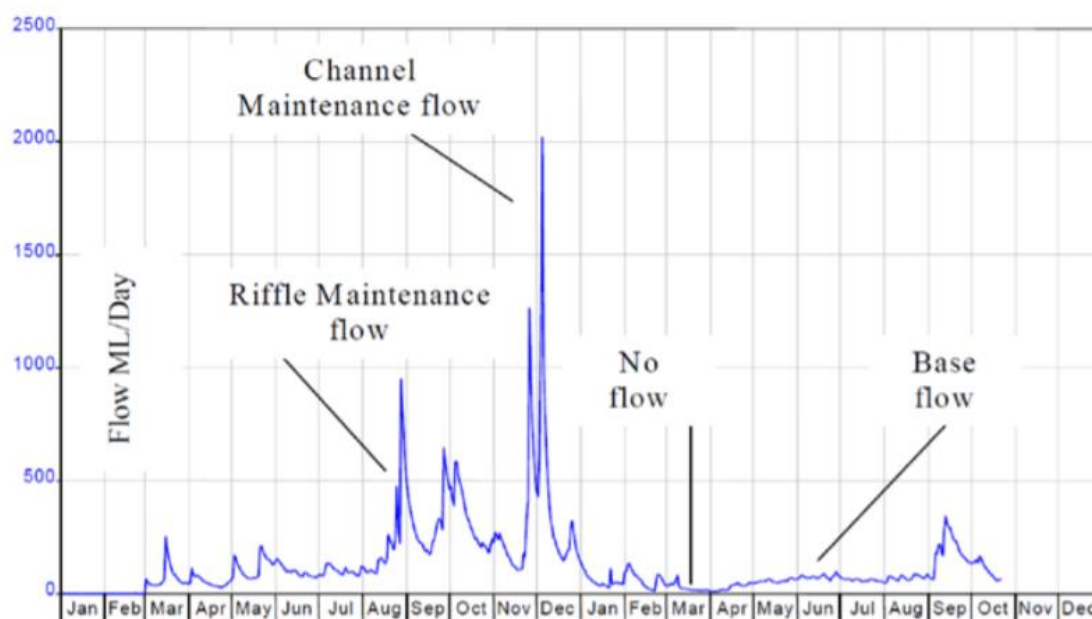
- It recognises the natural flow regime as a guide to the flow requirements of a system.
- It takes the approach that the flow requirements of a system should be compiled from different flow components meeting different ecological objectives, and that this can be done using field methods, expert advice and using historical data.
- The approach considers the entire aquatic ecosystem rather than a single selected component.
- It recognises that detailed ecological understanding is not available for many Australian rivers, and that an adaptive management process should be used to refine flow requirements.

Accordingly the holistic approach has been adopted for the setting of environmental flow guidelines in the ACT. This approach works by identifying the essential features of the flow regime, including the natural variability, seasonal variation, floods, and intermittent dry periods (See Figure 1). The influence of the flow components on the ecosystem components is identified, and when more information on flow requirements of particular ecosystem components becomes available e.g. fish spawning and specific flow volumes, it can be readily incorporated into the approach.

This approach is augmented by 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 approach is akin to elements of the building block methodology of establishing environmental flow requirements (King and Tharme 1994).

The combined approach of providing a general flow regime that is augmented by flows targeting specific valued ecosystem attributes ensures that PEAs and PEFs receive the environmental watering regime they require.

Figure 1: Snapshot of flow illustrating flow variability and flow elements to be considered in an environmental flow regime.



3.1 Techniques for calculation of flows

For the purpose of these Guidelines, the following methods shall be adopted as the basis for determining flows.

Flow statistics, including percentile flows, will be calculated using historical gauging data from stations with a suitable length of record. Modelling conducted during the 2017 review of the Guidelines indicated that the time period used to establish flow statistics has a considerable impact on calculated volumes.

In analysing appropriate time periods for flow volume calculations, considerations included that:

- 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
- the Basin Plan requires that the quantity and effectiveness of the PEW is at least maintained
- small changes in daily flow ($\pm 1-2$ ML/day) are unlikely to result in observable changes in the ecology of the system (Florance 2013, Dyer et al. 2013)
- there is an absence of evidence that would aid in selecting a time period.

From this, it was recommended that for most reaches records from a representative climate period that includes recent climate variability (eg. at least the most recent 30 years) be used to calculate flow volumes.

For the Murrumbidgee River in the ACT, flow statistics are calculated from gauged data taken subsequent to the construction of the Tantangara Dam in 1960. This is an interim approach and may be modified when significant environmental flow requirements in the Murrumbidgee upstream of the ACT are fully determined and implemented.

Where an abstraction point or sub-catchment boundary is not co-located with a gauging station, the flow at that point can be calculated from the gauged flow of the nearest appropriate station. A catchment area– run-off relationship is used to calculate flow:

$$\text{Flow}_{\text{req}} = \text{Flow}_{\text{gauge}} \times (\text{A}_{\text{req}}/\text{A}_{\text{gauge}})^{0.7}$$

Where Flow_{req} is flow at the required point, $\text{Flow}_{\text{gauge}}$ is flow at the gauging station, A_{req} is the catchment area upstream of the required point, and A_{gauge} is the catchment area upstream of the gauging station (ACT Government, 2004; and ActewAGL, 2011).

Rainfall run-off modelling (e.g. Alluvium, 2017a, b) can be used for sub-catchments without gauges if the modelling approach has been shown to calibrate accurately in those sub-catchments that have stream gauges.

In water supply sub-catchments in both the Cotter and Queanbeyan river systems an alternative approach, the water balance approach developed by Icon Water, has been used to determine flow at a point remote from a gauging station. This approach uses data on inflow, outflow, evaporation and abstraction from reservoirs to estimate what natural flow would have occurred in the absence of the reservoir.

3.2 Components of environmental flows

For ACT waterbodies there are particular components that may need to be built into the environmental flow regime for each river reach or lake. These components are:

- base flows;
- riffle maintenance flows;
- pool maintenance flows;
- channel maintenance flows;
- special purpose flows; and
- impoundment drawdown levels.

3.2.1 Base flows

Base flow describes the quantity of water that flows down a waterway in those periods between rainfall events. In the ACT much of the base flow originates from groundwater seepage into the stream. In the urban environment, the groundwater contribution is augmented by drainage from garden watering and car washing. Downstream of dam walls, stream flow may also be augmented by leakage from the dam. Downstream of sewerage treatment plants, base flows are significantly augmented by discharge of treated effluent.

Aquatic ecosystems in ACT rivers are assumed to be adapted to periods of low flow or no flow. Such conditions would have occurred before European settlement and still occur in pristine catchments. Ecological understanding indicates that natural low or no flow periods play an important role in maintaining ecosystems, permitting re-colonisation and succession. However, the stresses introduced by low flow periods should not be exacerbated by unnaturally long periods of low or no flow. Ecosystems are particularly sensitive to impact when stressed by low flows and further stress will result in harmful impacts. In addition, ecosystem recovery from low flow stress may be impeded by other catchment stressors such as land use change or point source pollution.

Low flows need to be maintained as close to natural low flow levels as possible, by the control of groundwater and surface water abstractions, and by environmental releases.

A critical decision in determination of environmental flow requirements, including base flows, is the time interval over which it is calculated. If a base flow requirement were based on total yearly flow, it would ignore the natural seasonal variability in river flow. ACT flows are naturally higher in winter. Calculation of flows using a smaller time interval (i.e. a week) would better reflect natural variability, but would be impractical for licensing purposes. As a pragmatic compromise, the base flow component of the environmental flow requirement is specified on a monthly basis, calculated using daily flow data.

Selection of a threshold that appropriately defines base flows has generated significant debate. In the 1999 Environmental Flow Guidelines the 80th percentile flow was accepted as the threshold of base flows based on approaches used in other jurisdictions. The 80th percentile flow is the volume that flows 80% of the time, that is, those commonly occurring (low) levels of flow.

This threshold was considered in the review of the 1999 Guidelines by the Cooperative Research Centre for Freshwater Ecology (CRCFE) (Ogden et al. 2004). The CRCFE concluded that protection of low flows, as defined by the 80th percentile flow, had demonstrated benefits for fish and macroinvertebrates in the water supply catchments, and this flow, together with other flow components, could maintain aquatic ecological values with moderate confidence. For operational purposes during this period, only 75% of the 80th percentile was released on a daily basis as the base flow during the initial part of each month, with the remaining volume released at the end of the month as a riffle and pool maintenance flow. This informal base flow regime maintained aquatic ecosystems in the Cotter River, and was the basis for changing the guideline base flow to 75% of the 80th percentile with the 2006 Guidelines.

The Hillman review of the 2006 Guidelines gave further support to the 80th percentile flow giving an appropriate base flow volume. During the drought various base flows, below the 80th percentile, were trialled in water supply ecosystems. The monitoring and assessment of those lower base flows indicated that the 80th percentile flow gives a low risk volume for sustaining ecological processes even though other flow volumes could be used for similar outcomes albeit with higher risk and requiring more intensive monitoring. Therefore for these Guidelines this measure will be retained for the protection of the base flow in non-water supply catchments.

Given the importance of groundwater discharge in maintaining base flows in streams, it is not possible to solely rely on controls of surface water abstraction to protect base flow requirements.

One of the mechanisms to protect base flow in rivers and streams is to limit abstractions of groundwater to 10% of the annual recharge. Studies have confirmed that limiting abstractions to 10% of the recharge is unlikely to affect the ecology of streams (Barlow et al. 2005), and causes very little change to the frequency of low flow events (Evans et al. 2005 and Rassam et al. 2010). Conversely, increasing abstraction to 20% of the annual recharge was estimated to result in unnaturally low flows 20% of the time (Evans et al. 2005) and is likely to have a negative effect on aquatic ecosystems (Barlow et al. 2005). Investigation of the ACT groundwater resources and their effect on stream flows will continue.

Base flow releases from controlled dams: where base flow is released from a dam with outlet controls, the base flow should not be held at a constant discharge for the month.

Research and assessment of various base flows volumes and release regimes in the Cotter River indicate that varying the discharge over a two week period can mitigate some of the effects caused by constant flows. In effect once the monthly volume has been determined, greater ecological benefits can be obtained with fortnightly variations in the rate of release of that monthly volume even though the total monthly volume remains the same

3.2.2 Flooding flows

Streamflow increases following storm events.

These increases in flow are important for the maintenance of aquatic ecosystems and channel structure. Flooding flows are of particular importance in streams downstream of water supply reservoirs. Water supply requirements can drastically change natural flow regimes, causing damage to downstream aquatic communities and changes to stream structure. The Snowy River downstream of Jindabyne Dam is an example of what can happen to a river flow if flooding flows are prevented from passing down a river. Without flooding flows that section of the Snowy River has degraded with pools filling with sand and the shape of the river being dramatically changed through growth of sand bars and the encroachment of riverine vegetation.

Three types of flooding flows have been identified for ACT rivers and streams:

riffle maintenance flows.

These are increases in flow necessary to keep riffles clear of fine surficial sediment

pool maintenance flows.

These are increases in flow necessary to keep pools clear of sediment.

channel maintenance flows.

These are increases in flow necessary for maintenance of the channel structure.

In water supply sub-catchments, specific releases can be made to meet flooding flow requirements.

The CRCFE recommended during the 2004 review that riffle and pool maintenance flows were required to sustain ecological values. In other ACT sub-catchments without reservoirs, there is not the opportunity to meet flooding flow requirements through specific releases. The approach taken has been to place a limit on abstraction of the volume of water passing down the river in higher flows to ensure that when high volume flows occur, rivers and streams will receive appropriate flooding flows.

In order to ensure naturally high flows are protected, abstraction will be restricted to a long-term average of 10% of the flow above the 80th percentile flow. In the previous guidelines, flooding flows were termed flushing flows and were defined as the flood events of 1.5 to 2.5 year annual recurrence interval. This requirement operates at the level of water planning and allocating water in the catchment, not at an instantaneous flow specification. In non-water supply catchments, an individual licensee does not have (in terms of infrastructure) the capacity to harvest flooding flows. However, there is a potential for all licensees to impact a flooding flow if their total combined volume was not restricted. This threshold was set using the best available scientific advice on the provision of habitat diversity and quality, nutrient and sediment cycling, movement of biota and connectivity between aquatic and terrestrial habitats. The knowledge gained by research on the effects of flushing flows of a range of volumes in the water supply areas indicates that the provision of such volumes of water is a low risk approach.

For these Guidelines this measure will be retained for the protection of the channel maintenance flow in non-water supply catchments. Guidelines for protection of flooding flows are in Section 5. The effectiveness of the guidelines for flooding flows will be assessed through monitoring of the flows.

3.2.3 Special purpose flows

Special purpose flows are volumes of water designed to meet specific ecosystem requirements, for example the inundation of a wetland or the drown-out of a fish migration barrier. The ecological requirements for special purpose flows in ACT rivers are not well understood, and no special purpose flows have been identified in these Guidelines. Further ecological research may lead to a need for special purpose flows for such purposes, for example, as maintaining spawning of native fish species in the Cotter River.

3.2.4 Impoundment drawdown levels for Urban lakes

Urban lakes are constructed water features, designed to protect downstream reaches from the effects of urban run-off. Macrophytes in urban lakes are recognised as an important ecological asset. Macrophyte stands are a significant component of aquatic habitat, and their destruction would affect dependent biota and associated ecosystem processes including sedimentation, nutrient cycling and water chemistry.

The water levels in lakes, ponds and reservoirs influence the survival and recruitment of submerged and emergent macrophytes. If the water level of urban lakes and ponds is lowered too far below spillway level for a significant period, macrophyte zonation may be significantly changed, compromising the ecological values of those waterbodies and their capacity to support other environmental functions.

However, waterbodies with a water level regime that fluctuates within a reasonable range at the right frequency and seasonality can support a diverse and resilient macrophyte community with beneficial zonation. Stable water levels can result in static and fragile macrophyte communities whilst dramatic water level variations can result in very limited or no macrophyte communities.

In the 2006 Guidelines a maximum drawdown limit of 0.20m was set for urban lakes to protect macrophytes as an important ecological component of such systems. A drawdown of this extent would expose approximately 2–3m of the lake shoreline and the macrophytes in this zone, which poses low risk to existing macrophytes. Recent research and investigations into drawdown levels in Canberra's urban ponds indicates that a higher drawdown level of up to 0.60m represents a low risk to macrophytes. The 2017 review extended the potential fluctuation of water level in urban ponds, lakes and wetlands to 0.60m where this aligns with seasonal variation.

There is already a significant demand for use of water from urban waterbodies for such purposes as irrigation of parklands and playing fields, and for irrigation of golf courses. If ponds are drawn down excessively and repeatedly, then the macrophytes may diminish or disappear over time resulting in declining water quality. More flexible drawdown limits than provided by these Guidelines can be applied to abstraction activities if they are accompanied by a specific monitoring and assessment program. In the absence of monitoring and assessment, having a precautionary limit of 0.60m on the drawdown level of lakes and ponds is considered to be an effective and efficient approach for the protection of urban lakes or ponds.

Thus, these Guidelines allow water level fluctuations of up to 0.60 m below full supply level while continuing to protect waterbird breeding habitat during breeding by limiting drawdown to 0.2m during July to November inclusively.

3.2.5 Temporary requirements

In any sub-catchment, there may be circumstances in which it is necessary to reduce the volume of environmental flows for a limited time. The types of incidents that could trigger the need for reduced flows could be:

- oil spill or other contamination within the catchment requiring the cessation of releases
- infrastructure failure, planned maintenance or upgrades requiring reduction in flow downstream of a dam
- landslides affecting water quality
- to meet competing environmental objectives, such as maintaining Cotter Reservoir at a level suitable for fish passage by drowning out barriers or
- other incidents.

Conversely there may be times when additional environmental flows are identified for ecological purposes. Environmental flow volumes and duration have been determined based on best available science or expert opinion. However, it is possible that, as further understanding is gained, a need for a particular short-term flow component is identified. Examples of increased flows for ecological purposes could include:

- additional riffle or pool maintenance flows following storm events
- drown out of fish migration barriers to facilitate access to spawning areas or
- other ecological requirements.

Flows required to meet both these sorts of requirements are termed temporary requirements. In order for these flows to be implemented, the Environment Protection Authority would need to be satisfied of the need for the change to flows. Temporary requirements are not intended to apply to drought situations, and it is envisaged that changes to flows would apply for a limited period until the incident or situation was resolved.

3.2.6 Water supply drought flows

A water supply drought is a concept describing an abnormally dry period resulting in not enough water for human needs. Urban communities experience a water supply drought when there is insufficient water available in reservoirs to allow normal domestic consumption. Aquatic ecosystems, under natural conditions, have adapted resistance and resilience to a full range of climatic conditions, including very dry periods. In regulated systems these dry periods can cause additional stress and it is important to minimise additional stress on these systems during such times.

Nevertheless, the Guidelines need to reflect the influence of flow requirements on provision of a domestic water supply during dry periods, and do so through three mechanisms. Firstly the Guidelines accommodate seasonal changes in flow by specifying different base flows for each month, calculated using historical data. This approach recognises that there are seasonal differences in river flow in the ACT; higher in winter and spring than in summer. Secondly, during non-drought periods in water supply catchments, the release requirement for base flows is never larger than the reservoir inflow.

Thirdly by recognising that during extended low flow periods, it may be necessary to reduce the environmental releases in water supply catchments in line with domestic measures to reduce water use, and so ensure the ongoing security of the water supply. Water supply drought environmental flows will apply as defined below.

A water supply drought is defined for the purpose of these Guidelines as occurring when the water supply utility initiates temporary water restrictions (DI2010-197). The water utility may introduce temporary restrictions in response to low reservoir levels, poor water quality in water supply reservoirs, adverse climate forecasts or other factors judged to be relevant. This approach recognises that the water utility may use a range of information to make a decision about restrictions. The Environment Protection Authority must be satisfied that the restrictions are necessary to ensure water supply security. During a period of a water supply drought, different environmental flow requirements termed water supply drought flows, will apply to ensure security of the ACT water supply (see Section 5). The implementation of permanent water conservation measures (DI2010-279) will not be considered to be water restrictions for the purposes of these Guidelines.

Water supply drought flows will be applied in two stages, reflecting the stages of water restrictions placed on domestic water consumption:

- Water supply drought flows under stage 1 restrictions
- Water supply drought flows under stage 2 or more severe restrictions

Water supply drought flows only apply to water supply catchments, and have different requirements for each reach within the catchment. Water supply drought flow guidelines are detailed in Section 5.

3.2.7 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.

The current flow rules implemented for the reaches downstream of Corin and Bendora dams recognise 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 variable 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.

4 ECOLOGICAL OBJECTIVES FOR ACT AQUATIC ECOSYSTEMS

The purpose of environmental flows is to protect river, stream, lake, and aquifer ecosystems. The setting of ecological objectives allows specific ecological values to be targeted by components of the environmental flow regime. In addition, quantified ecological objectives

can be used to assess the effectiveness of environmental flows, and the information can be used to develop an adaptive management approach for environmental flows.

Ecological values may be affected by factors other than environmental flow objectives for different reaches. The ecological objectives and indicators are listed in Table 3 are based on recommendations of the CRCFE (Ogden et al. 2004) and subsequent revision (Dusting et al. 2017). The objectives and indicators may be refined based on findings from a monitoring and assessment program (Section 6 Monitoring and Assessment). The scientific basis for recommendations and issues surrounding the objectives and indicators are provided as appendices to the Guidelines.

A number of ecological objectives do not have prescribed indicators or have estimated indicators. In the majority of cases this is due to one of three circumstances:

- Environmental flows cannot be actively managed for particular outcomes in the applicable waterbodies.
- There is limited capacity to manage water levels for ecological outcomes due to priority of water supply
- Baseline survey data does not exist for the objective, hence accurate indicators have not been developed.

Filling these knowledge gaps is a recommended research priority, discussed in Section 6 and detailed in Appendix 3.

5 ENVIRONMENTAL FLOWS FOR PARTICULAR ECOSYSTEMS

Environmental flows have been established for each of the ecosystem types and for specific reaches within the water supply catchments. The environmental flows are designed to maintain the ecological objectives determined in Section 4. Environmental flows for each ecosystem category and specific reaches within are summarised in Table 3 and discussed in detail in this section.

5.1 Water supply ecosystems

The primary use of waterbodies in water supply catchments is provision of a potable water supply. Although protection of aquatic ecosystems is a designated secondary goal in these areas, the primary function may require substantial drawdown of reservoirs and abstraction from streams. Nevertheless, as a consequence of the protected nature of the Cotter catchment, this system contains valuable aquatic ecosystems. For example, apart from the Murrumbidgee River, the Cotter River, along with the Goodradigbee River, has the highest number of threatened fish species of any river in the ACT or surrounding region. Reservoirs should be managed primarily for water supply, but complementary ecological benefits should be sought within the bounds of operational restrictions.

At present the Cotter River catchment from the boundaries of the headwaters to the Cotter Dam is the only catchment in this category in the ACT. While the Queanbeyan River is a water supply river for the ACT, regulation of its catchment area that is outside of the Googong Foreshore Area is under the control of NSW.

However, the ACT expects the NSW management of the catchment to be consistent with its water supply function as provided for by the Seat of Government Acceptance Act. For the

Googong Foreshore Area, and for releases from Googong Dam, environmental flow requirements for water supply ecosystems will apply.

In water supply catchments, environmental flows are not expected to mimic natural conditions; if this were the case, there would be a significant reduction in the available volume of potable water supply, which would pose a risk to the security of the domestic water supply. An alternative approach has been adopted; identifying ecological values that are expected to be maintained by environmental flows, and the associated flows required to achieve the ecological outcomes. Different types of reaches in water supply ecosystems are identified in order to specify appropriate flows. These reaches are listed in Table 4. Environmental flow requirements for these types of reaches are summarised in Table 3, and are also described below in Table 4.

5.1.1 Reaches upstream of all impoundments

Ecological objectives

To maintain healthy aquatic ecosystems in all natural ecosystems.

The reach upstream of Corin reservoir is unregulated and has a natural flow regime and high conservation value. Within this region there is to be no interruption to natural flows to achieve both conservation and water supply objectives.

For the Googong, Tinderry and Burra sub-catchments there should be no abstraction of inflows except that necessary for stock and domestic purposes and that are already provided for at the time these guidelines are listed. While the ACT has no statutory responsibility for management of the Googong Reservoir catchment to ensure compliance with the Seat of Government Acceptance Act, the ACT considers that any abstraction of natural flows should not be greater than that necessary to support best practice traditional grazing enterprises.

5.1.2 Reaches between impoundments used as a conduit for water supply between Corin and Bendora dams and between Bendora and Cotter dams

Ecological objectives

The ecological objectives for the reaches between Corin Dam and Bendora Reservoir and between Bendora Dam and Cotter Reservoir are:

- to maintain populations of Two-spined Blackfish (both reaches)
- to maintain riparian vegetation values
- to maintain healthy aquatic ecosystems (both reaches)
- to prevent degradation of riverine habitat through sediment deposition (both reaches)
- To maintain populations of Macquarie Perch (Bendora Dam to Cotter Reservoir).

The approach taken has been to base guidelines on the flow requirements that maintain these ecological objectives with a minimum safety standard.

Table 2: Water Supply Reaches

Reach Type	River	Reach
Reaches upstream of all impoundments	Cotter River	Upstream of Corin Reservoir
	Queanbeyan River	Upstream of Googong Reservoir
Reaches between impoundments used as a conduit for water supply	Cotter River	Between Corin Dam and Bendora Reservoir
	Cotter River	Between Bendora Dam and Cotter Reservoir
Reaches downstream of impoundments not used as a conduit for water supply	Queanbeyan River	Downstream of Googong Dam
Reaches downstream of impoundments used as a conduit for water supply	Cotter River	Downstream of Cotter Dam

5.1.3 Base flows

In all months in all years the defined base flow is to be protected. The base flow is defined as 75% of the 80th percentile of water flowing into the reservoir or the natural inflow, whichever is less. That is, flows entering the reservoir, up to and including 75% of the 80th percentile are to be released. This flow rate does not easily translate to a fixed percentile; depending on the reach and the month this equates to a flow rate between the 85th and 90th percentile.

The base flow volume required was determined from experience with environmental releases in the Cotter River. Where base flow is released from a dam with outlet controls the base flow should not be held at a constant discharge for the month. Research and assessment of various base flow volumes and release regimes in the Cotter River indicate that varying the discharge over a two week period can mitigate some of the effects caused by low constant flows, by assisting fish migration and connectivity. In effect once the monthly volume has been determined, greater ecological benefits can be obtained with fortnightly variations in the rate of release of that monthly volume even though the total monthly volume remains the same.

Weekly variation in flows should be reduced (from 50% to 25%) during Macquarie Perch breeding season (October–December inclusive, Bendora Dam to Cotter Reservoir). Reduction in the variation during this period is aimed at reducing the likelihood of egg stranding or egg displacement and assisting fish migration past low flow barriers.

5.1.4 Riffle maintenance flow

In the water supply catchments, riffle maintenance flows are not designed to mimic the pattern of natural flows; they are specified to achieve ecological outcomes. As such, regular riffle maintenance flows are designed to flush sediment from riffles to achieve the outcome normally provided by the irregular flushing flows that would occur naturally. A riffle

maintenance flow of 150 ML/Day for three consecutive days is to occur every two months. Riffle maintenance flows can be met by a sufficient volume of water flowing over the dam spillway, a release through the dam valves or a combination of these sources. Each time a riffle maintenance flow occurs, either by spill or by release, the next flush is required within the next two months +/- 1 week.

The riffle maintenance flow has been determined from the monitoring of riffle condition in the Cotter River before and after a series of experimental riffle maintenance flows. The effect of the riffle maintenance flows on the identified ecological objectives and indicators will continue to be monitored and assessed.

It is recognised that on occasions there may be significant volumes of water flowing over the dam spillway. If such a flow occurs of a volume and duration equal to the required riffle maintenance flow, it will be considered to be a riffle maintenance flow and the next riffle maintenance flow will not be required for two months +/- 1 week.

Downstream of both Bendora and Corin Dams, the riffle maintenance flow is to be measured at the gauging station downstream of the dam wall. If additional gauging stations are installed in the reaches downstream of either dam, or additional information provided, the point at which the riffle maintenance flow is measured may be changed if it can be demonstrated that any changes still ensure that the riffle maintenance function of the flows is being achieved.

5.1.5 Pool maintenance flow

A pool maintenance flow of >550 ML/day for two consecutive days is to be provided between mid-July and mid-October. Three sources of water may comprise a pool maintenance flow; tributary inflows, water flowing over the dam spillway or releases from the dam.

It is recognised that there may not be the infrastructure capacity to safely release the full pool maintenance flow and that the flow may need to be implemented by making a dam release in conjunction with a tributary inflows or dam overtopping.

If the pool maintenance flow is met solely by tributary inflows, then this flow will not be considered a riffle maintenance flow as experience has shown that during the falling leg of an event of this size, significant sediment can be deposited in riffle areas.

If the pool maintenance flow has been augmented by water flowing over the dam spillway or releases from the dam, then this flow will also be considered to be a riffle maintenance flow.

Downstream of Bendora Dam, the pool maintenance flow is to be measured at Vanities Crossing gauging station, and downstream of Corin dam, the flow is to be measured at the gauging station downstream of the dam wall. If additional gauging stations are installed in the reaches downstream of either dam, the point at which the pool maintenance flow is measured may be changed if it can be demonstrated that any changes still ensure that the pool maintenance function of the flows is being achieved.

5.1.6 Drought flows - stage 1 restrictions

During a defined water supply drought the following flow requirements apply for the reaches between Corin Dam and Bendora Reservoir, and between Bendora Dam and Cotter Reservoir.

Under stage 1 restrictions the domestic water supply is under threat and a reduction in environmental flow requirements is appropriate to protect supply security while still protecting ecosystem values.

The base flow requirement is an average of 40 ML/day, or 75% of the 80th percentile, or natural inflow, whichever is the lesser volume. It is anticipated that licensing requirements will ensure a scheme of variable low flow releases around the average of the daily base flow.

Riffle maintenance and pool maintenance flows remain the same as for non-drought periods.

5.1.7 Drought flows - stage 2 or more severe restrictions

Under stage 2 or more severe restrictions the domestic water supply is under significant threat and a significant reduction in environmental flow requirements is appropriate to protect supply security. This reduced flow regime poses an increased risk of degradation to the aquatic ecosystem; the river would be expected to recover from a short-term reduction in flow of this magnitude, but a long-term reduction would result in degradation.

The base flow requirement is an average 20ML/day. The licensing requirements will ensure a scheme of variable low flow releases around the average of the daily base flow.

Riffle maintenance and pool maintenance flows remain the same as for non-drought periods.

5.1.8 Reaches downstream of impoundments: Downstream of Cotter Dam Downstream of Googong Dam

Ecological objectives

The ecological objectives for the reaches downstream of impoundments are:

- to maintain riparian vegetation values downstream of Cotter Dam
- to maintain healthy aquatic ecosystems downstream of Cotter Dam
- to maintain healthy aquatic ecosystems downstream of Googong Dam

5.1.9 Base flows downstream of Cotter Dam

Downstream of Googong Dam from October to June is 10ML/day and from July to September is 15ML/day or natural inflow whichever is the lesser. The base flow specification incorporate flows variability and seasonal patterns into base flow which will assist riparian communities downstream of Googong Reservoir.

The base flows downstream of most downstream impoundments in the water supply catchments are specified as minimum channel wetting volumes in recognition that these reservoirs are the final capture point for domestic supply. A channel wetting volume is the flow that covers a reasonable proportion of a specified riffle, allowing adequate habitat for periphyton, macroinvertebrates, and fish to be wetted at all times. Channel wetting flows were established by an 'expert panel' approach and have been validated by specific research and monitoring on base flow volumes in each reach.

Compliance is also required by Icon Water for the Enlarged Cotter Dam (ECD) environmental requirements as specified in the conditions of the Public Environment Report from the Commonwealth Government and the Development Application from the ACT Government, following the ECD Environmental Impact Assessment process. 34ML/day environmental flow (12 month rolling average) is the Commonwealth requirement. As identified by EFTAG, flow

variability and seasonal patterns can be provided by Icon Water in the base flows required by the Commonwealth.

Fulton et al (2010) showed instream and riparian vegetation was important for crayfish in the lower Cotter.

As there are works to improve the riparian condition of the downstream of Googong reach and to minimise land use impacts in the catchment, there is considered a significant opportunity for improvement by investigating increases in environmental flows in this reach, to try to improve the river health. To this end Appendix 3 recommends increasing environmental releases up to 75% of the 80th percentile flow, plus riffle maintenance flows to 25% of the 80th percentile flow. These flows should be trialled over the next five years. This would increase environmental flows from Googong Dam by about 4GL per annum.

5.1.10 Riffle maintenance flow

In the water supply catchments riffle maintenance flows are not designed to mimic natural flows, rather they are managed for specific ecological outcomes. As such, regular riffle maintenance flows are required instead of irregular flows as would occur naturally.

A riffle maintenance flow of 100ML/day for one day is to occur every two months. Each time a riffle maintenance flow occurs either by spill, or by release, the next flush must occur two months +/- 1 week after the last riffle maintenance flow.

5.1.11 Pool maintenance flow

No pool maintenance flows are specified for reaches downstream of final impoundments. Following the completion of the Enlarged Cotter Dam, if further monitoring and assessment determine the need for pool maintenance flows, they can be provided as a temporary requirement until the next review of the environmental flow guidelines.

Drought flows – all levels of restriction

During a defined drought the following flow requirements apply downstream of Cotter Dam and Googong Dam, for all levels of water restrictions. The base flow downstream of Cotter Dam will be 15ML/day. The base flow downstream of Googong will be 10ML/day or natural inflow whichever is less.

Riffle or pool maintenance flows for these reaches are not required during drought. If further monitoring and assessment determine the need for riffle or pool maintenance flows, they can be provided as a temporary requirement.

5.1.12 Requirements applying to all water supply ecosystems

Impoundment drawdown levels

Guidelines have been established to control the Guidelines have been established to control the drawdown of the Cotter Reservoir to protect habitat for Macquarie Perch. Between the late 1960s and 2004 the Cotter Reservoir was not an active part of the ACT water supply, and so drawdown was not an issue. The only successfully breeding ACT population of the endangered Macquarie Perch lives principally in the Cotter Reservoir and the Cotter River upstream of the reservoir. The Cotter Reservoir population was reliant on the emergent macrophytes and boulder piles around the margins of the reservoir as its main shelter habitat. The construction of the enlarged Cotter Dam changed the nature and extent of potential habitat for the Macquarie Perch and large amounts of artificial habitat were placed in the new reservoir to accommodate this change. The reservoir is operated in such a

manner that fish habitat is available and connectivity with the Cotter River is provided during fish spawning periods. Drawdown limits are not set for other water supply reservoirs, though drawdown may impact on the breeding of threatened fish in these reservoirs.

Water quality

Reservoir releases to meet environmental flow requirements should be of a water quality similar to that of natural inflows as far as possible. Of particular concern are water temperature and dissolved oxygen. Water from the lower layers of deep, stratified reservoirs can have a much lower temperature and oxygen content than surface waters. If this bottom water is released to meet environmental flow requirements, water quality may compromise the value of the release for the maintenance of aquatic ecosystems. For example most native fish species use both water temperature and flow as cues for reproduction, and a cold-water release may severely disrupt spawning migrations and reproductive activity.

Another issue that has arisen is the release of turbid water from ACT reservoirs. Normally reservoirs act to trap sediment and releases have lower sediment levels than inflows. In some situations a layer of highly turbid water has persisted in ACT reservoirs with the potential to compromise the quality of the entire reservoir when bottom waters mixed with surface layers during winter. It may be desirable from a water supply perspective to release this turbid water. Such releases need to be managed to protect downstream ecological values. Water with high turbidity can reduce the abundance and diversity of macroinvertebrates. To minimise the potential impact of turbid releases, clean water releases may be required before and after a turbid release to protect aquatic ecosystems downstream.

Water quality issues can also arise when flows remain at a steady low volume. For example, constant low flows cause periphyton to accumulate in thick layers, trapping sediment and organic matter that can degrade water quality by lowering dissolved oxygen levels and changing pH levels (Stevenson 1996). To minimise this effect base flow releases should be varied by as much as 50% around the recommended volume, noting the restrictions on this around the Macquarie Perch breeding season.

Implementation of environmental flows

Environmental flows downstream of impoundments are implemented through a combination of releases and water flowing over the dam spillway. In the case of pool maintenance flows, these are supplemented by tributary inflows. Water released to achieve environmental flow requirements should be at a temperature approximating as closely as possible that of inflow water. If inflow water temperature is unknown, it should be assumed to be the same as surface water in the reservoir. Where the flow requirement is based on a flow percentile, percentiles should be calculated on a monthly basis but the volume so determined should be released in a manner to include short-term variability.

5.2 Natural ecosystems

Waterbodies in the natural ecosystem category include those within Namadgi National Park, excepting the Cotter River Catchment, and those within Tidbinbilla Nature Reserve. These are ecosystems that have persisted in a relatively natural state from a period prior to European settlement. The primary management goal for these ecosystems is the conservation of their natural state, and these ecosystems are secondarily managed for recreation and other purposes.

Ecological objective

- To maintain healthy aquatic ecosystems in all natural ecosystems.
- To prevent degradation of riverine habitat through sediment deposit.
- To maintain high biodiversity values.
- To maintain riparian zone and in-stream macrophytes.

5.2.1 Base flows

In all months in all years the base flow is to be protected. The base flow is defined as the 80th percentile of flows. Abstraction of groundwater is limited to 10% of the recharge rate to protect base flow.

5.2.2 Flooding flows

Flooding flows, particularly channel maintenance flows, are to be protected by restricting abstraction in water management areas to 10% of the flow 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.

Specific conditions that can be placed on licenced abstracters in relation to infrastructure limitations will also ensure that flooding flows of this magnitude are protected.

5.2.3 Impoundment drawdown levels

No abstraction is permitted from natural lakes and ponds.

Implementation

Environmental flows are to be maintained through restrictions on abstractions as detailed above.

5.2.4 Water quality

Water quality issues can arise when flows remain at a steady low volume. For example, constant low flows cause periphyton to accumulate in thick layers, trapping sediment and organic matter that can degrade water quality by lowering dissolved oxygen levels and changing pH levels (Stevenson 1996). To minimise this impact, abstractions should allow natural flow variability to be maintained.

5.3 Modified ecosystems

Rivers, lakes and streams in the modified ecosystem category include those waterbodies outside Namadgi National Park, Tidbinbilla Nature Reserve and the Canberra urban area. Lake Burley Griffin and the Molonglo River are also considered modified ecosystems. These ecosystems have been modified by catchment activities including landscape change, and modifications to the natural flow regime.

In modified ecosystems, 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
- other ACT reaches including the Molonglo, Paddys, Naas and Gudgenby downstream of Namadgi National Park (unless designated as water supply catchments under the Territory Plan)

- reaches in NSW over which the Commonwealth has paramount rights to the water other than those in the Queanbeyan River catchment.

Ecological objective

- To maintain healthy aquatic ecosystems.

5.3.1 Murrumbidgee River environmental flows

The NSW water sharing plan for the unregulated Murrumbidgee (NOW, 2012), specifies the current environmental flow rules implemented in the NSW section of the Murrumbidgee upstream of the ACT. In addition, some environmental releases are made from Tantangara Dam as required by the Snowy Hydro Licence, which are in accord with the Snowy Water Inquiry Outcomes Implementation Deed 2002. Environmental flow releases from Tantangara Dam may not be extracted through the ACT. This is a requirement under the Basin Plan to protect from take, Held Environmental Water (HEW) and Planned Environmental Water (PEW). The ACT ensures that environmental flow requirements in the rivers for which it has responsibility are met by flows under the control of the ACT. In consequence, environmental flows from NSW upstream, including releases from Tantangara Dam, pass through the ACT unaffected by activity in the ACT as they are effectively protected from extraction through the ACT by existing environmental flow requirements and limits on take. Similarly as required by the Basin Plan, it is expected that environmental flows from the ACT will be protected from take in NSW downstream to Burrinjuck, through the NSW water resource plan for the Murrumbidgee.

Ecological objective

- To maintain healthy aquatic ecosystems in terms of biota.
- To prevent degradation of riverine habitat through sediment deposition.
- To maintain extent of water dependent riparian and in-channel native vegetation.
- To enhance native fish community, including Murray Cod and Murray River Crayfish.
- To maintain diversity and increase abundance of waterbirds.

5.3.2 Base flows

In all months in all years the base flow is to be protected. The base flow is defined as the 80th percentile of stream flow in the months November to May inclusive, and the 90th percentile of stream flow in the months June to October inclusive. In addition, once base flows drop to 50ML/d during January to March additional monitoring is required. See Dyer et al (2014) below.

These flows also ensure the Murrumbidgee to Googong (M2G) environmental requirements are met as specified in the conditions of the Public Environment Report from the Commonwealth Government and the Development Application from the ACT Government, following the M2G Environmental Impact Assessment process. The Icon Water Stream flow and water quality management plan, outlines how the Commonwealth and ACT conditions are met. The 2018 plan identifies base flow protection rules under drought conditions, as well as riffle maintenance flow rules, which are more comprehensive than previous ACT environmental flow guidelines for this reach and are to be used for drought conditions.

Base flows requirements in the Murrumbidgee recognise that the Murrumbidgee has become an important source of water for contingency domestic water supply, and will become an ongoing source of domestic supply. That is through Icon Water being able to take

up to 100ML/d (the capacity of the M2G system) from flows greater than the base flows. Within this large river, lower base flows can be accepted in the wetter months of the year without significantly compromising the processes supporting aquatic ecosystems. In the winter months the absolute volumes are greater and consequently a 90th percentile flow will still ensure that key riffle habitat is inundated and connectivity is provided. The information supporting this approach for a differing percentile for summer/winter flows in certain systems is from research and experience in Victoria (Department for Natural Resources and Environment 2002).

Dyer et al (2014) showed that the combination of low flow and high temperatures may result in adverse water quality conditions for fish in refuge pools and that small freshes can provide short term improvements in water quality. During January to March, when flows are at or below the protected flows for more than 2 weeks, pool water quality should be monitored to inform adaptive flow management. Further monitoring and research is needed to confirm the benefit of protecting base flows up to 50ML/d during those months.

When flows in the Murrumbidgee reduce to 50ML or less, then monitoring used in an adaptive management process will be initiated, if abstraction is to be permitted to continue. Abstraction of groundwater is also limited to 10% of the recharge rate to protect base flow.

5.3.3 Flooding flows

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. 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.

Specific conditions can be placed on licenced abstracters in relation to infrastructure limitations to ensure that flooding flows of this magnitude are protected.

5.4 Other reaches in the ACT

This group includes the Naas and Gudgenby Rivers downstream of Namadgi National Park, and the Molonglo River

Ecological Objective

- To maintain healthy aquatic ecosystems in terms of biota.
- To prevent degradation of riverine habitat through sediment deposition.
- To maintain and improve functional assemblages of macrophytes in modified lakes, ponds and wetlands.
- To maintain and improve riparian vegetation in Molonglo R. downstream of Lake Burley Griffin.
- To maintain and improve populations of platypus and other vertebrate fauna in Molonglo R. downstream of Lake Burley Griffin.
- Enhance native fish community (including BWS key species) in Molonglo R. upstream and downstream of Lake Burley Griffin.

5.4.1 Base flows

In all months in all years the defined base flow is to be protected. The base flow is defined as the 80th percentile of stream flow unless another base flow regime is identified through

specific assessment. 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 base flow.

5.4.2 Flooding flows

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.

Specific conditions that can be placed on licenced abstracters in relation to infrastructure limitations will also ensure that flooding flows of this magnitude are protected.

5.4.3 NSW reaches with paramount rights for the ACT

This group of reaches includes waters in NSW, over which the Commonwealth has paramount rights to water for all the purposes of the Territory as a result of the Commonwealth Seat of Government Acceptance Act. It includes the Queanbeyan River and its tributaries upstream of Googong Dam, and the Molonglo River and its tributaries in NSW including Jerrabomberra Creek. Waters from the Queanbeyan River and tributaries entering the Googong Dam area have been specifically developed for urban water supply purposes by the Googong Dam and associated infrastructure. Waters from the remaining NSW reaches in this category are important for existing or future Territory purposes (as previously identified). The determination and maintenance of flow requirements in these waters to protect environmental values is the responsibility of NSW which has yet to specifically address this issue in these waters. However, to ensure protection of the Commonwealth rights to water under the Seat of Government Acceptance Act for all the purposes of the Territory, it is expected that water use be limited to that necessary to support stock and domestic purposes for traditional grazing enterprises and associated long established rural villages (or equivalent use). This is expected to ensure that adequate environmental flows into the ACT are maintained.

5.4.4 Requirements applying to all modified ecosystems

Impoundment drawdown levels

Ponds and lakes sustain aquatic ecosystems within the waterbody, and protect downstream waters by removing pollutants. An integral component of pond ecosystems is the zone of macrophytes around the margin. Macrophytes provide habitat, stabilise and protect margins from wave action and assist with removal of pollutants. Macrophytes and their associated ecosystem components can be affected if a pond is drawn down too far or for too long, compromising the ecological function of the pond. For this reason drawdown limits are set for urban lakes and ponds.

For urban lakes and ponds that were constructed before the year 2000 the nominal 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. This drawdown limit had been established on the basis that those existing lakes and ponds had been designed to fulfil their ecological functions at operating at close to full supply level. 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. Exceeding this level may increase the risk of fish kills.

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 allow water level fluctuations of up to 0.60 m below full supply level to be consistent with natural seasonal patterns, while continuing to protect water bird breeding habitat from drawdown during breeding season.

Implementation

Control of abstraction is seen as the appropriate mechanism for achieving environmental flows for these types of ecosystems. Total abstractions are limited to the volume determined by these Guidelines, and detailed in the Water Resource Plan. During low flow periods licensees would not be permitted to withdraw their entitlement except for stock and domestic purposes (as provided by the Water Resources Act). Conversely, during normal or high flow periods abstraction of stormwater can play a significant role in improving the ecological values of modified ecosystems, as detailed in Section 2.5.

The Guidelines do not require releases from lakes and ponds in modified ecosystems to maintain environmental flows in downstream waters.

The environmental flow requirements of the streams downstream of impoundments are met through a combination of dam maintenance releases and water passing over the spillway. Although these waterbodies are commonly used for irrigation, this loss of water is compensated by the augmented run-off coming from urban catchments.

Urban impoundments generally only have the capacity to release water by overtopping, or by discharge through a valve at the base of the dam. Water in the bottom of these reservoirs can be of a lower quality such that release of this water would potentially compromise downstream aquatic ecosystems. It is recommended that new dams be fitted with release structures that allow water released from the dam to be at temperatures that reflect natural inflow temperature.

However, it is recognised that this would be a major expense and realistically only undertaken in conjunction with other major dam works. This also applies to Scrivener Dam.

The lake and pond water level requirement will be met principally by controls on abstraction. Abstraction from lakes and ponds will be permitted only if the water level was above the drawdown specified in these Guidelines or in a watering plan developed for the specific waterbody.

In 2013 management of issuing water access entitlements and Licences to take water for Commonwealth water resources (including Lake Burley Griffin) in the ACT is under ACT Government management. The National Capital Authority has a Lake Burley Griffin Water Quality Management Plan (2011).

5.5 Urban ecosystems

All streams, lakes and ponds within the urban area excluding the Molonglo River fall into this category. There have been considerable changes to urban waterbodies as a result of urbanisation. Prior to European settlement, streams in the now urbanised part of the ACT, with the exception of the Molonglo River, flowed only intermittently. Streams took the form of 'chains of ponds' where the stream was a set of ponds joined by a poorly defined

streambed. Initially through land clearing, and more recently through the presence of impervious surfaces in urban areas, the urban streams now receive flows that exceed natural flows. Additionally, urban stormwater can contain large quantities of sediment, nutrients and pollutants.

In recent years, there has been significant community support for restoring urban streams to a more natural condition. Introduction of water sensitive urban design in Canberra has led to installation of features such as ponds, rain gardens, pervious pavements, bioswales and stormwater drains as more natural waterways and on-site detention of stormwater.

These Guidelines recommend that flows in urban streams be restored to natural flow regimes as far as practicable, while recognising that it is unlikely that streams will return to the pre-development 'chain of ponds' condition. It should be noted that creeks in this category were ephemeral prior to their catchment's urbanisation, hence assessment in comparison to perennial creeks may not be appropriate.

Ecological objectives

- To maintain a range of healthy aquatic ecosystems (all waterbodies).
- To prevent degradation of downstream aquatic ecosystems through sediment deposition and high flow rates (urban streams).
- To maintain healthy aquatic ecosystems in terms of biota.
- To maintain functional assemblages of macrophytes in urban lakes, ponds and wetlands.
- To protect waterbird breeding habitat from drawdown during breeding season.
- To maintain populations of fish in urban impoundments where stocking occurs.

5.5.1 Base flows

In all months in all years the base flow is to be protected. The base flow is defined as the modelled natural 80th percentile of stream flow. In addition abstractions of surface water may never cause cessation of flow in a stream.

5.5.2 Flooding flows

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.

Specific conditions that can be placed on licensed abstracters in relation to infrastructure limitations will also ensure that flooding flows of this magnitude are protected.

Impoundment drawdown levels

To be consistent with 5.3.4

Implementation

To be consistent with 5.3.4

Table 3 Summary of ecological objectives, indicators and flow requirements for ecosystems and reaches

Ecosystem and reach	Objective	Indicators	Flow requirements		
			Permanent water conservation measures	Drought stage 1 restrictions	Drought stage 2 restrictions
Water Supply Ecosystems					
Reach upstream of Corin	To maintain healthy aquatic ecosystems	Macroinvertebrate assemblages are maintained at AUSRIVAS band A level	Maintain natural flows		
Corin Reservoir	To maintain healthy aquatic ecosystems To maintain populations of Two-spined Blackfish				
Corin Dam to Bendora Reservoir	To maintain populations of Two-spined Blackfish To maintain healthy aquatic ecosystems To prevent degradation of riverine habitat through sediment deposition	Young of the year and year 1+ age classes (<120 mm total length) comprise >30% of the monitoring catch; AND total catch +is >2 blackfish for 60% of samples (30 m sections) in each reach - across 2 years	Base flow - Maintain 75% of the 80th percentile of the monthly natural inflow, or inflow,	Base flow - Maintain a flow of 40 ML/day or 75% of the 80th percentile of the monthly	Base flow - Maintain an average flow of 20 ML /day or inflow, whichever is lower. RMF - Maintain a flow of 150 ML/day for 3consecutive days every 2 months PMF - Maintain a flow of >550 ML/day for 2 consecutive days between mid-July and mid-October

Ecosystem and reach	Objective	Indicators	Flow requirements		
			Permanent water conservation measures	Drought stage 1 restrictions	Drought stage 2 restrictions
		<p>Macroinvertebrate assemblages are maintained at AUSRIVAS band A level , Non-dominance (<20% cover) of filamentous algae in riffles, Temperature, turbidity and DO mimic natural inflows, Instream macrophyte cover <20%4</p> <p>Sediment deposition is limited to <20% of total depth of pools measured at base flow using techniques as per Ecowise Environmental (2005). Five yearly monitoring and reporting recommended for all sediment monitoring.</p>	<p>whichever is less.</p> <p>RMF - Maintain a flow of 150 ML/Day for 3 consecutive days every 2 months</p> <p>PMF - Maintain a flow of >550 ML/day for 2 consecutive days between mid-July and mid- October</p>	<p>natural inflow, or natural inflow whichever is lesser volume</p> <p>RMF - Maintain a flow of 150 ML/day for 3 consecutive days every 2 months</p> <p>PMF- Maintain a flow of >550 ML/day for 2 consecutive days between mid-July and mid- October</p>	

Ecosystem and reach	Objective	Indicators	Flow requirements		
			Permanent water conservation measures	Drought stage 1 restrictions	Drought stage 2 restrictions
Bendora Reservoir	<p>To maintain populations of Two-spined Blackfish</p> <p>To maintain healthy aquatic ecosystems</p> <p>To maintain populations of Trout Cod</p>	Minimum 2 post-juvenile Two-spined Blackfish per fyke net night per year. Note: Drawdown could be carefully managed around mid-November, as Blackfish eggs and larvae are tied to spawning site for about 6 weeks.			
Bendora Dam to Cotter Reservoir	To maintain populations of Two-spined Blackfish	Young of the year and year 1+ age classes (<120 mm total length) comprise >30% of the monitoring catch; AND total catch +is >2 blackfish for 60% of samples (30 m sections) in each reach - across 2 years	Maintain 75% of the 80th percentile of the monthly natural inflow, or inflow, whichever is less.	Maintain a flow of 40 ML/day or 75% of the 80th percentile of the monthly natural inflow, or natural inflow	<p>Maintain an average flow of 20 ML /day or inflow, whichever is lower.</p> <p>RMF - Maintain a flow of 150 ML/day for 3 consecutive days every 2 months</p> <p>PMF- Maintain a flow of >550 ML/day for 2 consecutive days between mid-July and mid-October</p>
	To maintain populations of Macquarie Perch	Recruitment detected at 80% of monitoring sites. Minimum capture of 1 Macquarie Perch (< 150 mm) per net night per	Weekly variation in		

Ecosystem and reach	Objective	Indicators	Flow requirements		
			Permanent water conservation measures	Drought stage 1 restrictions	Drought stage 2 restrictions
		site. Annual sampling of 12 net nights per site.			
	To maintain healthy aquatic ecosystems	<p>Macroinvertebrate assemblages at AUSRIVAS band A level.</p> <p>Non-dominance (<20% cover) of filamentous algae in riffles.</p> <p>Temperature, turbidity and DO mimic natural inflows</p> <p>Instream macrophyte cover <20%.</p>	<p>flows reduced from 50% to 25% during Macquarie Perch breeding season (October – December inclusive).</p> <p>RMF- Maintain a flow of 150 ML/Day for 3 consecutive days every 2 months</p> <p>PMF - Maintain a</p>	<p>whichever is lesser volume</p> <p>RMF - Maintain a flow of 150 ML/day for 3 consecutive days every 2 months</p> <p>PMF- Maintain a flow of >550 ML/day for 2 consecutive days between mid-July and mid- October</p>	
	To prevent degradation of riverine habitat through sediment deposition	Sediment deposition is limited to <20% of total depth of pools measured at base flow. Five yearly monitoring and reporting recommended for all sediment monitoring.			

Ecosystem and reach	Objective	Indicators	Flow requirements		
			Permanent water conservation measures	Drought stage 1 restrictions	Drought stage 2 restrictions
			flow of >550 ML/day for 2 consecutive days between mid-July and mid-October2		
Cotter Reservoir	To maintain populations of Macquarie Perch and Murray River Crayfish To maintain healthy aquatic ecosystems	Minimum total catch 3 Macquarie Perch per fyke net night, per year, comprised of > 50% individuals <150 mm.	An adaptive management program will be used to guide drawdown to protect Macquarie Perch		
Downstream of Cotter Dam	To maintain healthy aquatic ecosystems To maintain riparian vegetation values	Macroinvertebrate assemblages are maintained at AUSRIVAS band A level. Non-dominance (<20% cover) of filamentous algae in riffles.	Base flow 15ML/Day If release volumes are above this rate, do in a manner that reflects	Base flow 15ML/Day. If release volumes are above this rate, do in a manner that reflects	Base flow 15ML/Day Minimum. If release volumes are above this rate, do in a manner that reflects seasonal variability

Ecosystem and reach	Objective	Indicators	Flow requirements		
			Permanent water conservation measures	Drought stage 1 restrictions	Drought stage 2 restrictions
		Temperature, turbidity and DO mimic natural inflows.	seasonal variability RMF - Maintain a flow of 100 ML/Day for 1 day every 2 months	seasonal variability	
Googong Reservoir	To maintain healthy aquatic ecosystems				
Downstream of Googong Dam	To maintain healthy aquatic ecosystems	Macroinvertebrate assemblages are maintained at AUSRIVAS band A level Non-dominance (<20% cover) of filamentous algae in riffles Temperature, turbidity and DO mimic natural inflows.	Base flow October – June of 10ML/Day and July to September of 15 ML/day or natural inflow	Base flow 10ML/Day or natural inflow whichever is the lesser.	Base flow 10ML/Day or natural inflow whichever is the lesser.

Ecosystem and reach	Objective	Indicators	Flow requirements		
			Permanent water conservation measures	Drought stage 1 restrictions	Drought stage 2 restrictions
			whichever is the lesser. RMF- Maintain a flow of 100 ML/Day for 1 day every 2 months		
Modified Ecosystems					
Murrumbidgee River (ACT reaches)	<p>To maintain healthy aquatic ecosystems in terms of biota</p> <p>To enhance native fish community, including Murray Cod and Murray River Crayfish³</p> <p>To prevent degradation of riverine habitat through sediment deposition</p>	<p>Macroinvertebrate assemblages are maintained at AUSRIVAS band A level.</p> <p>Non-dominance (<20% cover) of filamentous algae in riffles.</p> <p>Recruitment of Murray Cod detected at 80% sites in reach across 2 sampling years.</p>	<p>Maintain 80th percentile monthly flow November – May, and 90th percentile monthly flow June –</p>	<p>Protect natural flows at Angle Crossing as shown in Icon Water Management Plan (2018)</p>	<p>Protect natural flows at Angle Crossing as shown in Icon Water Management Plan (2018)</p>

Ecosystem and reach	Objective	Indicators	Flow requirements		
			Permanent water conservation measures	Drought stage 1 restrictions	Drought stage 2 restrictions
	<p>To maintain extent of riparian vegetation</p> <p>To maintain and improve populations of platypus and other vertebrate fauna</p> <p>To maintain diversity and increase abundance of waterbirds</p>	<p>Sediment deposition is limited to <20% of total depth of pools measured at base flow</p>	<p>October inclusive</p> <p>RMF- Protect a minimum of 195 ML/d natural flow for a period of 1 day, once every 30 days.</p> <p>abstraction will be restricted to a long-term average of 10% of the flow above the 80th percentile flow</p>		

Ecosystem and reach	Objective	Indicators	Flow requirements		
			Permanent water conservation measures	Drought stage 1 restrictions	Drought stage 2 restrictions
Lake Burley Griffin	<p>To maintain and improve functional assemblages of macrophytes</p> <p>To enhance native fish community, including Murray Cod and Golden Perch</p> <p>To maintain diversity and abundance of waterbirds</p>	<p>Presence of Murray Cod and Golden Perch detected at 80% sites during fish surveys</p> <p>Silver Gull population on Spinnaker Island</p>	Allow water level fluctuations of up to 0.6 m below full supply level. Limit drawdown to 0.2 m July-November (to protect waterbird breeding)		
Wetlands	<p>To maintain and improve functional assemblages of macrophytes</p> <p>To maintain healthy aquatic ecosystems in terms of biota</p>		<p>Maintain 80th percentile monthly flow in all months. Protect natural flow and water level regime</p> <p>Jerrabomberra Wetland - Allow periodic drawdown (through drought or LBG changes)</p>		
Other Modified Reaches	To maintain healthy aquatic ecosystems in terms of biota	Macroinvertebrate assemblages are maintained at AUSRIVAS band A level	<p>Maintain 80th percentile monthly flow in all months.</p> <p>Drawdown is limited to 0.20m below the spillway</p>		

Ecosystem and reach	Objective	Indicators	Flow requirements		
			Permanent water conservation measures	Drought stage 1 restrictions	Drought stage 2 restrictions
		Non-dominance (<20% cover) of filamentous algae in riffles.	abstraction will be restricted to a long-term average of 10% of the flow above the 80th percentile flow		
Molonglo River Upstream and Downstream of LBG	<p>Enhance native fish community</p> <p>To prevent degradation of riverine habitat through sediment deposition</p> <p>To maintain and improve functional assemblages of macrophytes in modified lakes, ponds and wetlands</p> <p>To maintain and improve riparian vegetation in Molonglo R. Downstream of LBG</p>	<p>Upstream of LBG: Murray Cod present and detected at 80% of sites across 2 years</p> <p>Sediment deposition is limited to <20% of total depth of pools.</p> <p>Median suspended solids load from rural catchments less than 5,000kg/km²/yr.</p>			
Molonglo River	To maintain and improve populations of platypus and other vertebrate fauna in				

Ecosystem and reach	Objective	Indicators	Flow requirements		
			Permanent water conservation measures	Drought stage 1 restrictions	Drought stage 2 restrictions
Downstream of LBG					
Urban Ecosystems					
Urban streams (lined and unlined)	To prevent degradation of downstream aquatic ecosystems through sediment deposition and high flow rates	<p>Turbidity does not exceed guidelines for freshwater ecosystems 80% of the time</p> <p>Median suspended solids load from urban catchments less than 10,000 kg/km²/yr.</p> <p>Peak flows not greater than natural flows for large peak flows.</p>	<p>Maintain 80th percentile modelled natural monthly flow</p> <p>abstraction will be restricted to a long-term average of 10% of the flow above the 80th percentile flow</p>		
urban streams (Unlined)	To maintain healthy aquatic ecosystems in terms of biota	<p>Macroinvertebrate assemblage long-term improvement as measured by AUSRIVAS</p> <p>Non-dominance (<20% cover) of in-stream macrophytes</p>			

Ecosystem and reach	Objective	Indicators	Flow requirements		
			Permanent water conservation measures	Drought stage 1 restrictions	Drought stage 2 restrictions
Urban lakes, ponds and wetlands	<p>To maintain functional assemblages of macrophytes in urban lakes and ponds</p> <p>Protect waterbird breeding habitat during breeding season</p> <p>To maintain healthy aquatic ecosystems in terms of biota</p> <p>To maintain populations of native fish in urban impoundments where stocking occurs</p>	No Fish kills of stocked species	<p>Allow water level fluctuations of up to 0.6 m below full supply level, where possible</p> <p>Limit drawdown to 0.2 m July-November</p>		
Natural Ecosystems					
All reaches	To maintain healthy aquatic ecosystems	<p>Macroinvertebrate assemblages are maintained at AUSRIVAS band A level</p> <p>Non-dominance (<20% cover) of filamentous algae in riffles.</p>	<p>Maintain 80th percentile monthly flow in all months.</p> <p>No abstraction is permitted from natural lakes or ponds</p> <p>abstraction will be restricted to a long-term average of 10% of the flow above the 80th percentile flow</p>		

Ecosystem and reach	Objective	Indicators	Flow requirements		
			Permanent water conservation measures	Drought stage 1 restrictions	Drought stage 2 restrictions
Groundwater					
All reaches	Maintain natural base flow discharge		Groundwater abstraction is limited to 10% of the long term recharge		

6 MONITORING AND ASSESSMENT

A monitoring and assessment program is needed to confirm the flow requirements of local aquatic biota and ecological processes, and to determine if the indicators and ecological objectives nominated in the guidelines are the most appropriate for individual waterbodies. Using this information to refine the environmental flows is integral to the holistic approach used to develop these guidelines.

Understanding the environmental flow requirements for rivers in the ACT, as elsewhere in Australia, is not a straightforward task. In Australia, we cannot rely on understanding gained from the very different northern hemisphere ecosystems. Australian streams have much more variable flow regimes than those in most other regions of the world. Understanding the effect of daily, seasonal, and event based flow variability to the long-term health of aquatic ecosystems is of great importance, but also presents a significant challenge. There is a considerable amount of research currently being undertaken into environmental flows in the Australian context, including work being conducted locally. The monitoring and assessment program will continue to build on this work.

The monitoring and assessment program will also review the appropriateness of the ecological objectives and indicators identified in Section 4, and evaluate the effectiveness of the environmental flows in maintaining these ecological objectives. In part, this assessment process will be based on a continuation of the licence based monitoring that occurs in water supply catchments, and on the ongoing biological and water quality monitoring program in other catchments. However, there are also knowledge gaps that are not covered by these programs, and additional research will need to occur if we are to evaluate the effectiveness of these guidelines. Knowledge gaps are identified in Appendix 3.

The ACT Government aims to modify existing monitoring programs through its Integrated Water Monitoring Plan.

It is recommended that the additional research required should be a collaborative effort with other agencies to consolidate research and monitoring requirements and available resources in the context of the interconnected ecosystem processes and functions. The information gained from the monitoring programs and additional research should be reviewed on a regular basis and the findings used to guide adjustments to the different environmental flows, ecological objectives and ecological indicators.

This program will also allow us to refine our understanding of flow–biota relationships and to fill the identified knowledge gaps in Table 2 and in particular the Priority A objectives in Appendix 3.

As a guide for developing a comprehensive environmental flows monitoring and assessment program, a framework has been adapted from Cottingham et al. (2004) Environmental Flows Monitoring and Assessment Framework. The framework can be applied to each of the different environmental flow requirements and ecological objectives, and is outlined below:

- Define the information needed for each ecosystem and environmental flow component, over appropriate temporal and spatial scales.
- Define the conceptual understanding of flow-ecology relationships and the questions to be tested as formalised as ecological objectives as in Section 4.
- Select the ecological indicators to be tested as defined in Section 4.

- Determine the study design, accounting for the specific flows, and ecological objectives and indicators and location within each ecosystem, guided by the decision framework in Cottingham et al. 2004.
- Optimise study design for the size of the ecological response to be detected, and the temporal and spatial extent of the sampling design.
- Implement the study design.
- Assess whether the environmental flows have met the specific objectives and review the conceptual understanding and hypothesis, and feed this back into the adaptive management process.

In addition, the Murray–Darling Basin water reforms framework for evaluating progress (MDBA, 2014b) will be considered in developing the environmental flows monitoring and assessment program.

The specific monitoring requirements for each ecosystem type, and generic flow components are outlined in more detail below. Research needs are listed in appendix 2.

- filamentous algae assessed using standardised collection and processing methods as per Norris et al.(2004).
- Macroinvertebrate assemblages assessed using protocols in the ACT AUSRIVAS sampling and processing manual Nichols et al. (2000).
- Sediment deposition using techniques as per Ecowise Environmental (2005).

Other issues raised during this and previous environmental flow reviews include:

- Appendix 2 recommendations from the 2010 review of the EFG (2006).
- Review of ‘Ecologically sustainability of modified environmental flows in the Cotter River during drought conditions January 2003–April 2004. Final Report August 2004’ by Norris, Chester and Thoms (Chessman, 2004).
- Need to strengthen analysis of data including statistics and trends.
- Need to review the reference sites used for AUSRivas to ensure they represent natural ecosystems. Determine if there is a relationship of populations to flows. Consider adoption of genus as the default level of taxonomic resolution (Chessman, 2010). Consider if macroinvertebrates in urban areas could use SIGNAL as well. SIGNAL is used by Waterwatch.
- Need to ensure AusRivas sampling sites are representative of the reach, especially downstream of dams, the sampling sites should not be too close to the dams.
- Rapid Appraisal of Riparian Condition (RARC, Jansen et al, 2005) or other method to be developed which is better suited to the ACT’s upland zones.

The difference between fish threshold and recovery population indicators should be explored. For example, the threshold may be fine for the populations that are going well e.g. Blackfish and Macquarie Perch pre the Enlarged Cotter Dam, but to improve populations from an impact, may require more stringent indicators.

6.1 Applying the framework to the different ecosystems and flow components

6.1.1 Water supply

In the water supply catchments, the significant research that has taken place during 2000–17 (for example, Chester 2003; Norris et al. 2004; and ECD references in the Bibliography) has enabled environmental flows to be better targeted to achieve specific ecological outcomes. Given the extensive datasets that have now built over time, further work is needed to

formulate general relationships between flow and flow responses in terms of the various ecological indicators of river health. The determination of such relationship will improve predictive ability for managing environmental flow releases under changing environmental circumstances. Monitoring of flows and the ecological indicators will continue and be used to refine environmental flows.

Further information is particularly needed regarding the flows needed to enhance Macquarie Perch and Two-spined Blackfish populations, including requirements for spawning and survivorship of young of the year. Understanding these relationships will assist in adapting environmental flows to protect these threatened fishes, and to evaluate the suitability of the fish-based ecological indicators. In addition, subsequent reviews of the indicators for Blackfish should consider the Jacobs (2017) report findings and recommendations. The annual Fish Management Plan produced by Icon Water considers how water can be optimally managed for positive fish outcomes.

Previous versions of the Guidelines included ecological objectives for the Cotter River Frog. However, genetic analyses suggest this frog is a colour morph of *Litoria nudidigitus*, a widely distributed species (W. Osborne, Pers Comm 2017). The 2017 review of the 2013 Guidelines recommended that objectives specific to the Cotter River Frog be removed from the EFG

6.1.2 Modified and urban ecosystems

The CRCFE review of the 1999 Guidelines and the Hillman review of the 2006 Guidelines indicated a need for a monitoring and research program in the modified and urban ecosystems to assess the effectiveness of the environmental flows. The environmental flows monitoring and assessment approach outlined by Cottingham et al. 2004 assumes that the role of the environmental flow in maintaining or improving the ecological condition of the river has been identified. This is not the case for most aquatic ecosystems.

The evaluation of environmental flows outside the water supply catchments is not a straightforward process as streams can be affected by many impacts, for example; flow regulation, water quality degradation, riparian vegetation change and land use change. The environmental flows research challenge is to disentangle these confounded effects so that the effectiveness of the environmental flow regime can be assessed. A research program has not yet been developed, but areas recommended for consideration are:

- investigation of the effectiveness of the base flows and flooding flows at protecting ecological objectives
- review of the appropriateness of the ecological indicators in representing ecological outcomes
- refinement and elaboration of ecological objectives being maintained by environmental flows
- evaluation of the effectiveness of the drawdown limit of urban lakes and ponds at protecting their aquatic ecosystems
- review of effectiveness of engineered log jams to build ecosystem resilience.

6.1.3 Groundwater

Groundwater discharge is important in maintaining base flows in streams, it is not possible to rely solely on controls on surface water abstraction to protect base flow requirements. Recent investigations have reported that increasing groundwater abstractions above 10% of the volume of long term recharge are likely to increase the periods of low flow in rivers

(Evans et al. 2005 and Rassam et al. 2010) and this is likely to have a negative effect on biota (Barlow et al. 2005). We know from the literature that such changes will affect macroinvertebrates, but it is likely that other components including fish, macrophytes and algae will also be affected. The investigations were desktop studies, and further on-ground research was put in place to assist in the management of this resource. A program monitoring groundwater levels and rainfall recharge rates was in place throughout areas where groundwater use is highest. Data used to quantify groundwater processes and assessment of safe groundwater volumes for abstraction is described in ABARES (2013). While there is still a level of uncertainty associated with each of the techniques used, the consistency in the assessment outputs provides a level of confidence in the results.

6.1.4 Future environmental flow considerations

Requirement for all river and major creek longitudinal waterway constraints to provide passage for listed species of fish, and identifying the genetic stock of the listed species, are legislated for in the ACT. There is currently little support to create additional fish passages at dams in the ACT, on the basis that there are more cost-effective opportunities to assist listed species. In addition, the Cotter River needs to be isolated from the Murrumbidgee River due to the EHN virus and Carp, as does Googong from Carp, although the latter may already have been compromised. Urban dams are stocked and fish ladders at those dams would not necessarily provide access to good breeding sites.

Section 2.7 identifies possible impacts of climate change which may affect macroinvertebrate monitoring.

Section 3.1 describes the different methodologies used to derive flow volumes, including the time period used. Further analysis is required to determine the most appropriate time period to be used.

GLOSSARY and BIBLIOGRAPHY

Glossary

Abstracter

An abstracter is a person or corporation that abstracts water from a waterway, impoundment or bore

Abstraction

Abstraction refers to the removal of water from a natural waterway, impoundment or bore, and includes diversion of water.

Adaptive Management

Adaptive management is the systematic process of continually improving management policies and practices by learning from the outcomes of operational programs

Aquatic Ecosystem

For the purposes of these guidelines, an aquatic ecosystem is an ecosystem in a river stream, lake or pond bounded by the riparian zone.

Aquifer

An aquifer is a layer of rock or soil that is permeable and has the capacity to contain groundwater

Augmentation

The addition of water to a stream or aquifer, from an anthropogenic process.

Base flow

Base flow is the flow in a waterway that occurs between run-off events. For ACT streams most base flow is a result of seepage of groundwater into the channel.

Biota

Biota is a general term describing the animal or plant life of an area.

Channel Maintenance Flows

Channel maintenance flows are flows necessary for maintenance of the channel structure

Urban Ecosystem

An urban ecosystem is an aquatic ecosystem that has been significantly altered by human activity.

Discharge

Discharge refers to the release of water from a detention structure into a waterway.

Diversion

See abstraction. Note that for licensing or allocation purposes, abstraction and diversion may differ but for impacts on ecosystems the terms are effectively the same.

Drawdown

Drawdown is the extent to which the water level of an impoundment has been reduced below the full supply level.

Ecosystem

An ecosystem is a biological community of interacting organisms and their physical environment.

Ephemeral Streams

Ephemeral streams are waterways that do not flow continuously. That is, they tend to flow for a relatively short period of time, usually only days or weeks, after a storm event.

Flooding Flows

Flooding Flows are flows of water after storm events.

Flow Regime

Flow regime describes the pattern of flow that occurs in a stream and will include such components as low flows and flood events.

Flushing Flows

Flushing Flows are flows resulting from storm events or specific releases from impoundments, and typically comprise high flow rates of a relatively short duration that mobilise sediments and change other instream physical and chemical processes.

Fractured Rock Aquifer

A fractured rock aquifer is an aquifer in which groundwater is stored in cracks and joints in the bedrock, and not within the rock itself. Fractured rock aquifers tend to contain smaller volumes of water than alluvial or consolidated aquifers and transmit the water slowly.

Impoundment

An Impoundment is an artificial body of water created by the building of a dam. In the Guidelines the term is used interchangeably with reservoir.

Key species

Species as defined under the Nature Conservation Act 2014 and DI2012-11.

Macrophytes

Macrophytes are large water plants. Emergent macrophytes are plants that are rooted in the riverbeds or lakebeds, and protrude through the water surface. Submerged macrophytes are plants that are rooted in the riverbeds or lakebeds, but may have both aquatic and aerial adapted stems, leaves and reproductive parts.

Modified Ecosystem

In the context of this document a modified ecosystem is an aquatic ecosystem that has been somewhat altered by direct or indirect human influence.

Multi-level Off-takes

Multi-level Off-takes are structures that allow the release of a controlled quantity of water from a variety of depths in an impoundment thus allowing water of a particular quality i.e. temperature to be released or diverted.

Natural Ecosystems

A natural ecosystem is an aquatic ecosystem in which there has been minimal human impact.

Operational flexibility

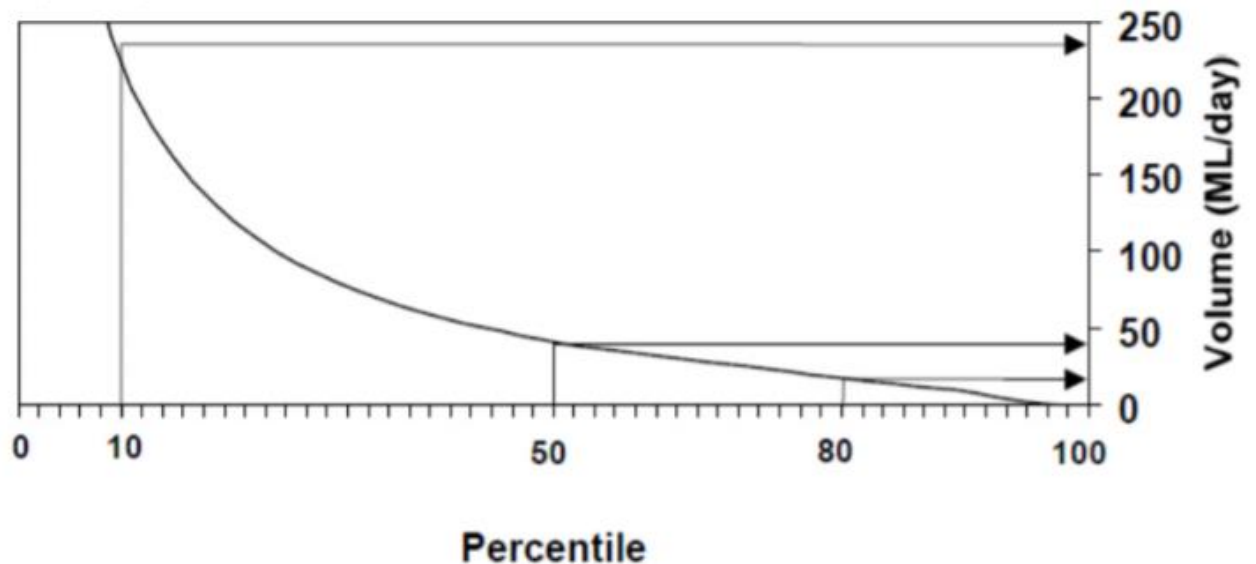
Operational flexibility refers to the ability to use existing infrastructure to manipulate flow or water level within a waterbody to achieve certain outcomes. Potential operational flexibilities include the timing, capacity of regulate the temperature of releases, volume and water quality of flows.

Percentile

A percentile is a value between 0 and 100 that indicates the proportion of measurements that fall above the percentile value. In this document the range of stream flows are expressed in percentiles. The 80th percentile flow is the flow that is exceeded 80% of the time.

That is, it is those commonly occurring (low) levels of flow. The 50th percentile, or median is that flow that is exceeded only half of the time. Percentile flows are represented graphically in Figure 2.

Figure 2. A graphical representation of percentile flows



Planned Environmental Water (PEW)

Environmental water committed in a water plan (e.g. the ACT's Water Resource Plan) for achieving environmental outcomes

Pool Maintenance Flows

Pool Maintenance flows are flows of water necessary to keep pools clear of sediment

Priority Ecosystem Function (PEF)

An ecosystem function that can be managed with environmental water and fulfils at least one criterion set out in Schedule 9 of the Murray–Darling Basin Plan

Priority Environmental Asset (PEA)

An environmental asset that can be managed with environmental water and fulfils at least one criterion set out in Schedule 8 of the Murray–Darling Basin Plan

Riffle Maintenance Flows

Riffle maintenance flows are flows of water, necessary to keep riffles clear of fine sediment but does not break up armoured layer if one has formed in the riffle

Riparian Vegetation

Riparian vegetation is vegetation growing on the banks of streams or rivers that is influenced by its proximity to a body of water.

Special Purpose Flows

A special purpose flow refers to a particular flow regime that is required to meet a specified purpose. For example, some fish require a relatively unique flow regime, in terms of flow and temperature, before spawning is initiated.

Stratified Reservoir

A reservoir becomes stratified when the water forms a layered structure, each layer having a distinct temperature and water quality.

Stressed Stream

A stressed stream is a stream that has endured a prolonged period of low flow. These conditions are often detrimental to stream health in the short term yet are a necessary component of the flow regime because they improve the resistance of local organisms to period of low flow or drought conditions. A stressed stream may also refer to a stream that is suffering from pollution.

Sustainable Yield

Sustainable yield refers to the quantity of water that may be diverted without having an adverse effect on dependent ecosystems

Urban Lake or Pond

Water Features listed in the Territory Plan defined as public land (unless specifically excluded). Generally an urban lake or pond is an impoundment that was constructed for the purposes of minimisation of peak storm flows, pollution control and recreation. The impoundment is connected to the stormwater system, does not occur on private property and does not include the Jerrabomberra Wetlands.

Water-dependent Biota

Organisms that rely upon proximity to a waterbody for survival. They are typically biota that live within or immediately adjacent to a waterbody.

Water Supply Ecosystem

A water supply ecosystem is an ecosystem in a catchment primarily used for water supply.

Water Use Restrictions

Water use restrictions are defined in regulations made under the Utilities Act

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Appendices

APPENDIX 1: SCIENTIFIC BASIS FOR RECOMMENDATIONS FROM 2004 REVIEW OF THE ENVIRONMENTAL FLOW GUIDELINES (1999)

The following text is extracted from the 2004 review of the ACT's Environmental Flow Guidelines (1999) (Ogden et al. 2004). It presents the scientific basis for the ecological objectives set in the subsequent 2006 Guidelines. Those objectives are near identical to those reproduced in the 2013 Guidelines.

Science underpinning draft objectives

The science underpinning the ecological objectives, and the environmental flows to achieve them, is summarised here. The environmental flows information (in italics) has been surmised from a review of the literature.

Macquarie Perch

The biology and status of Macquarie Perch in the ACT have been thoroughly reviewed in Lintermans (2002) and ACT Government (1999b). Macquarie Perch is a threatened species in the ACT and nationally. Key aspects of its biology related to flow, and potential environmental flows benefits, are:

It releases eggs that lodge in riffle gravels and cobbles. It therefore requires clean riffle gravels for spawning. *Flushing flows may be needed to remove fine surficial sediments (FSS).*

It prefers deep, rocky pools. *Flushing flows that clear pools of sediment may be required if sedimentation events occur, e.g. as has happened following recent fires.*

It has difficulty passing through relatively low-level stream barriers. *Environmental flows might be required to drown out barriers.*

It uses rising water temperatures as a cue for spawning, and cold bottom-water releases from dams inhibit spawning. *Cold water releases should be minimised.*

Although recruitment is required to sustain the fish populations, the scientific basis is not well established for the size and composition of the catch specified in Table 3 for Macquarie Perch. If the objectives in Table 3 are adopted, monitoring and assessment should be undertaken to determine if these levels of recruitment are adequate, or exceeds that required for sustainability

Two-spined Blackfish

The biology and status of Two-spined Blackfish in the ACT have been thoroughly reviewed in Lintermans (1998, 2002) and ACT Government (1999a). Two-spined Blackfish is a threatened species in the ACT. Key aspects of its biology related to flow, and potential environmental flows benefits, are:

It shelters in the interstices of boulder and cobble riffle beds, and is suspected to lay adhesive eggs on the underside of boulders or cobbles. *Flushing flows to keep the bed clear of sediment infill may enhance the survival.*

It may use rising water temperatures as a cue for spawning, so that cold bottom-water releases from dams might inhibit spawning. *Cold water releases should be minimised.*

The comments about recruitment targets for Macquarie Perch apply equally to Two-spined Blackfish.

Leaf-green Tree Frog (Cotter River Form)

The Cotter River form of the Leaf-green Tree Frog (*Litoria nudidigitus*), known as the Cotter River Frog, is described by Gillespie and Osborne (1994). The Cotter River Frog is strikingly different from the rest of the species (Osborne et al. 1994). As well, this population is now apparently confined to the Cotter River upstream of Bendora Dam (Osborne unpublished). It is therefore of considerable regional significance. Key aspects of its biology related to flow, and potential environmental flows benefits, are (also see Appendix C):

It breeds in streamside pools (Hero and Gillespie 1993; Holloway 1997). *Flooding of semi-detached streamside pools in spring may be needed to provide breeding sites.*

High stream flows during the warmer months are likely to impact upon riverine frog populations by flushing eggs and larvae downstream (Gillespie and Hines 1999; Gillespie and

Hollis 1996). As well, trout are effective predators of the Cotter River Frog (Gillespie 2001) and may gain access to streamside pools during inundation. *High stream flows (above natural peaks and frequencies) should be minimised during the period when eggs and tadpoles are present.*

Healthy Ecosystems — algae

An over-dominance of filamentous algae has flow-on effects to macroinvertebrates (Allan 1995; Chester 2003) and fauna that feed on them (e.g. fish). In addition algal growth during periods of low flow can trap sediment and accumulate organic matter that can eventually degrade both water quality and physical habitat used by fish and invertebrates (Allan 1995, Norris et al. 2004a). Key aspects of algae related to flow, and potential environmental flows benefits, are:

Natural flushing flows clean surface and interstices of sediment and prevent the build-up of filamentous algae (Allan 1995; Norris et al. 2004a). *Flushing flows below dams may reduce the build-up of filamentous algae and FSS (e.g. Norris et al. 2004a).*

Constant flow levels (reduced flow variability) favour shifts in the algal community to filamentous forms (Allan 1995, Norris et al. 2004a). *Variation in low flows below dams may reduce shifts to filamentous forms of algae (e.g. Norris et al. 2004a).*

Healthy Ecosystems — fine surficial sediment (FSS) deposition

The accumulation of fine surficial sediments in riffles reduces the area of the stream bed where healthy biofilm and macroinvertebrate communities can develop (and provide food for fish). This problem has been particularly acute in the Cotter and adjacent catchments following the recent fires (e.g. Nelson 2003, Norris et al. 2004a). *Flushing flows are the key to preventing the build-up of FSS (Norris et al. 2004a).*

Healthy Ecosystems — channel form

Gross channel form (i.e. 'channel types') is influenced by a number of factors related to stream flow: stream power, sediment supply, and the competence of channel flows to move sand, gravel, cobbles and boulders (Young et al. 2002). There are two main features of channel types in the ACT that it might be possible to manage using environmental flows: (1) the burial of channels by sediments, often to several metres depth, and (2) channel incision.

The smothering of channels with sediments reduces habitat quality and the number and depth of refuges in streams (Bond and Lake 2004, in press). Sediment deposition may occur if flows are not sufficient to remove material introduced into streams. This situation is an extreme version of the problem of deposition of FSS, although the sediments may have been mobilised as a result of land use rather than fires (Scott 2001). As for FSS, flushing flows are the key to sediment removal (see section 5.2), although sediments brought in by flows from upstream may confound the 'flushing' effects of sediment removal.

Channel incision will mainly be an issue in valleys where there is a degree of floodplain development, reflecting long-term (e.g. 1000+ years) sediment deposition; otherwise channels will not have sediments to be incised. Incised channels are usually observed to have less bed sediments (although they may be partially filled with sand) and flatter profiles, representing more degraded habitat than unincised channels (Ralph Ogden pers. obs.). Channel incision is thought to be controlled in part by stream power (Watson et al. 2002).

There is therefore a risk that channels will be incised if flows are augmented by inflows from interbasin transfers. ‘Environmental flows’ in such rivers should aim to allow transmission of extra water while minimizing channel erosion and incision.

Potential environmental flows benefits are:

Flushing flows to help prevent smothering of pools and riffles with sediments.

In instances where inter-basin transfers may occur, *restoring the flow to match the natural flow regime may minimize impact of increased stream power (cf. DNRE 2002).* However, further investigation of this is needed.

APPENDIX 2: RECOMMENDATIONS FROM 2010 REVIEW OF THE ENVIRONMENTAL FLOW GUIDELINES (2006)

The following text is extracted from the 2010 review of the ACT’s Environmental Flow Guidelines (2006) (Hillman 2010). It presents the major recommendations from that review and was included in the 2013 Guidelines as a separate section.

As part of the 2017 review (Dusting et al. 2017) it was noted of the 2010 review recommendations:

“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. As far as possible, these issues were addressed in the present review through the revision of ecological objectives and indicators (see Table 2). However, the ability to set meaningful objectives or indicators was impeded in many reaches by a lack of baseline data.”

2.1.1 Advice on changes to guidelines

As part of the review of the 2006 Guidelines, assessment of the performance of the Guidelines and advice on potential changes was received from eminent aquatic ecologist Professor Terry Hillman. Professor Hillman’s recommendations’ are summarised below.

Recommendation 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 populations (incl. age structure and recruitment) and selected macroinvertebrates with a view to determining the need and nature of special flow arrangements.

Recommendation 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. This material should be available for audit in line with Government practise and consideration should be given to providing a summary report of compliance with the Guideline’s flow rules annually as part of the ACT Water Report.

Recommendation 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. This should lead to concise summary reports of performance data against ecological objectives in the annual ACT Water Report.

Recommendation 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. This will lead to the establishment of a long term monitoring program.

Recommendation 5. Compliance and performance monitoring should be undertaken to close the adaptive management cycle for urban lake drawdown and macrophyte maintenance. Where the volume of water potentially warrants the work, specific studies should be carried out that maps the bathymetry of a lake and the distribution of macrophytes and, on the basis of conceptual models describing the provision of human (including water supply) and ecological services by the lake ecosystem, develop a hydrological management plan that optimises those services. Execution of that management plan, and appropriate monitoring and evaluation, should, in time, form the basis of revised environmental flow recommendations for that system.

APPENDIX 3: SCIENTIFIC BASIS FOR RECOMMENDATIONS FROM 2017 REVIEW OF THE ENVIRONMENTAL FLOW GUIDELINES (2013)

The following text is extracted from the 2017 review of the ACT's Environmental Flow Guidelines (2013) (Dusting et al. 2017). It presents the scientific basis for the ecological objectives recommended for the revision of the 2017 Guidelines. In general, the information in the tables is not an exhaustive description of each reach, but largely restricted to information pertinent to environmental flow provision. The tables assess and revise, where necessary, the ecological values, objectives and flow requirements on a reach by reach basis.

Note: comments which have been subsequently added to the extract from Dusting et al (2017), have been annotated accordingly.

Priority environmental assets and priority ecosystem functions

The Basin Plan requires that Priority Environmental Assets (PEAs) and Priority Ecological Functions (PEFs) are identified as part of the 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).

The five criteria applied by the ACT for identifying ecosystem assets:

- The water-dependent ecosystem is formally recognised in international agreements or, with environmental watering, is capable of supporting species listed in those agreements.
- The water-dependent ecosystem is natural or near-natural, rare or unique.
- The water-dependent ecosystem provides vital habitat.
- Water-dependent ecosystems that support Commonwealth, State or Territory listed threatened species or communities.
- The water-dependent ecosystem supports, or with environmental watering is capable of supporting, significant biodiversity.

The four criteria applied by the ACT for identify ecosystem function:

- The ecosystem function supports the creation and maintenance of vital habitats and populations.
- The ecosystem function supports the transportation and dilution of nutrients, organic matter and sediment.
- The ecosystem function provides connections along a watercourse (longitudinal connections).
- The ecosystem function provides connections across floodplains, adjacent wetlands and billabongs (lateral connections).

In line with Basin Plan requirements, the ACT considers that Priority Ecosystem Assets and Priority Ecosystem Function 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 environmental water can only be managed by limiting or prohibiting extractions. The tables describing the recommended objectives for reaches within the ACT include the identification of PEAs and PEFs.

Basin-wide environmental watering strategy

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, water birds 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 EFG. 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.

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, fish, reptiles, birds, spiny crayfish and other aquatic invertebrates)

PEA/PEF

All wetland systems and unregulated tributaries meet at least two criteria for identification as a PEA under MDB Plan Schedule 81.

“Criterion 2: The water-dependent ecosystem is natural or near-natural, rare or unique”

“Criterion 5: The water-dependent ecosystem supports ... 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 significant water-dependent vegetation

(*Note that environmental water can only be managed in these reaches by limiting/prohibiting extraction.)

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
<i>2013 EFG objectives:</i> To maintain healthy aquatic ecosystems in all natural ecosystems <i>No additional objectives identified</i>	None identified. See note ¹	See note ¹
<p>1. In the absence of options to actively manage environmental flows for particular outcomes in this reach, indicators are of limited use. Instead, this reach may be monitored to establish reference condition.</p>		

Reaches upstream of Googong Reservoir

Information

The ACT has no statutory responsibility for management of the Googong Reservoir catchment (the Googong, Tinderry and Burra sub-catchments) 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.*

(*Note that environmental water can only be managed in these reaches by limiting/prohibiting extraction (in NSW).

Flow recommendations:

No change to current requirements.

Objectives	Proposed indicators	Monitoring
<i>2013 EFG objectives:</i> To maintain healthy aquatic ecosystems in all natural ecosystems <i>No additional objectives identified</i>	None identified. See note ¹	See note ¹
1. In the absence of options to actively manage environmental 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. ACT Govt consider Corin reservoir a PEA/PEF as it supports threatened fish species.

BWS

Presence of BWS key fish species (Two-spined Blackfish)*

(*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.)

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, transfer for water management and 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
<i>2013 EFG objectives:</i> To maintain healthy aquatic ecosystems	None identified. See notes ^{1,2}	See notes ^{1,2}
<i>Additional objectives:</i> To maintain populations of Two-spined Blackfish	1 fish per net night ³	Bi-ennial, 10 fyke net nights
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) Baseline for Two-spined Blackfish population needs correlation with flows (Priority A) Added by ACT Govt, also to be added to other Cotter reservoirs and reaches where applicable, also see Corin dam to Bendora reach note ³ .		

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*

(*While there are BWS key species present in Googong Reservoir (eg Silver Perch), they are not self-sustaining populations and their on-going persistence is a result of recreational stocking rather than response to water management)

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
<p><i>2013 EFG objectives:</i></p> <p>To maintain healthy aquatic ecosystems</p> <p><i>No additional objectives identified¹</i></p>	<p>None identified.</p> <p>See notes²</p>	<p>See notes²</p>
<p>Notes</p> <p>1.</p> <p>While there are BWS key species present in Googong Reservoir (eg Silver Perch), they are not self-sustaining populations and their on-going persistence is a result of recreational stocking rather than response to water management</p> <p>2.</p> <p>There is limited capacity to manage environmental flows for ecological outcomes in Googong Reservoir. Thus, indicators are not included.</p>		

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

Potential values (currently data deficient):

Waterbirds

Bendora to Cotter:

Diversity of fauna (including reptiles, platypus, water rats, frogs, fish, invertebrates)

Intact riparian and aquatic vegetation

Water delivery to water supply reservoirs

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**

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

(*See EFG Section 3 for details on calculation of recommended flow volumes)

Operational flexibility

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.

Objectives ¹	Proposed indicators	Monitoring
<i>2013 EFG objectives:</i> To maintain populations of Two-spined Blackfish (both reaches)	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 ²	Annual sampling. EFTAG to further consider details – e.g. timing, sites and effort.

Objectives ¹	Proposed indicators	Monitoring
To maintain populations of Macquarie Perch (Bendora Dam to Cotter Reservoir)	Recruitment detected at 75% of sites ³ . Minimum capture of 1 Macquarie Perch (< 150 mm) per net night ⁴ .	Annual sampling of 12 net nights per site, 5 sites between Bendora Dam and Cotter Reservoir ⁵ .
To maintain healthy aquatic ecosystems (both reaches)	Macroinvertebrate assemblage (AUSRIVAS Band A) Non-dominance (<20% cover) of filamentous algae in riffles ⁶ Temperature, turbidity and DO mimic natural inflows Instream macrophyte cover <20% ⁷	Maintain current monitoring and reporting
To prevent degradation of riverine habitat through sediment deposition (both reaches)	Sediment deposition is limited to <20% of total depth of pools at base flow	Currently not monitored or reported ⁸ . Five yearly monitoring and reporting recommended.
<p>Riparian/macrophyte – flow relationships. Ability of environmental flows to prevent encroachment in these reaches (B)</p> <p>Riparian and macrophyte baseline condition in these reaches (B)</p> <p>There are considerable knowledge gaps 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)</p> <p>Water level in Bendora Reservoir that leads to stranding of Two-spined Blackfish eggs (B)</p> <p>Notes</p> <p>1. The 2013 EFG refer to an objective for Cotter River Frog, however, genetic analyses suggest it is a colour morph of <i>Litoria nudidigitus</i>, 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.</p> <p>2. 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.</p> <p>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 site criterion (75% across 2 years) is selected to account for there</p>		

Objectives ¹	Proposed indicators	Monitoring
<p>only being 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).</p> <p>3. 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.</p> <p>4. Considerable variation in catch size means a presence/absence indicator is most appropriate in lieu of increased sampling.</p> <p>5. Annual sampling is appropriate because of expanding distribution. Monitoring details are consistent with current sampling.</p> <p>6. 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 are found to constitute >20% cover that more intensive sampling takes place.</p> <p>7. 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 environmental flows to prevent encroachment in these reaches.</p> <p>8. 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.</p>		

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. ACT Govt consider Bendora and Cotter reservoirs as PEA/PEF as they supports threatened fish species.

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 or Trout Cod 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
<p><i>2013 EFG objectives (for adjacent riverine reaches):</i></p> <p>To maintain populations of Two-spined Blackfish (Bendora Res.)</p>	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}	
<p><i>Additional objectives:</i></p> <p>To maintain populations of Trout Cod (Bendora Res.)</p>	None identified ⁶	
<p>Baseline information regarding waterbird composition and abundance in these reaches (B).</p> <p>Impact of fluctuating water levels on Two-spined Blackfish and Trout Cod recruitment (B).</p> <p>Two-spined Blackfish population condition and recruitment considered “good” for Bendora Reservoir (B).</p> <p>Location of Trout Cod spawning and what role Bendora Reservoir might play (B).</p> <p>Notes</p> <p>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. ACT Govt: noting that 2001 to 2009 was a period of extreme fire and drought; while 2010 to 2016 was more representative of average conditions.</p> <p>2. See Appendix 1 for relevant data.</p> <p>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.</p> <p>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.</p> <p>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.</p> <p>6. Knowledge gaps are too broad to devise meaningful indicators for Trout Cod in Bendora Reservoir.</p>		

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

Major tributary to the Murrumbidgee R.

Sediment transportation

Prevent encroachment

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:

Base flows downstream of Cotter: 15 ML/day

Base flows downstream of 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**

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 with other reaches below impoundments

Base flows: 75% of the 80th percentile 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

(*See EFG Section 3 for details on calculation of recommended flows)

Operational flexibility

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 environmental flows would need to be considered carefully. For example, fish in this reach are from stocked populations and unlikely to respond to increases in environmental flows.

Objectives ¹	Proposed indicators	Monitoring
2013 EFG objectives: To maintain healthy aquatic ecosystems downstream of Cotter Dam	Macroinvertebrate assemblage (AUSRIVAS Band A) Non-dominance (<20% cover) of filamentous algae in riffles ² Temperature, turbidity and DO mimic natural inflows	Maintain current monitoring and reporting ²

To maintain healthy aquatic ecosystems downstream of Googong Dam	Macroinvertebrate assemblage (AUSRIVAS Band A) Non-dominance (<20% cover) of filamentous algae in riffles ² Temperature, turbidity and DO mimic natural inflows	Maintain current monitoring and reporting ²
Additional objectives: To maintain riparian vegetation values downstream of Cotter Dam	Extent and condition of riparian vegetation is maintained or improved	vegetation condition and extent monitoring (5 yearly)
To maintain connectivity for fish populations/habitats downstream of Cotter Dam	None identified ^{1,3}	
<p>Seasonal patterns for both reaches – a requirement for determining base flows (A)</p> <p>Flows required to allow fishway downstream of Cotter Dam to operate effectively and if releases from Cotter Dam are required to meet these flows (B)</p> <p>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)</p> <p>Notes</p> <p>1. The 2013 EFG contain fish-specific objectives downstream of Cotter Dam, it is recommended that these objectives be removed. While some BWS key fish species exist downstream of Cotter Dam, these are not self-recruiting populations. Flows should be targeted at supporting their survival through healthy aquatic ecosystems.</p> <p>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.</p> <p>3. There is a fishway in this reach, which dominates level of connectivity for fish (rather than environmental 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.</p>		

Natural Ecosystems

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 consideration¹

Flow requirement

2013 EFG flows:

Base flows are to be protected: Base flow 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
<i>2013 EFG objectives:</i> To maintain healthy aquatic ecosystems in terms of biota To prevent degradation of riverine habitat through sediment deposition	None identified. See note ¹

<p><i>Additional objectives:</i></p> <p>To maintain high biodiversity values</p> <p>To maintain riparian zone and in-stream macrophytes</p>	
<p>Notes</p> <p>1. In the absence of options to actively manage environmental 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.</p> <p>2. ACT Govt: Climate change indicators are not related to eflows, but should be considered in future.</p>	

Modified Ecosystems

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 (descendents of conservation stockings)

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 (eg Murray Cod)*

Presence of significant water-dependent vegetation

Presence of waterbirds

(*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.)

Flow requirement

2013 EFG flows:

Base flows: 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 base flow.

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*

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

(*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.)

Objectives	Proposed indicators	Monitoring
<p><i>2013 EFG objectives:</i></p> <p>To maintain healthy aquatic ecosystems in terms of biota</p>	<p>Macroinvertebrate assemblage (AUSRIVAS Band A)</p> <p>Non-dominance (<20% cover) of filamentous algae in riffles¹</p>	<p>Continue existing monitoring and reporting¹</p>
<p>To prevent degradation of riverine habitat through sediment deposition</p>	<p>None identified²</p>	
<p><i>Additional objectives:</i></p> <p>To maintain extent of water dependent fringing and in-channel native vegetation</p>	<p>None identified³</p>	
<p>To enhance native fish community, including Murray Cod and Murray River Crayfish</p>	<p>Recruitment of Murray Cod detected at 75% sites in reach across 2 sampling years^{5,6}</p> <p>Murray River Crayfish detected⁸</p>	<p>EFTAG fish group to consider details, including timing, techniques and sites</p>
<p>To maintain diversity and increase abundance of waterbirds.</p>	<p>None identified^{3,4}</p>	
<p>To maintain habitat complexity and geomorphic values</p>	<p>None identified³</p>	
<p>Fish requirements for connectivity in the Murrumbidgee River. Promoting connectivity for fish is an objective of the BWS (B).</p> <p>A number of native fish recruitment: flow relationships are unknown (B).</p> <p>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).</p> <p>Notes</p> <p>1. 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</p> <p>2. 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.</p> <p>3. 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</p>		

Objectives	Proposed indicators	Monitoring
<p>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.</p> <p>4. There is an absence of baseline data for waterbirds in this system, thus meaningful indicators could not be formulated.</p> <p>5. 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).</p> <p>6. The proposed indicator targets population recruitment on account of methodological issues with sampling adult population. Adult presence is somewhat inferred by recruitment.</p> <p>7. Detection probability using existing methods is low for Murray River Crayfish. While presence/absence detection may be achievable, population estimates are unreliable.</p>		

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 upstream of 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, fish 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:

Base flows are to be protected: Base flow 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*

Molonglo Downstream LBG:

Maintain natural flow and temperature regime, where possible.**

(* Note that there is no capacity for actively managing flows in Jerrabomberra Wetlands.

**Note there is limited capacity for top releases from LBG)

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
<p><i>2013 EFG objectives:</i></p> <p>To maintain healthy aquatic ecosystems in terms of biota</p>	<p>Macroinvertebrate assemblage (AUSRIVAS Band A)</p> <p>Non-dominance (<20% cover) of filamentous algae in riffles¹</p>	<p>Continue existing monitoring and reporting¹</p>
To prevent degradation of riverine habitat through sediment deposition	None identified ²	
To maintain and improve functional assemblages of macrophytes in modified lakes, ponds and wetlands ³	None identified ⁴	
<p><i>Additional recommended objectives:</i></p> <p>To maintain and improve riparian vegetation in Molonglo R. Downstream of LBG</p>	None identified ⁴	
To maintain and improve populations of platypus and other vertebrate fauna in Molonglo R. Downstream of LBG	None identified ⁴	
Enhance native fish community (including BWS key species) in Molonglo R. Upstream and Downstream of LBG	<p>Upstream of LBG: Murray Cod present and recruitment detected at 75% of sites across 2 years⁵</p> <p>Downstream of LBG: None identified⁵</p>	EFTAG fish group to consider details, including timing, techniques and sites
<p>Limitations imposed by thermal pollution on fish population in Molonglo River downstream of LBG (B)</p> <p>Response of fish populations to increased flows in Molonglo River downstream of LBG (A)</p> <p>Baseline macrophyte assemblages in Modified Ecosystems (A)</p> <p>Notes</p> <p>1. 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.</p> <p>2. 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.</p> <p>3. Amended from reference to “urban lakes and ponds” in 2013 EFG</p> <p>4. Knowledge gaps are too broad to devise meaningful indicators for macrophytes in Modified Ecosystems.</p>		

Objectives	Proposed indicators	Monitoring
<p>Additionally, there is limited potential to actively manage flows for in Modified Ecosystems (also see table pertaining to management of Lake Burley Griffin).</p> <p>5. 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 by the ACT Govt: there is no evidence of Murray Cod spawning upstream of LBG, so the recruitment indicator should be deleted.</p> <p>6. For the most part, large-bodied fish populations in the reach upstream of LBG are non-recruiting. They are typically fish stocked and lost from Googong Reservoir</p> <p>7. The potential for maintaining waterbird populations at Jerrabomberra Wetlands was considered. This is unlikely to be achieved through environmental flows in Jerrabomberra Wetlands. Additionally, any enhancement of waterbird population could threaten operational requirements of the nearby Canberra airport.</p>		

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

Vertebrate fauna (flying foxes, water rats, fish, platypus)

Macrophytes

Silver gulls (on Spinaker Island)

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:

Base flows are to be protected: Base flow 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 1 GL, 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
<i>2013 EFG objectives:</i>	None identified ¹	

Objectives	Proposed indicators	Monitoring
To maintain healthy aquatic ecosystems in terms of biota		
To maintain and improve functional assemblages of macrophytes	<p>Presence of emergent macrophytes of sufficient density and diversity to perform beneficial WQ processes and provide habitat for desired fauna.</p> <p>Submerged macrophytes present at density that perform beneficial WQ processes</p>	Littoral zone monitored from aerial photos, examining macrophyte spatial extent over time, species and colour.
<p>Additional objectives:</p> <p>To maintain diversity and abundance of waterbirds</p>	None identified ²	
<p>Baseline survey data of waterbird diversity and abundance on Lake Burley Griffin (A)</p> <p>Notes</p> <p>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.</p> <p>2. Knowledge gaps are too broad to devise meaningful indicators for waterbirds in Lake Burley Griffin.</p>		

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:

Base flows are to be protected: Base flow 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
<i>2013 EFG objectives:</i> To maintain healthy aquatic ecosystems in terms of biota	None identified ¹	
To maintain functional assemblages of macrophytes in wetlands ² <i>No additional objectives were identified</i>	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.
Distribution of wetlands potentially affected by urban development. Recommend mapping of these wetlands for inclusion in EFG (A)		
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

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:

Base flows are to be protected: Base flow 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 run-off volumes, velocities and the transport of pollutants from urban areas to downstream ecosystems.¹

Naturalised channels:

Manage flows to reduce run-off volumes, velocities and the transport of pollutants from urban areas to downstream ecosystems.¹

Protect base flows where base flow 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
<i>Additional objectives:</i> 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
<p>1. This measure may require a focus on catchment measures to reduce run-off.</p> <p>2. It is recommended that monitoring against this objective is considered as part of the review of the ACT water quality monitoring activities.</p> <p>3. Macroinvertebrate indicator targets of AUSRIVAS Band A may not be achievable in urban streams. A target condition less than Band A may be acceptable within an adaptive management process.</p> <p>4. Changed from indicator around non-filamentous algae. Macrophytes are a more appropriate measure for naturalised streams</p>		

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:

Lake – 3 zones/processes

Pond – 2 zones

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).*

(*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 base flows in these streams, with the target being a more natural streamflow downstream of the urban lakes.)

Objectives	Proposed indicators	Monitoring
2013 EFG objectives: To maintain healthy aquatic ecosystems in terms of biota	None identified ^{2,3}	
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 ⁴	Observation
<p>1. Frogs are present in many of these waterbodies, but population health is dominated by land management rather than environmental flows. The links between frog abundance and water level are not well established. Urban frog populations are considered under the WSUD code.</p> <p>2. 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</p> <p>3. 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.</p>		

Indicators and issues with indicators¹

Ecosystem and reach ²	Objective	Indicator trigger points
Water Supply Catchment Ecosystems		
Reach upstream of Corin	To maintain healthy aquatic ecosystems	These reaches provide the reference condition for potentially impacted sites Indicators as per Corin Dam to Bendora Reservoir reach, where applicable
Corin Reservoir	To maintain healthy aquatic ecosystems	Non-dominance (<20% cover) of filamentous algae
	To maintain populations of Two-spined Blackfish	Knowledge gaps are currently too broad to devise meaningful indicators, see Table 2a.
Corin Dam to Bendora Reservoir	To maintain populations of Two-spined Blackfish	Young of the year and year 1+ age classes (<120 mm total length) comprise >30% of the monitoring catch; AND total catch +is >2 blackfish for 60% of samples (30 m sections) in each reach - across 2 years
	To maintain healthy aquatic ecosystems	Macroinvertebrate assemblages are maintained at AUSRIVAS band A level Non-dominance (<20% cover) of filamentous algae in riffles. Temperature, turbidity and DO mimic natural inflows ¹¹ Instream macrophyte cover <20% ⁴ Riparian vegetation knowledge gaps are currently too broad to devise meaningful indicators ⁵ , see Table 2a.
	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). Five yearly monitoring and reporting recommended for all sediment monitoring.
Bendora Reservoir	To maintain populations of Two-spined Blackfish	Minimum 2 post-juvenile Two-spined Blackfish per fyke net night per year. Note: Drawdown could be carefully managed around mid-November, as Blackfish eggs and larvae are tied to spawning site for about 6 weeks.
	To maintain healthy aquatic ecosystems	Non-dominance (<20% cover) of filamentous algae.
	To maintain populations of Trout Cod	Trout Cod knowledge gaps are currently too broad to devise meaningful indicators ¹⁰ , see Table 2a.

Ecosystem and reach ²	Objective	Indicator trigger points
Bendora Dam to Cotter Reservoir	To maintain populations of Two-spined Blackfish	Young of the year and year 1+ age classes (<120 mm total length) comprise >30% of the monitoring catch; AND total catch + is >2 blackfish for 60% of samples (30 m sections) in each reach - across 2 years
	To maintain populations of Macquarie Perch	Recruitment detected at 80% of monitoring sites. Minimum capture of 1 Macquarie Perch (< 150 mm) per net night per site. Annual sampling of 12 net nights per site, 5 sites between Bendora Dam and Cotter Reservoir
	To maintain healthy aquatic ecosystems	Macroinvertebrate assemblages are maintained at AUSRIVAS band A level. Non-dominance (<20% cover) of filamentous algae in riffles. Temperature, turbidity and DO mimic natural inflows ¹¹ Instream macrophyte cover <20%. Riparian vegetation knowledge gaps are currently too broad to devise meaningful indicators ⁵ , see Table 2a.
	To prevent degradation of riverine habitat through sediment deposition	Sediment deposition is limited to <20% of total depth of pools measured at base flow. Five yearly monitoring and reporting recommended for all sediment monitoring.
Cotter Reservoir	To maintain populations of Macquarie Perch and Murray River Crayfish	Minimum total catch 3 Macquarie Perch per fyke net night, per year, comprised of > 50% individuals <150 mm. Murray River Crayfish knowledge gaps are currently too broad to devise meaningful indicators ⁶ , see Table 2a.
	To maintain healthy aquatic ecosystems	Non-dominance (<20% cover) of filamentous algae.
Downstream of Cotter Dam	To maintain healthy aquatic ecosystems	Macroinvertebrate assemblages are maintained at AUSRIVAS band A level. Non-dominance (<20% cover) of filamentous algae in riffles. Temperature, turbidity and DO mimic natural inflows ¹¹ .
	To maintain riparian vegetation values	Riparian vegetation knowledge gaps are currently too broad to devise meaningful indicators ⁵ , see Table 2a.
Googong Reservoir	To maintain healthy aquatic ecosystems	Non-dominance (<20% cover) of filamentous algae.
Downstream of	To maintain healthy aquatic ecosystems	Macroinvertebrate assemblages are maintained at AUSRIVAS band A level

Ecosystem and reach ²	Objective	Indicator trigger points
Googong Dam		<p>Non-dominance (<20% cover) of filamentous algae in riffles</p> <p>Temperature, turbidity and DO mimic natural inflows¹¹.</p> <p>Riparian vegetation knowledge gaps are currently too broad to devise meaningful indicators⁵, see Table 2a.</p>
Natural Ecosystems		
All reaches	To maintain healthy aquatic ecosystems	<p>Macroinvertebrate assemblages are maintained at AUSRIVAS band A level</p> <p>Non-dominance (<20% cover) of filamentous algae in riffles.</p> <p>Temperature, turbidity and DO mimic natural inflows</p> <p>Instream macrophyte knowledge gaps are currently too broad to devise meaningful indicators⁴, see Table 2a</p>
Modified Ecosystems		
Murrumbidgee River (ACT reaches)	To maintain healthy aquatic ecosystems in terms of biota	<p>Macroinvertebrate assemblages are maintained at AUSRIVAS band A level.</p> <p>Non-dominance (<20% cover) of filamentous algae in riffles.</p>
	To enhance native fish community, including Murray Cod and Murray River Crayfish ³	<p>Recruitment of Murray Cod detected at 80% sites in reach across 2 sampling years.</p> <p>Murray River Crayfish knowledge gaps are currently too broad to devise meaningful indicators⁶, see Table 2a.</p>
	To prevent degradation of riverine habitat through sediment deposition	Sediment deposition is limited to <20% of total depth of pools measured at base flow
	To maintain extent of riparian vegetation	Riparian vegetation knowledge gaps are currently too broad to devise meaningful indicators ⁵ , see Table 2a.
	To maintain and improve populations of platypus and other vertebrate fauna	Knowledge gaps are currently too broad to devise meaningful indicators, see Table 2a.
	To maintain diversity and increase abundance of waterbirds.	Knowledge gaps are currently too broad to devise meaningful indicators, see Table 2a.
Lake Burley Griffin	To maintain and improve functional	Knowledge gaps are currently too broad to devise meaningful indicators ⁴ , see Table 2a

Ecosystem and reach ²	Objective	Indicator trigger points
	assemblages of macrophytes	
	To enhance native fish community, including Murray Cod and Golden Perch	NCA target (for information only): Presence of Murray Cod and Golden Perch detected at 80% sites during fish surveys
	To maintain diversity and abundance of waterbirds	NCA target (for information only): Maintain a viable Silver Gull population on Spinnaker Island
Wetlands	To maintain and improve functional assemblages of macrophytes	Knowledge gaps are currently too broad to devise meaningful indicators ⁴ , see Table 2a
	To maintain healthy aquatic ecosystems in terms of biota	Knowledge gaps are currently too broad to devise meaningful indicators ⁷ , see Table 2a
Other Modified Reaches	To maintain healthy aquatic ecosystems in terms of biota	Macroinvertebrate assemblages are maintained at AUSRIVAS band A level Non-dominance (<20% cover) of filamentous algae in riffles.
	Enhance native fish community in Molonglo R. Upstream and Downstream of LBG	Upstream of LBG: Murray Cod present and detected at 80% of sites across 2 years Downstream of LBG: None identified
	To prevent degradation of riverine habitat through sediment deposition	Sediment deposition is limited to <20% of total depth of pools. Median suspended solids load from rural catchments less than 5,000kg/km ² /yr.
	To maintain and improve functional assemblages of macrophytes in modified lakes, ponds and wetlands	Knowledge gaps are currently too broad to devise meaningful indicators ⁴ , see Table 2a
	To maintain and improve riparian vegetation in Molonglo R. Downstream of LBG	Knowledge gaps are currently too broad to devise meaningful indicators ⁵ , see Table 2a

Ecosystem and reach ²	Objective	Indicator trigger points
	To maintain and improve populations of platypus and other vertebrate fauna in Molonglo R. Downstream of LBG	Knowledge gaps are currently too broad to devise meaningful indicators, see Table 2a
Urban Ecosystems		
Urban streams	To prevent degradation of downstream aquatic ecosystems through sediment deposition and high flow rates	Turbidity does not exceed guidelines for freshwater ecosystems 80% of the time ⁹ Median suspended solids load from urban catchments less than 10,000 kg/km ² /yr. Peak flows not greater than natural flows for large peak flows. (new)
	To maintain healthy aquatic ecosystems in terms of biota	For unlined streams only: Macroinvertebrate assemblage long-term improvement as measured by AUSRIVAS Non-dominance (<20% cover) of in-stream macrophytes
Urban lakes, ponds and wetlands	To maintain functional assemblages of macrophytes in urban lakes and ponds	Knowledge gaps are currently too broad to devise meaningful indicators, see Table 2a ⁴
	To maintain healthy aquatic ecosystems in terms of biota	Knowledge gaps are currently too broad to devise meaningful indicators, see Table 2a.
	To maintain populations of native fish in urban impoundments where stocking occurs	Fish kills of key species do not occur except for when being undertaken as managed biocontrol for pest fish species eg redfin and European carp. Noting fish kills should not, but may occur, during water body drawdown/refill.
	To protect waterbird breeding habitat from drawdown during breeding season	Knowledge gaps are currently too broad to devise meaningful indicators ⁷ , see Table 2a.
<p>1. The rationale for the changes to the above table since the 2013 Guidelines are outlined in Appendix 3.</p> <p>2. Locations of downstream of dam monitoring sites needs to be approved by the EPA.</p> <p>3. The BWS (Table 8) 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</p>		

Ecosystem and reach ²	Objective	Indicator trigger points
<p>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.</p> <p>4. For macrophyte coverage, baseline data needs to be collected before this Indicator is implemented.</p> <p>5. Riparian vegetation method and baseline data needs to be collected before this Indicator is implemented. Rapid Appraisal of Riparian Condition (RARC, Jansen et al, 2005) or other method to be developed which is better suited to the ACT's upland zones.</p> <p>6. Current monitoring techniques for Murray River Crayfish are considered unsuitable to provide a reliable method for detection,</p> <p>7. Information has been collected by Waterwatch volunteers on frogs, birds and macroinvertebrates, and some signal based scoring. Investigations into linkages with water levels/flows needs to be undertaken to confirm the value of these attributes as indicators. There is also currently work to identify AUSRIVAS style assessments for wetlands so that macroinvertebrate data can be useful.</p> <p>8. Data analysis indicates that annual sampling for Blackfish and Macquarie Perch is much better than biennial sampling, for reducing the risks of unnecessary management eg false negative results.</p> <p>9. Turbidity downstream of lakes, ponds and wetlands should be the measuring point because the function of these systems is to trap sediment at the water body point.</p> <p>10. Trout Cod were stocked in Bendora reservoir in the 1980s, hence the indicator is a trigger to identify recruitment issues with the current population.</p> <p>11. Where possible, within the operational constraint of supplying the best water for treatment and distribution, the water utility will endeavour to release water downstream of the water supply dams that is similar or better than the temperature, turbidity and DO of the water entering the reservoir.</p>		

Table 2a lists the Ecosystem and reach objective indicator trigger points which cannot be reasonably specified until sufficient monitoring and analysis is undertaken to address the current knowledge gap. Indicator trigger points from the EFG review (see Appendix 3) have been included below as indicative indicator trigger points

Table 2a Knowledge gaps for Ecosystem and reach objective indicator trigger points

Ecosystem and reach	Objective	Indicator trigger points
Corin Reservoir	To maintain populations of Two-spined Blackfish	Review recommendation (see Appendix 3): Biennial catch is at least 1 fish per net night, 10 fyke nets nights. See footnote ⁸ Table 2 for preference for annual monitoring and Note 3 under Appendix 3 for Corin Reservoir.
Bendora Reservoir	To maintain populations of Trout Cod	Minimum 2 post-juvenile Trout Cod per fyke net night. See footnote ¹⁰ Table 2 above

Ecosystem and reach	Objective	Indicator trigger points
Cotter Reservoir and Murrumbidgee River	To maintain populations of Murray River Crayfish	Murray River Crayfish detected. See footnote ⁶ Table 2 above.
Applicable reaches	To maintain and improve functional assemblages of macrophytes	Presence of emergent macrophytes of sufficient density and diversity to perform beneficial water quality processes and provide habitat for desired fauna. See footnote ⁴ Table 2 above. Submerged macrophytes present at density that perform beneficial water quality processes.
	To maintain healthy aquatic ecosystems in terms of biota	Knowledge gaps are currently too broad to devise meaningful indicators. See footnote ⁷ Table 2 above.
	To maintain riparian vegetation values	Extent and condition of riparian vegetation is maintained or improved. See footnote ⁵ Table 2 above.
	To maintain and improve populations of platypus and other vertebrate fauna	Knowledge gaps are currently too broad to devise meaningful indicators
	To maintain diversity and increase abundance of waterbirds.	Knowledge gaps are currently too broad to devise meaningful indicators. See footnote ⁷ Table 2 above.