Environment and Sustainable Development Directorate
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ACT Non-potable Water Master Plan Study

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Prepared for

Environment and Sustainable Development Directorate

Prepared by

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Front cover image: Lake Tuggeranong Foreshore (AECOM)

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Abbreviations

ACT	Australian Capital Territory
ACTPLA	ACT Planning and Land Authority
AECOM	AECOM Australia Pty Ltd
ASTR	Aquifer storage, transfer and recovery
CSIRO	Commonwealth Scientific and Industrial Research Organisation
EDD	Economic Development Directorate
ESDD	Environment and Sustainable Development Directorate
EPIC	Exhibition Park in Canberra
LDA	Land Development Agency
LMWQCC	Lower Molonglo Water Quality Control Centre
MDBA	Murray-Darling Basin Authority
MUSIC	Model for Urban Stormwater Improvement Conceptualisation
NCRWS	North Canberra Recycled Wastewater System
PWCM	Permanent water conservation measures
SDL	Sustainable Diversion Limits
SRS	Sports and Recreation Services
TaMSD	Territory and Municipal Services Directorate
WSUD	Water Sensitive Urban Design

Executive Summary

Drought conditions in many parts of Australia since the mid to late 1990s have focused governments on the emerging challenges of securing reliable water supply for urban environments. As the urban population increases, there will also be a corresponding increase in demand for fresh water. The challenge to supply fresh water to a growing population is exacerbated by a changing climate and has resulted in a fundamental shift in the way urban water issues are perceived and managed — as reflected in reports by the Prime Minister's Science, Engineering and Innovation Council (2007)[1] and, more recently, the National Water Commission (2011)[2].

Many urban environments, including the Australian Capital Territory (ACT), typically depend, almost exclusively, on water resources derived from the capture of rainfall run-off from largely rural or forested catchments. Communities are increasingly susceptible to rising global temperatures and, consequently, increased moisture deficits in the catchment, leading to decreased catchment runoff into water storages and an increased likelihood of water scarcity. For example, inflows to Canberra's dams have been 60% below average over the past decade.

> "*Water supplies to Australia's cities need to move from reliance of traditional sources to an efficient portfolio of water sources which can provide security through diversity. Like a share portfolio, flexible and cost effective access will be underpinned by diversity, including centralised and decentralised infrastructure. Like a share portfolio, the composition of water source portfolios also needs to reassessed as new information on costs, prices, climate, environmental objectives and impacts, and risks becomes available*".
>
> (Prime Minister Science Engineering Innovation Council, 2007).

A strategy built around diverse water sources and a mixed water infrastructure would allow cities the flexibility to access a portfolio of sources at least cost, with costs to include environmental impacts and other externalities. It is envisaged that access to these sources of water for non-potable use would reduce the demand on higher-valued potable water and build a level of water security and resilience for the ACT, avoiding expensive water-resources augmentation projects and stringent water restrictions in the future.

The ACT Government and Actew Corporation are undertaking augmentation works at Cotter Dam and the Murrumbidgee to Googong Pipeline, to increase the security of potable water supply. In addition, the ACT Government has set a target of 25% reduction in demand for potable water by 2030. The target reduction in demand for potable water can be achieved by a combination of water efficiency measures and potable water substitution for non-potable uses. It is anticipated that the combination of a reduction in demand on potable water and the augmentation works will result in the ACT community being protected from water restrictions until between 2030 and 2040.

The master plan presented in this report is designed to enable a systematic assessment and development of alternative water sources — principally recycled water from sewage treatment plants and urban stormwater — for the ACT. The supply of non-potable water to maintain public open spaces, particularly playing fields, is the main focus at present. However, the provision of non-potable water for domestic fit-for-purpose uses (for example, toilet flushing) may ultimately provide the most significant means of potable water substitution.

Recycled water is a reliable source of water but requires a higher level of treatment compared with urban stormwater. At present, the majority of treated sewage is discharged into the Molonglo River and subsequently used for agriculture and water supply by downstream communities. Owing to its higher nutrient levels, treated wastewater has a detrimental impact on the receiving water environment and any recycling of this water source would have a positive impact on the natural water environment.

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[1] Prime Minister's Science, Engineering and Innovation Council Working Group (2007), Water for Our Cities: building resilience in a climate of uncertainty, a report of the PMSEIC Working Group, June 2007.
[2] National Water Commission (2011), Urban water in Australia: future directions, April 2011, ISBN 978-1-921853-06-7.

Urban stormwater is intermittent and requires a lower level of treatment for non-potable uses (compared with wastewater) — often through green infrastructure, such as constructed wetlands and other biofiltration systems. Because of its intermittent supply characteristics, the reliability of urban stormwater as a water resource is often influenced by access to viable storages. The many lakes and ponds throughout the ACT can be used to make stormwater harvesting economically feasible.

Discussion papers (refer to Appendix K) were prepared during the course of this project to guide the selection of fit-for-purpose use of these alternative sources of water, which take into consideration such issues as supply reliability, suitability and preferential uses of water sources, as well as secondary beneficial outcomes.

At the commencement of this study, it was recognised that the development of a non-potable water master plan would need to involve the participation of key stakeholders through a series of consultative and deliberative forums. A model was therefore developed to facilitate rapid and integrated evaluation of multiple alternative water sources, and to allow consideration of the interactions and potential for cooperation and competition between schemes. This model will enable workshop participants to rapidly compute the net present capital, operational and levelised costs of non-potable water derived from a variety of different combinations of recycled wastewater and harvested stormwater schemes. This model was calibrated against two existing stormwater harvesting schemes and was subsequently used in a number of workshops with key stakeholders. These workshops examined a number of non-potable water supply scenarios, including an option to supply recycled wastewater to the whole of Canberra from the Lower Molonglo Water Quality Control Centre (LMWQCC).

An optimum mix of recycled wastewater and harvested stormwater was selected to form the basis of the non-potable master plan, with an implementation timeframe of 25 years. Five five-year work programs were formulated on a 'just in time' basis, to meet projected non-potable water demands — particularly in relation to meeting non-potable domestic demands with new developments, such as those at Lawson South and Molonglo Valley. The master plan will deliver a net average annual yield of 13.7 GL/year of non-potable water with a reliability of 95% and a capital investment of $452M over a staged period of 25 years. The portion of capital investment the ACT Government and Actew Corporation will be responsible for will need to be explored in detail as the master plan is progressed and implemented. The ACT non-potable water master plan is a combination of wastewater recycling and stormwater harvesting schemes. The non-potable water secured represents a potable water substitution of up to 20% of the ACT's present water supply in line with current *Think water, act water* targets.

The LMWQCC wastewater recycling scheme was identified as the single largest source of non-potable water. This resource will be developed over the next 25 years. The modelling undertaken has also highlighted that stormwater harvesting is a viable and cost-effective option around the major lakes in Canberra, notably Lake Tuggeranong, Lake Ginninderra, Gungahlin and Yerrabi Ponds, and Flemington Ponds.

There are multiple benefits associated with the development of decentralised non-potable supply schemes supplemented by the centralised potable water supply system in the ACT. The environmental benefits associated with this strategy include a reduction in nutrients to ACT waterways, estimated to be of the order of 2.84 tonnes of Total Phosphorus (TP) and 25.3 tonnes of Total Nitrogen (TN) annually. In addition, harvesting of stormwater will mitigate the degradation of natural waterways associated with the hydrological impacts of increased catchment runoff brought about by urban developments.

A snapshot of the five-year action plans of the master plan and estimated capital cost is presented in Table 1. Refer to Appendix E for a description of modelling tool variables and Appendix G for a breakdown of costs.

Table 1 Overview of the Non-potable Water Master Plan

Period	Projects	Target[1] (GL/year)	Yield (GL/year)	Capital Costs ACT & Actew ($M)
2011-2015	Inner North (Flemington Ponds), Lake Tuggeranong, North Weston Creek Pond, LMWQCC-A, Lake Ginninderra-A	2.1	2.6	101
2016-2020	Gungahlin & Yerrabi, Lake Ginninderra-B, LMWQCC-B, LMWQCC-C	5.7	6.2	182
2020-2025	Fyshwick-A (and connection to LMWQCC), Lake Ginninderra-C, Lake Ginninderra-D, W19 Pond (Woden East), WC4 Pond (Weston Creek)	4.4	2.0	92
2025-2030	LMWQCC-E	1.0	2.8	73
2030-2035	Point Hut Pond	0.9	0.1	4
	Total:	**14.1**	**13.7**	**$452**

[1] Estimated volume of water that should be met through non-potable sources to achieve the Think Water Act Water target of a 25% reduction in potable water demands (assuming 12% is achieved through water efficiency and 13% through non-potable sources)

In its recent report[3] on its inquiry of Australia's urban water sector, the Productivity Commission advocated the adoption of a 'real options' or adaptive approach to water resources planning. Having access to a diversity of water sources would present a desirable degree of water resources operational flexibility for the ACT government. It would also promote both a 'real options' approach to attaining water security within an uncertain climatic future and a sustainable integrated urban water management strategy that delivers on multiple economic, social and environmental benefits beyond that of water security.

The master plan developed in this project should be viewed as a preliminary plan, which would be reviewed and updated regularly. As it is, the master plan could be further refined with ongoing consultation and deliberative forums with relevant stakeholders. To that end, the model developed in this project provides the Environment and Sustainable Development Directorate (ESDD) with a tool for effective ongoing stakeholder consultation in refining the non-potable water master plan for the ACT.

[3] Productivity Commission 2011, Australia's Urban Water Sector, Report No. 55, Final Inquiry Report, Canberra.

1.0 Preamble to master plan

AECOM was engaged by the Environment and Sustainable Development Directorate (formerly ACT Planning and Land Authority) to prepare a non-potable water master plan for the use of non-potable water across Canberra for fit-for-purpose uses, predominantly irrigation. The master plan provides a framework to guide the future provision of infrastructure for non-potable water supply.

Recent challenges relating to the combined impacts of climatic extremes (drought) and population pressures have led to significant work to estimate future demands and improve the security of water supplies. Aspirational targets have been established to reduce future water demands in the ACT and investments in infrastructure have been made incorporating these targets into the overall water planning models. Studies have been undertaken to determine the feasibility of a number of stormwater and wastewater reticulation schemes to augment potable supplies. While a number of promising schemes are proposed and under construction, there is a need for an integrated master plan. The plan will ensure a strategic approach is taken to pursuing the best opportunities taking account of the interactions between the different schemes.

This master plan complements previous and ongoing projects. It will guide efficient investment into the development of stormwater harvesting and treated effluent reticulation systems and considers drivers such as supply security, cost and environmental protection. Input from stakeholders including Actew, ActewAGL, Environment and Sustainable Development Directorate, Health Directorate and Treasury Directorate was sought during development of the master plan with invited workshops on both the methodology and outcomes.

As part of the stakeholder consultation process, a series of discussion papers were prepared and these are contained in Appendix K.

- *Discussion Paper 1: An outline of the hierarchy of use for non-potable water sources* describes the rationale behind the master plan. It describes a generic approach that considers the risk of different sources of water to public health, and the risks and benefits to the environment of using these alternative sources. It is accompanied by a risk assessment that describes apparent risk, mitigation strategies and residual risks for public health, environmental impacts and asset costs.
- *Discussion Paper 2: Infrastructure Requirements for Water Recycling and Reuse Infrastructure* sets out infrastructure requirements for rainwater, stormwater and treated wastewater.
- *Discussion Paper 3: Residential Dual Reticulation in the ACT* examines the opportunities and issues surrounding dual reticulation of non-potable water for residential use. Potential costs and benefits, the legislative framework, suitable end uses for non-potable supplies and treatment requirements are described.

With this rationale, the master plan was developed using a decision support computational model developed by AECOM to assess the performance of varying supply scenarios. The model assessment approach was predominantly based on a volumetric and economic analysis to support the rapid testing of scenarios required at the master plan stage. A summary of the model including inputs and assumptions is contained in Appendix E. Each scenario was assessed on:

- the source of non-potable water (i.e. stormwater or treated effluent)
- storage location
- transfer pipe infrastructure
- target reliability and yields; and
- costs and benefits of each scenario

Staged implementation plans were developed for each five year period up to 2035. Measuring the full impact of any investment option at subsequent design development stages will require a broader and more detailed decision making process to ensure that feasibility and option selection is based on a comprehensive appreciation of site and project specific outcomes. The full spectrum of costs and benefits, including the flexibility and resilience of systems, will need to be considered through further multi criteria assessments to account for both tangible and intangible impacts.

The master plan is designed to enable the existing potable water use targets to be achieved. The ultimate objective is to secure a diversity of water supplies for the ACT to enable continued strong growth in the region.

1.1 Water Sensitive Cities

- A diversity of sources are needed for a resilient water supply
- Waterway health will be improved through stormwater reuse and wastewater recycling to reduce stormwater excess flows and pollutant discharges
- Restoring evapotranspiration will reduce urban heat island effects
- A water sensitive city empowers its citizens to choose water sensitive behaviour
- Improved green spaces will improve liveability and the health of the community

The Australian Commonwealth's National Water Initiative has developed the stated goal of creating Water Sensitive Cities. Canberra is well placed to capitalise on its locality and existing infrastructure to drive a transition towards a more sustainable approach to water management. As such the population could benefit from a diversity of water supply sources whilst also mitigating the impacts of urbanisation on the local environment.

Three key principles set the foundation for a water sensitive city:

- Cities as water supply catchments – access to water through a diversity of sources at a diversity of supply scales
- Cities providing ecosystem services – the built environment functions to supplement and support the function of the natural environment; and
- Cities comprising water sensitive communities – socio-political capital for sustainability exists and citizens' decision-making and behaviour are water sensitive

The recent decade-long drought has demonstrated the vulnerability of a water supply dependent upon a single type of water source with inflows to Canberra's catchments for the past decade declining to 63% of the long term average. The system is under increasing pressure due to population growth and there is significant uncertainty associated with climate change, drought and bushfire. It is recognised that a resilient water supply system will have a diversity of decentralised sources and decentralised water supply infrastructure. In addition to efficiency and structural augmentation measures, the security of Canberra's water supply should be pursued by tapping the city itself as a catchment, providing new sources for non-potable water through wastewater recycling and stormwater reuse. This will create a system that is more resilient to drought, bushfire and future climate change uncertainty.

A water sensitive city aims to implement water sensitive urban design approaches to manage the volume, frequency and quality of stormwater runoff and utilise this water effectively within the built form and landscape of the city. Urbanisation results in significant stormwater excess flows being discharged to waterways resulting in urban streams with minimal biodiversity. In a water sensitive city, the ecological health of the waterways is restored through distributed water sensitive urban design, increased evapotranspiration and infiltration within the catchment and reduced direct surface runoff. Stormwater reuse projects can contribute significantly towards achieving this. The recycling of wastewater discharges within the city simultaneously reduces the importation of potable water into the city while reducing the pollutant loads discharged from the city and impacting on downstream receiving waters.

The loss of vegetation and thermal mass of infrastructure leads to urban heat island effects. These can be reduced through increased moisture levels and evapotranspiration in public open space to restore the natural energy balance and increased shading from vegetation. Well managed public open spaces can significantly reduce urban heat island effects to reduce their impacts on health and improve thermal comfort.

The citizens of a water sensitive city recognise the importance of water and appreciate its value in their daily lives. Opportunities to interact with water through integration of functional systems within landscapes and the built form as well as access to green open spaces supported by resilient supply systems promote an increased awareness of water within the community.

There is a clear link between mental, physical and social health and access to green spaces. The provision of high quality public open space including parks for passive recreation and sporting fields to consistently support sporting clubs will result in improved participation in physical activity and significant direct and indirect health and social benefits for the community.

1.2 Canberra's water systems

Canberra has a predominantly conventional water management system with water supplied from natural catchment areas and a centralised sewage treatment system. Stormwater is drained using conventional drainage systems to prevent flooding and Canberra has a large number of constructed ponds and lakes for recreational amenity and management of stormwater. These systems have historically served the city well and continue to evolve to respond to population growth, climate change, environmental protection and other pressures.

Water Supply

- Canberra relies on water supply from four dams
- To improve supply security, the water supply system is being augmented
- The ACT Government are committed to providing alternative sources of water to further augment supplies
- ACT diverts 65 GL per year from the Murray-Darling basin for potable supplies, and returns 30 GL per year as treated wastewater

Canberra's current water supply is mostly dependent on catchment dams. At present, the ACT's water assets are owned by Actew Corporation with ActewAGL providing the water supply service for consumers. There are three dams in the Cotter River catchment - the Cotter, Bendora and Corin dams; and one on the Queanbeyan River, Googong Dam. Until recently these operated as run of the river type storages intercepting flows from upstream forested catchments, allowing limited releases to downstream waterways as environmental flows. A minor proportion of water supplies are also currently sourced from distributed groundwater extractions.

For the period 2000 to 2010 the ACT has used between 32 GL/yr and 66 GL/yr with the majority extracted for potable water supplies. Water use has reduced in recent years due to drought and water restrictions. Based on the current population of approximately 400,000 and average water use of 438 L/person/day, it is expected that potable water usage would be approximately 65 GL/yr (without restrictions).

Wastewater

Canberra has two sewage treatment plants, the Lower Molonglo Water Quality Control Centre (LMWQCC) and the Fyshwick sewage treatment plant while a third sewer mining plant at Southwell Park has recently been decommissioned. Approximately 35 GL/yr (~55% of water supplied) is returned to the Molonglo River via the two sewage treatment plants. The LMWQCC is the main sewage treatment plant providing tertiary treatment of 95% of Canberra's wastewater and serves a population of up to 360,000. The Fyshwick sewage treatment plant treats wastewater from Majura, Fyshwick, Jerrabomberra and Narrabundah.

Stormwater

Stormwater in North and South Canberra and the satellite districts (Woden, Belconnen, Tuggeranong and Gungahlin) are drained using conventional systems to prevent flooding. The Canberra urban area has a large number of constructed ponds and lakes which are used for recreational amenity as well as management of stormwater. These provide a degree of flow attenuation and treatment but many also require protection as receiving waters that can be impacted by stormwater pollution. In recent years there has been a shift from large open water bodies to vegetated wetland systems for effective control of nutrients. The ACT has guidelines for water sensitive urban design (WSUD) for all new developments requiring specified best practice objectives to be achieved.

1.2.1 Non-potable water supplies

- Two wastewater treatment plants currently operate in Canberra
- Fyshwick wastewater treatment plant performs poorly while much of the available effluent is reused
- Sewer mining is much more costly than using treated wastewater from the LMWQCC
- Several stormwater reuse schemes are in the process of being implemented with more planned
- Stormwater reuse does not yet significantly contribute to Canberra's overall water supply

Canberra recycles wastewater for non-potable uses. Actew is committed to increasing the volumes of wastewater recycling and has commissioned a number of studies in recent years to investigate the optimal arrangement for expanding the current recycled wastewater reticulation network. There are currently two sewage treatment plants operating in Canberra. These treatment plants supply some recycled water to meet limited demands. The quality of treated effluent and scale of operations vary between each of the respective treatment plants.

The LMWQCC currently supplies recycled water for internal plant uses, to irrigate the Belconnen Golf Course and a vineyard and for tanker supply.

Treated wastewater from the Fyshwick sewage treatment plant is recycled through the North Canberra Recycled Wastewater System (NCRWS) and provided to a number of mostly irrigation users. The remainder of effluent is discharged to LMWQCC via sewer for further treatment.

A small sewer mining scheme at Southwell Park was trialled, but was found not to be economically viable and has recently been decommissioned.

Existing stormwater harvesting and groundwater sources are locally significant but do not yet contribute a significant proportion of the overall Canberra water supply. The Territory, through the Environment and Sustainable Development Directorate (ESDD), is committed to increasing the volumes of reused stormwater supplied to the ACT. These are in accordance with the *Think water, act water* targets to reduce potable water consumption by 12% by 2013, and 25% by 2023 [*Australian Capital Territory Government*, 2004] (currently under review) through water conservation and efficiency and source substitution.

A number stormwater reuse schemes including Lake Tuggeranong [*GHD*, 2010], Inner North (Flemington Ponds [*URS*, 2011]) and North Weston Creek Pond are at various stages of planning, construction and operation while a number of schemes at Lake Ginninderra, Coombs Ponds and Valley Ponds are also planned.

Urban groundwater use is relatively insignificant within Canberra. The local hydrogeology is the subject of ongoing investigation to accurately quantify both the potential groundwater yields and the viability of aquifer storage, transfer and recovery (ASTR) projects. An ASTR project is proposed to be developed in conjunction with the Inner North stormwater reuse scheme. Where feasible, ASTR schemes can be relatively highly cost effective and further investigations are anticipated.

1.3 Water management challenges

Population growth and future water demands

- ACT's *Think water, act water* policy sets targets to reduce potable water consumption by 12% by 2013 and 25% by 2023
- Alternative water supplies are required to meet the 25% target
- Insufficient supply from existing and augmented storages may limit higher levels of population growth by 2030

Due to concerns related to the security of supply for the ACT given population growth, climate change, bushfire and other factors, a large body of work has looked at the future projections for water use and the ability to support the demands from an infrastructure perspective. The overall demand depends on population growth, behavioural changes and expected climate change. The available supply is also closely linked to the impacts of climate change and the assets in place to harvest, store and treat water.

Canberra's population is growing and under a high growth scenario could increase from the current 400,000 to 500,000 by 2025, 600,000 by 2035 and 700,000 by 2050. The *Review of Planning Variables for Water Supply* *and Demand Assessment* [*ActewAGL*, 2010b] provides estimates of future population and demands. A number of cross border localities were included such as Queanbeyan to reflect the total volume of supply to be serviced from infrastructure within the ACT.

The ACT Government's *Think water, act water* document (currently under review) defines targets to reduce potable water consumption by 12% by 2013, and 25% by 2023. It is intended that a variety of means are used to achieve these targets including:

- education and advertising;
- Permanent Water Conservation Measures;
- effluent reuse;
- stormwater harvesting;
- water efficiency systems at large irrigation sites such as sports fields
- rainwater tanks;
- water efficient appliances and fittings;
- leakage reduction; and
- requiring new developments to reduce water use by 40% through water sensitive urban design.

It is expected that the 12% target can be achieved through permanent water conservation measures, demand management programs and an increased awareness of the need for water conservation. However, further augmentation measures such as non-potable substitution including recycling treated wastewater, stormwater reuse and rainwater tanks will be required to reach the 25% target by 2023 [*ACT Government*, 2007; *Institute for Sustainable Futures*, 2003]. Recent water resource modelling to assess the need for and benefit of augmentation works assumes the target demand reductions of 25% by 2023 specified in *Think water, act water* will be achieved [*ActewAGL*, 2010b]. Based on discussions at the workshops it is understood the Cotter Dam expansion and Murrumbidgee to Googong pipeline are expected to provide an acceptable level of security until between 2030 and 2040.

Figure 1 summarises the relevant total population estimates (based on high growth), estimated daily per capita demands (based on 12% reduction by 2013 and 25% by 2023) and the total annual water demand based on the respective reduction targets, see Appendix B for underlying data. These figures indicate that, based on the need to achieve the remainder of the 25% reduction by 2023 and then a continuation of the 2023 demand level into the future, approximately 1 GL/yr will be required to be supplied from alternative sources and/or strategies by 2014. This 'deficit' will increase to approximately 8 GL by 2020, 13 GL by 2030, 15 GL by 2040 and 17 GL by 2050.

Any shortfall in the efficiency measures and alternative non-potable supply volumes will result in a reduced design life for the current augmentation projects or shortfall in supply. If only water efficiency actions to achieve reductions of 12% were taken, the design life before further action is required would be reduced to between 2020 and 2030. If no action were taken, the design life could be reduced to between 2015 and 2025.

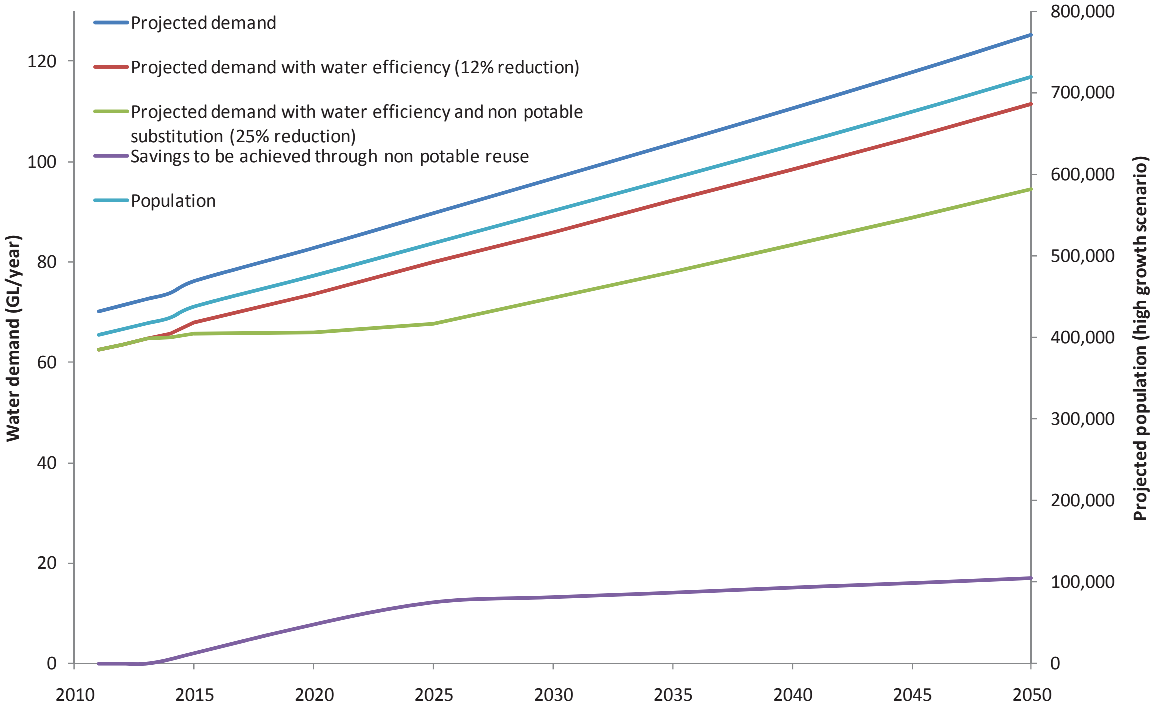


Figure 1 **Projected population and water demand under a range of scenarios**

1.3.1 Climate change and drought

- Potable supplies rely on on-line dams to capture and store winter run-off for year-round supply
- Inflows over the last 10 years have been 63% below the long-term average
- Rainfall and run-off are predicted to decrease and evaporation is expected to increase in the ACT with climate change
- The ACT will be vulnerable to water shortages if it continues to rely primarily on a single type of water source

Periods of drought and flooding rains are part of the Australian landscape. Water availability is highly dependent on climate and significant annual and decadal fluctuations occur. Under expected climate change scenarios [*CSIRO and BoM*, 2007], higher temperatures and evapotranspiration as well as reduced and less frequent rainfall are expected. These will result in reduced soil moisture levels and a greater proportion of rainfall being absorbed and subsequently returned to the atmosphere through evapotranspiration. Therefore expected climate change will result in reduced runoff as a greater proportion of rainfall being absorbed by catchment soils. This effect has been observed during the recent drought period. Measured inflows into ACT storages were below the long term average from 1994 to the spring of 2010 and approximately 63% below the period from 2001 to June 2010, as illustrated in Figure 2. These reductions in catchment flows greatly exceed the corresponding reductions in precipitation, demonstrating the influence of soil moisture on flows from natural catchments and the potential vulnerability of this water source to low rainfall periods and expected changes in climate.

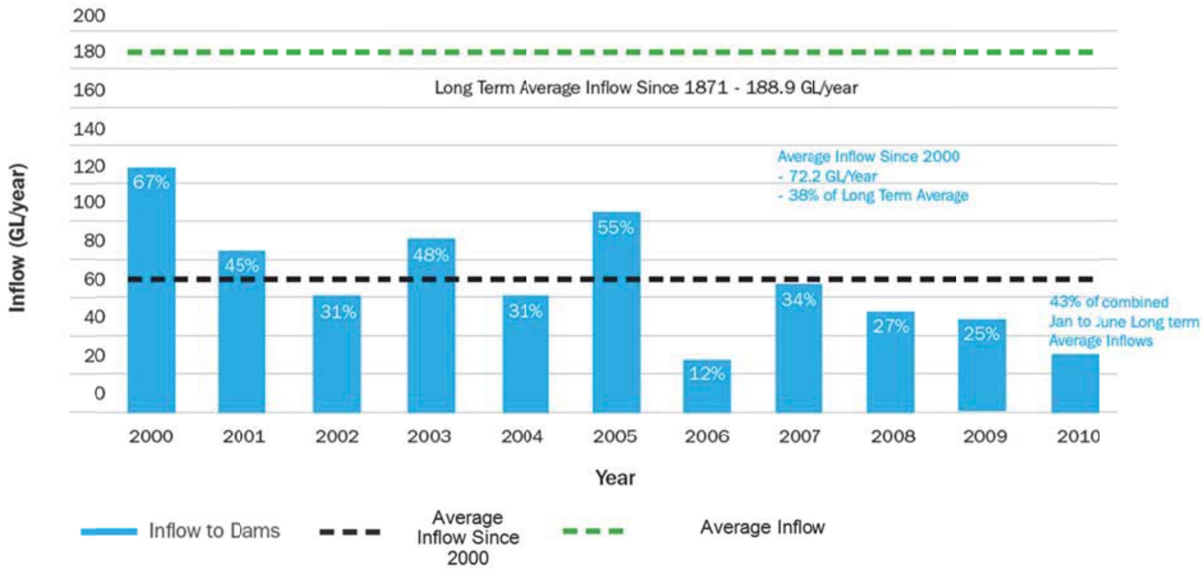


Figure 2 **Recent inflows to Corin, Bendora and Googong Reservoirs [*ACTEW Corporation*, 2010] fix key to graph – inflows swapped**

The potable supply network is largely reliant on three river catchments (Cotter, Murrumbidgee and Queanbeyan) and on-line dams to capture flows during the wetter months and provide storage for a reliable supply throughout the remainder of the year. A proportion of inflows to the dams must be released as environmental flows. Dependency on this single type of water source may leave the ACT vulnerable to water shortages in future due to drought or climate change reducing natural catchment runoff.

1.3.2 Bushfire

- Bushfires result in contamination of the water storage and reduce run-off for up to 50 years
- The peak runoff reduction of 15% occurs about 17 years after the fire or around 2020 for the 2003 fires

In the ACT, the potential risk of catchment bushfires must be considered given the high proportion of forested land within the water supply catchments. The 2003 bushfires illustrated the vulnerability of the ACT's water supply with the widespread destruction of forests within the Cotter River catchment. Bushfires within water supply catchments result in short term damage through contamination of storages through ash, sediments, debris and fire retardant. Further, inflows to water storages are reduced after fire due to an increase in water uptake by the regenerating forest. Following the 2003 bushfires, work has been undertaken to quantify the impact of severe bushfire events on catchment hydrology based upon observed catchment recovery to date. Modelling (calibrated against limited observations) suggests that the maximum inflow reduction is 15% about 17 years after the fire, and reduced inflows are predicted to occur for more than 50 years [*ActewAGL*, 2010b].

1.3.3 Ecological impacts of urbanisation

- The Murrumbidgee River is in poor condition
- Lakes and ponds in Canberra are highly valued, but prone to blooms of potentially toxic blue-green algae
- Urbanisation creates flashy stormwater run-off with high flow rates and increased frequency of disturbance and damages downstream waterways
- Urban stormwater run-off is polluted
- Treated wastewater discharges pollute the Murrumbidgee River
- Diversions from dams disrupt environmental flows

As occurs with all urban centres, development within Canberra and the ACT has had a negative impact on waterways. The Murrumbidgee River is considered to be in poor to very poor condition [*Murray-Darling Basin*

Authority, 2010] with significant issues related to clearing of vegetation, declining native fish populations, an increase in exotic fish (which make up approximately 87% of biomass), low biodiversity of macro invertebrates, altered hydrology and poor water quality [*MDBC*, 2008]. Specifically, ongoing water quality issues include high turbidity, elevated nutrient levels and blue-green algal blooms during spring and summer. Whilst it is recognised that downstream agricultural practices are the principal contributors to waterway degradation, the montane and upland zones in and downstream of the ACT are also considered to be in poor to extremely poor condition [*MDBC*, 2008]. As such, it is recognised that the effects of urbanisation in terms of increased surface runoff from impervious areas, reduced base flows, diversions for water supply and treated sewage discharges, are likely to have adversely impacted the health of downstream aquatic environments. If left unmitigated, these impacts will continue to have detrimental consequences for these receiving environments.

There are also many large scale open water bodies across Canberra affected by urban runoff. These, particularly Lake Burley Griffin, have become valued for their recreation and amenity value. These 'lakes' provide some attenuation of peak runoff events, but are generally not configured for flood attenuation. The existing lakes receive urban stormwater runoff that is mostly untreated. Whilst they provide some settlement of sediments and biological nutrient uptake, the size of the water bodies can result in re-suspension through wind driven circulation and seasonal algal blooms due to insufficient through flows. The algal blooms present a significant risk to the community with blue green algae, which can be toxic. More recently, the ACT has supported the construction of regional stormwater quality control ponds and wetlands. These typically receive flows from large areas of residential development to provide water quality improvements through physical and biological processes. Some of the earlier stormwater ponds are not sufficiently vegetated to control internal nutrient releases, may be prone to seasonal algal blooms and should be managed as receiving waters. Since the ponds are hydraulically connected to the downstream river systems, problems generated within the ponds can adversely impact the rivers. Therefore, management of the water quality in the receiving environments must also include management of water quality in the ponds. The vegetated wetlands and better vegetated ponds provide an effective treatment function for upstream catchments to remove nutrients.

Increasingly these ponds and wetlands are being integrated with stormwater harvesting projects, providing storage and supply to irrigation demands in close proximity. This typically involves draw-down from the natural water level. Research by Dr Fiona Dyer at the University of Canberra (Pers. Comm., 2011) has shown there are potential water quality benefits associated with draw-down of approximately 600mm, so such a design can provide both water for reuse and additional water quality benefits.

The impacts of urbanisation on waterways generally result from the following factors which are of relevance to the Canberra context:

- Altered Hydrology. Urbanisation and development significantly increase surface stormwater runoff flows while reducing evapotranspiration, base flows and groundwater recharge [*Arnold Jr and Gibbons*, 1996; *Booth and Jackson*, 1997; *Paul and Meyer*, 2001; *Walsh et al.*, 2004a]. Urban stormwater excess flow volumes are generated by the conversion of vegetated land cover to impervious surfaces, see Figure 3. Under natural pre-development conditions (open woodland and grassland for Canberra) rainfall events recharge the shallow soil moisture stores. Most of the water is evaporated or transpired by plants back to the atmosphere. The remaining water infiltrates into groundwater systems and is discharged to waterways as base flow or infiltrates into deeper groundwater systems. Losses through interception and evapotranspiration can account for up to 85% of rainfall [*Arnold Jr and Gibbons*, 1996; *Wong et al.*, 2011]. Higher surface runoff rates, volumes and frequencies and reductions in filtered and attenuated base flows adversely impact on urban waterway ecology. Stormwater excess flow volumes can be as much as five times natural catchment flows [*Paul and Meyer*, 2001]. Failure to understand and account for urban stormwater excess will result in ongoing downstream impacts to waterways and a lost opportunity to harvest stormwater. The reuse of stormwater helps to reduce this urban excess, increase evapotranspiration within urban areas and restore a more natural hydrology. This yields a range of environmental and social benefits such as high quality irrigated urban areas for recreation, water bodies for urban amenity and reduced urban heat island effects.
- Stormwater Pollution. Urban stormwater contains pollutants from the atmosphere and washed off impervious surfaces. These include heavy metals, nutrients, oxygen demanding substances, particulates, pathogens and litter which impact the visual and recreational amenity of waterways or receiving water bodies through discolouration and visible debris, scums and odours and contamination with pathogens. They have a range of ecological impacts such as smothering of habitat, asphyxiation of organisms, algal blooms, and loss of biodiversity and abundance [*Wong*, 2006].

- Wastewater pollution. Treated wastewater is discharged to the Murrumbidgee and Molonglo Rivers. Treated wastewater is discharged to the river throughout the year, creating ongoing elevated flows through summer that would not naturally occur, see Figure 4. Decreases in winter flows and increases in summer flows adversely impact on waterway ecology and it is important that both volumes and timing of flows are considered. Under the Murray-Darling Basin Plan, treated wastewater discharges are accounted as beneficial return flows whereas timing also needs to be taken into account. The LMWQQC provides a high level of treatment to tertiary standard. However, the discharge is still characterised by elevated nutrient levels including nitrogen and phosphorous and high total dissolved salts (TDS) relative to natural waterway conditions for the Murrumbidgee River. The continued discharge of treated wastewater impacts the ecological health of the Molonglo and Murrumbidgee Rivers and increases nutrient and salt loads to Burrinjuck Dam and the Darling and Murray Rivers. It is recognised that the rivers provide a level of attenuation and treatment of pollutants, however nutrient levels may still contribute to algal blooms in Burrinjuck Dam and management of phosphorus to nitrogen ratios in discharges have been shown to be important to manage these. Further study of the implications of elevated nutrient and pollutant and concentrations for the Murrumbidgee River would be useful in better understanding these impacts.
- Catchment dams for water supply disrupt the natural flow regime while new dams result in flooding of large areas upstream. Operating frameworks have been established to manage the release of environmental flows, however these will never replicate natural hydrology. Natural freshwater ecosystems depend on a full range of runoff events and in particular need the variability of natural rainfall runoff to support biodiversity. These can addressed through increased use of non-potable sources to allow greater flexibility in the timing and volume of environmental flows released from dams. See Figure 4 for an illustration of the impacts of irrigation diversions, urban diversions and wastewater discharges on the Murrumbidgee River.

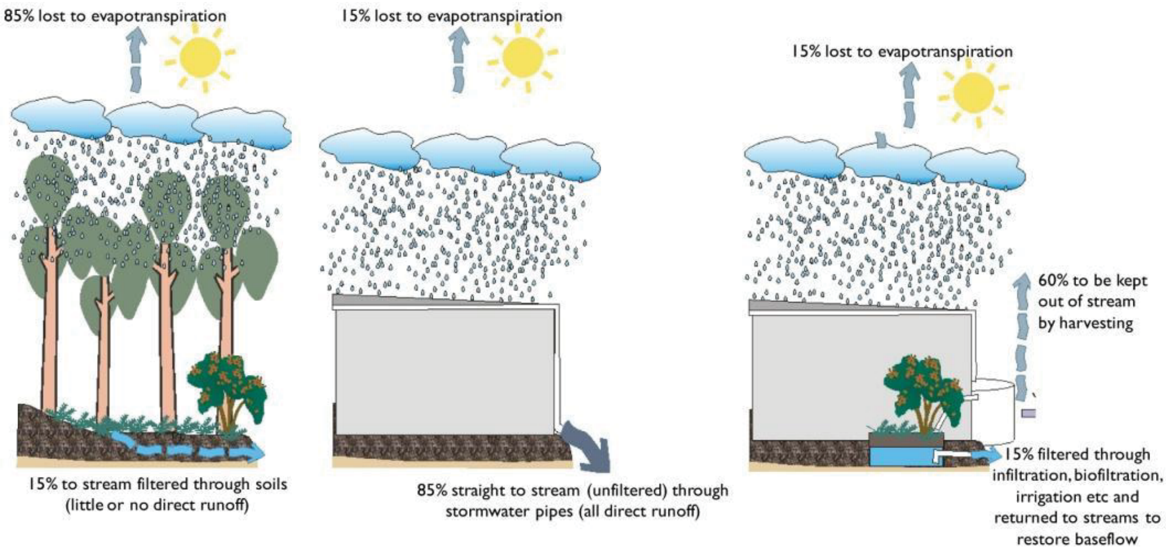
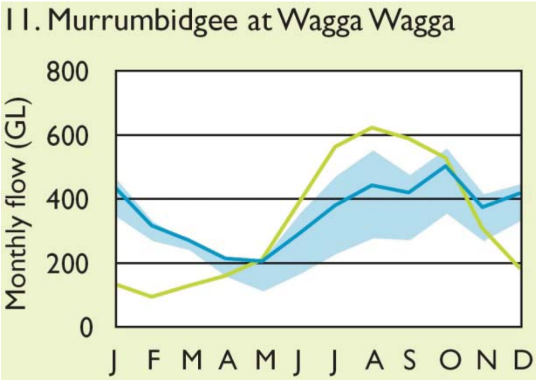


Figure 3 Impact of urbanisation on stream flows in urban waterways [*Wong et al.*, 2011]

In response to these current and ongoing issues, opportunities exist to modify the current approach to improve the ecological outcomes. The adoption of integrated water management approaches can benefit habitats and communities both within and downstream of Canberra through the implementation of WSUD, stormwater reuse and wastewater recycling for Canberra to:

- Improve the ecological health of urban waterways and water bodies by reducing stormwater flow volumes, frequency of disturbance and pollutant loads discharged to receiving waters through the implementation of WSUD and stormwater reuse.
- Improve the ecological health of the Murrumbidgee River by reducing the discharge of unseasonal flows during summer and elevated nutrient loads through wastewater recycling.
- Provide water for irrigation of high quality public open space to increase shading and evapotranspiration, reduce urban heat island effects and enhance biodiversity.

- Reduce reliance on natural catchment dams allowing an increase in environmental flows providing good quality water to waterways with timing appropriate for aquatic ecosystems.



*Yellow line indicates flow without development, blue line with development, for historical climate

Figure 4 Impact of urban and irrigation diversions and wastewater discharges on Murrumbidgee River flow regime [*CSIRO*, 2008]

In addition to ecological outcomes, the health and financial implications (as well as risk assessments) of the management of infrastructure for alternative water sources is assessed in Discussion Papers 1 and 3.

1.3.4 Murray Darling Basin Plan

This report was completed prior to the 28 November 2011 release of the proposed Basin Plan 2012. The proposed Basin Plan 2012 has not been fully reviewed and incorporated into this report due to time constraints. However, it should be noted that no reduction in the long term average sustainable diversion limits (SDLs) are proposed for the ACT.

- The Murray-Darling basin authority will set SDLs[4] for the ACT to protect the health of the Murray-Darling River system
- The proposed SDLs[4] are 26-34% lower than the current limit or 34-38 GL/year and only slightly higher than current net use of 30 GL
- Diversion limits can increase in future to allow for population growth however this will place increasing stress on the Murray-Darling River system
- The SDLs[4] do not presently account for increases in run-off from urban impervious surfaces although extractions of urban stormwater and wastewater are included
- It is essential that an appropriate means of accounting for urban stormwater excess and extractions for stormwater reuse and wastewater recycling is agreed with the MDBA to ensure the viability of non-potable water reuse and recycling

The Murray-Darling Basin Authority (MDBA) is a statutory authority with a mandate to manage the water resources within the Murray-Darling watershed. The MDBA works closely with the States and Territories including NSW, VIC, SA, QLD and the ACT to set water allocation rights to provide an acceptable level of protection for the nationally significant freshwater ecosystem, whilst meeting needs for productive demands relating to agriculture, horticulture and urban usage. The MDBA will set diversion limits to replace the limits previously set by the ACT water cap.

[4] This report was completed prior to the 28 November 2011 release of the proposed Basin Plan 2012. The proposed Basin Plan 2012 has not been fully reviewed and incorporated into this report due to time constraints. However, it should be noted that no reduction in the long term average SDLs are proposed for the ACT.

In accordance with the Water Act 2007, the MDBA has developed a plan[5] (Basin Plan) for the management of water resources throughout the entire Murray-Darling Basin. The Basin Plan provides long term SDLs to be applied to both surface and groundwater extractions. The Act and Basin Plan seek to address the over-extraction of water to restore and maintain the Basin's key environmental assets and ecosystem functions. Final decisions on the exact detail around the SDLs was based on extensive consultation with community and key stakeholders and provides a legislated means of governing water within the expansive system. As a precursor to the proposed Basin Plan 2012, the MDBA released a Guide to the proposed Basin Plan, henceforth referred to as *The Guide* [*Murray-Darling Basin Authority*, 2010], which provides provisional SDL targets for geographical regions across the basin. Assessments have been made of the environmental water requirements of key natural systems such as the large flood-dependent wetlands that support populations of waterbirds, fish, and large forests and woodlands. These were based on comprehensive hydrological modelling and assumptions related to predicted climate change impacts.

The scale of the overall Murray-Darling system and the economic importance of primary industries within the basin and to both the local and national economies inevitably results in an emphasis in *The Guide* on irrigation demands and runoff projections from non-urbanised catchments. The objective of maximising the net economic returns to communities and key industries [*Murray-Darling Basin Authority*, 2010] necessarily focuses mostly on rural communities who rely on irrigation water for employment and therefore stand to gain economically from the provision of water. As a consequence, there is a lesser focus on the behaviour and needs of urban areas. The Basin Plan should consider the potential benefits of non-potable reuse in terms of high quality open space, improved health, reduced urban heat island effects and improved seasonality of flow and ecological health of urban waterways in the allocation of water to urban areas.

Full details of the assumptions underlying the Basin Plan were not yet available during preparation of this report.[5] Based on our interpretation of *The Guide* and discussions with officers of the ACT Government and MDBA, an acknowledged limitation of the hydrologic analysis is that the impacts of land use change (such as urbanisation) are not considered. For the purposes of the Basin Plan, comparisons are made between natural conditions (defined as no extractions) and current conditions with extractions to determine SDLs. Urbanisation reduces evapotranspiration and increases stormwater excess runoff, resulting in adverse impacts on waterways and increasing flow volumes and these are not accounted for. A further difficulty is that while the increases in flow due to urbanisation are not accounted, the extractions of this urban stormwater and treated wastewater are accounted. This inconsistency is the subject of ongoing discussions between the MDBA and ACT Government. *It is considered that the Plan should acknowledge the detrimental impacts of urban stormwater runoff and treated wastewater discharges and recognise stormwater excess flows generated by urban areas. The plan should also recognise the potential benefits of reuse of stormwater excess and treated wastewater where diversions do not exceed stormwater excess flows generated.*

Sustainable Diversion Limits[5]

The Guide proposes that SDLs should achieve a basin wide reduction in the current long-term average surface water diversion limit from 13,700 GL per year to between 10,700 GL and 9,700 GL per year or 22% - 29% of current allocation levels. The range of reductions refers to three distinct scenarios to provide differing levels of buffering to environmental, social and economic impacts.

Within the Murrumbidgee system, 258 key environmental assets were identified including the Lower Murrumbidgee River floodplain and the mid-Murrumbidgee River wetlands. Based on extensive assessment and analysis the environmental water requirements for the total Murrumbidgee region have been estimated between 1,478 GL/yr and 2,417 GL/yr. To achieve these environmental flows the Murrumbidgee region would need to reduce the current diversion allocation (surface and groundwater) from 2,613 GL/y to between 1,935 GL and 1,704 GL per year. This represents an overall reduction of between 26% and 35%.

Within the ACT sub region of the Murrumbidgee catchment, *The Guide* has proposed the SDL targets to be applied to groundwater and surface water extractions in order to meet these Basin Plan commitments. Table 2 summarises the current and proposed diversion limits for the ACT as documented in the Guide. These limits include all extractions from surface waters including direct river diversions and floodplain interceptions. It is noted

[5] This report was completed prior to the 28 November 2011 release of the proposed Basin Plan 2012. The proposed Basin Plan 2012 has not been fully reviewed and incorporated into this report due to time constraints. However, it should be noted that no reduction in the long term average SDLs are proposed for the ACT.

that surface water diversions and returns vary from year to year and groundwater extractions within the urban area are estimated at 0.4 GL/year.

Table 2 Current and proposed diversion limits for the ACT within the Murrumbidgee River Catchment [*MDBA*, 2010][6]

Diversion source	***Current average net water usage (GL/yr)***	***Current net Diversion Limits (GL/yr)***	***Proposed net Sustainable Diversion Limits (GL/yr)***	***Reduction in Diversion Limits***
Surface water (includes diversion and interception)	30	51	34 - 38	26% - 35%
Ground water	-	7.25	4.4	39%

The ACT Water Cap defines the total amount of water the ACT can extract from the Murray-Darling Basin. The cap is presently a net of 51 GL/year including extractions for potable use and treated wastewater returns. Canberra's water supply of 65 GL/yr and treated wastewater discharges of approximately 35 GL/yr result in a net diversion of approximately 30GL/yr. Therefore under the existing population and water usage scenario, the ACT is operating within its cap limits with an average annual surplus of approximately 20 GL/yr, as shown in Table 2. Under the proposed SDLs the allowable net diversion will be just slightly higher than the existing usage, leaving limited room for future increases in water use that may occur due to relaxation of water restrictions or to provide high quality public open space. While the cap can be increased to account for population growth assuming similar per capita use, such increases will put further pressure on the already stressed Murray-Darling River system.

The proposed SDLs will not be exceeded until between 2030 and 2040 based on a projected 25% reduction in future demands and a ratio of 55% of total supply being returned to the system as treated wastewater, see Section 1.0. However, in the absence of non-potable substitution and only a 12% reduction in demands, *the current SDLs would only support the predicted population until between 2020 and 2030*. These projections indicate that the predicted growth rates for the ACT can realistically be managed within the proposed SDLs without reliance on increases in the cap for population growth provided that water demands are reduced using both demand reductions and non-potable substitution in accordance with the targets in *Think water, act water*. Achievement of these targets is complicated by the current approach to setting SDL's which does not accurately account for changes in hydrology due to urbanisation. *It is recommended that the proposed non-potable master plan is pursued in conjunction with an agreement with the MDBA for appropriate accounting of urban hydrology including both generation of stormwater excess as well as extractions.*

1.4 Response to challenges

– Water restrictions and permanent water conservation measures have been introduced and prevented Canberra' s water supply from running dry in the recent drought

– Structural augmentation projects will increase the available supply and reliability of the existing system by also drawing water from the Murrumbidgee River and additional storage in Cotter Dam

– New water supplies will generally have higher energy use and marginal costs than existing supplies

– Water efficiency targets to reduce demand by 12% by 2013 have likely been achieved through persistent changes in consumption behaviour

– Think Water Act Water sets a target for non-potable substitution to reduce demands by a further 13% by 2023

– Implementation of the master plan for non-potable water use is essential to secure Canberra's water supply for the next 20 to 30 years

[6] This report was completed prior to the 28 November 2011 release of the proposed Basin Plan 2012. The proposed Basin Plan 2012 has not been fully reviewed and incorporated into this report due to time constraints. However, it should be noted that no reduction in the long term average SDLs are proposed for the ACT.

Concerns regarding the security of Canberra's water supply have increased in recent years with the combined effects of an increasing population and reduced rainfall and runoff through a prolonged drought placing the existing system under significant pressure. The 2003 bushfires highlighted the vulnerability of the ACT water supply catchments to bushfire. There is also concern that climate change will lead to long term reductions in rainfall and water supply catchment yields.

Figure 5 **Canberra's augmented water supply system**

The ACT Government and ActewAGL have and are continuing to take action to respond to these challenges and events through a number of approaches including the following:

- Water restrictions were implemented across the Territory to reduce consumption, and these and other measures have been shown to be effective in preventing Canberra’s storages running dry in 2007 by reducing consumption by an estimated 34% [*Purves et al.*, 2011], see Figure 6.
- Permanent Water Conservation Measures (PWCM) have been introduced.
- Structural augmentation projects have commenced to increase the security of the potable water supply. The capacity of the Cotter Dam is being increased from 4 GL to 78 GL and water will be pumped to the Mt Stromlo treatment plant for treatment and subsequent gravity distribution. A pipeline is being constructed to divert water from the Murrumbidgee River at Angle Crossing into the Googong Dam catchment. Refer to Figure 5.
- *Think Water Act Water* target for demand management and water efficiency improvements to reduce demand by 12% by 2013.
- *Think Water Act Water* target for non-potable substitution and other measures to further reduce demands by 25% (a further 13%) by 2023.

The structural augmentations provide a buffer to allow time for further alternative water supply schemes to be pursued that are less susceptible to drought and climate change including wastewater recycling and stormwater reuse. A difficulty for the structural augmentation projects is that they continue the reliance on natural vegetated catchments which are vulnerable to climate change and drought and it is important that they are complemented with demand reduction and non-potable substitution works that are less susceptible to these risk factors. The projects also necessitate a shift from a low energy gravity system to a higher energy system with greater reliance on pumping. Up to 100 ML/day may be pumped from the Murrumbidgee River at 600 m above sea level over the Gibraltar Range (approximately 850 m above sea level) to the Googong Dam while historically the use of Cotter Dam has been avoided due to the high cost of pumping to Mt Stromlo.

It is expected that the combined effect of the structural augmentation works and achievement of the objectives for demand management set out in *Think Water Act Water* will provide water security and protection from water restrictions until between 2030 and 2040. The master plan developed in this study sets out works for non-potable supplies to complement the augmentation works under construction and it is essential that the works described in the master plan are completed in a timely manner to secure Canberra’s water supply for the next 20 to 30 years. The master plan and water saving mechanisms effectively defer the timeframe before further water supply investment may be required.

The Canberra Spatial Plan states that the necessary planning and design of new water supply infrastructure should take place well in advance of the need to begin construction [*ActewAGL*, 2010b]. This will ensure a state of readiness to respond to a range of different scenarios that may occur under climate change or to drought or bushfire impacts, while refraining from committing to large infrastructure works until they are needed. *It is imperative that the planning of works for non-potable supplies continues to be progressed to ensure the timely construction of works and a state of readiness to develop new non-potable water supplies as needed.*

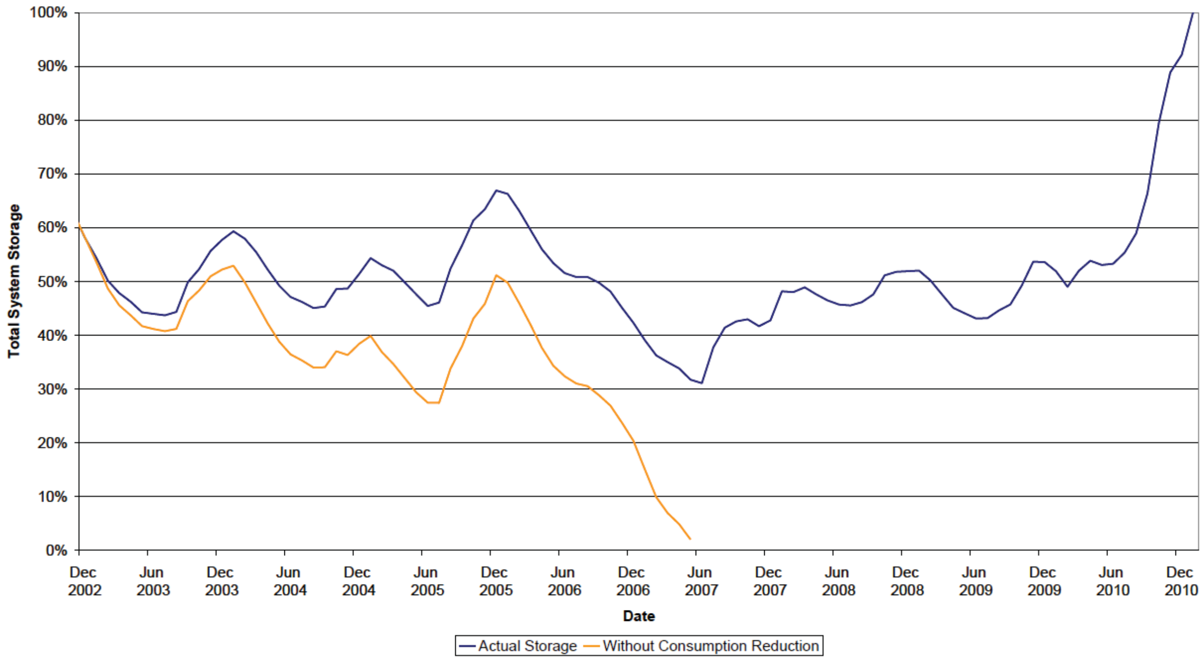


Figure 6 Estimated water supply storage with and without reductions in consumption [*Purves et al.*, 2011]

1.5 Benefits of non-potable water use

- Stormwater harvesting can mitigate the impacts of urban stormwater hydrology and pollution
- Stormwater can be harvested as a water supply, reducing the need to divert natural catchment run-off to dams
- Recycling treated wastewater reduces summer discharges of treated wastewater and can allow dam releases of environmental flows during winter to improve river hydrology and water quality

Urban stormwater harvesting provides the potential to benefit the aquatic ecosystems through improving water quality by diverting, treating and harvesting the polluted urban excess from impervious surfaces and dampening the flashiness of urban runoff. The *Centre for Water Sensitive Cities* at Monash University is currently undertaking a large research program focused on Cities as Water Supply Catchments. Research projects are specifically looking at the environmental, social, economic, public health and technological aspects as they relate specifically to stormwater harvesting. Findings documented in the Blueprint 2011 [*Wong et al.*, 2011] include:

- In natural catchments, most waterway flows are derived from base flow and inter-flow which is filtered through the vegetated root zone and soil resulting in relatively high quality water, while often only a small proportion is derived from direct surface runoff. Urbanisation significantly increases the volumes of surface runoff and the associated pollutants.
- Flow volume and variability are primary controls of geomorphology and the ecological health of streams and rivers. Urban stormwater runoff alters these aspects greatly, causing degraded urban waterways. Harvesting urban stormwater reduces runoff volumes, rates and frequency and, when combined with other stormwater management measures, can help to restore the pre-development catchment water balance.
- Integrated stormwater treatment and harvesting systems can reduce stormwater pollutant loads and concentrations, which are also an important control of ecosystem health in urban waterways.
- Distributed application of stormwater harvesting, treatment and infiltration throughout the urban landscape is an effective way of protecting urban waterway ecosystems through reductions in event flows and pollutant loads and restoration of base flows.

Additionally, the harvesting of stormwater from urban catchments such as Canberra has the potential to provide significant volumes which can be used to service various demands on a fit for purpose basis. Whilst the current augmentation projects being implemented across the ACT are intended to address concerns related to supply security in the medium term, they do not provide long term water security when projected population growth is considered. The implementation of large scale distributed stormwater harvesting projects, which result in significant yields can be used to meet the deficit in future water requirements.

The flow and pollutant loads were estimated for Canberra for urban and forested areas using recommended parameters for Canberra (Waterways - Water Sensitive Urban Design General Code, 2009) for soils and default water quality parameters in MUSIC. The effects of urbanisation on both flows and pollutant loads are readily apparent, see Table 3.

Table 3 An estimate of possible flows and pollutant loads for different catchment types in Canberra (Area 100 ha)

	Forest*	Urban pervious areas	Urban impervious areas
Flow volume (ML/year)	57	57	583
TSS Load (kg/year)	5,200	8,600	90,000
TP Load (kg/year)	5.2	12.7	131
TN Load (kg/year)	58	152	1,550

*Assumes same soils as urban, however forested areas typically have much greater soil storage capacity than disturbed soils in rural and urban areas so the actual flows and loads from a forested catchment would actually be less than these

Stormwater harvesting can potentially significantly reduce the flow volumes and pollutant loads discharged to receiving waters through both treatment and reuse. The pollutant loads per ML of water were estimated and are shown in Table 4. It can be seen that stormwater and also treated wastewater has significantly higher pollutant loads than natural catchment areas.

Table 4 Pollutant loads per ML

	Forested catchment runoff	Urban stormwater runoff	Treated wastewater from LMWQCC
Flow volume (ML/year)	1	1	1
TSS Load (kg/year)	91	154	-
TP Load (kg/year)	0.09	0.22	0.2
TN Load (kg/year)	1.0	2.7	15

Wastewater re-use provides the potential to benefit the aquatic ecosystems through an improvement in water quality by reducing the discharge of polluted water with higher nutrient loads than natural catchment flows and a reduction in the elevated summertime base flow discharges. Both of these characteristics of treated effluent are recognised as contributing to the ongoing degradation of downstream receiving waterways.

The nature of effluent generation results in a relatively uniform distribution with relatively little variation between summer and winter flow rates to treatment plants. The constant supply of wastewater available makes treated wastewater ideal for servicing constant demands such as toilet flushing. The constant supply of treated wastewater can provide a high reliability of supply for irrigation demands and can also be used to benefit irrigation demands serviced by treated stormwater by meeting any shortfall during drier summer months. With the inclusion of appropriate balancing storages the use of treated effluent can achieve reliabilities close to 100%. Opportunities exist to integrate treated wastewater and stormwater through connected transfer networks where appropriate. This option can enable certain demands to be serviced by stormwater as a priority with wastewater improving the supply reliability during summer months.

The use of treated wastewater for non-potable purposes can allow a reduction in the diversion of natural catchment runoff, and thus contribute to improving environmental flows and downstream water quality.

It is recognised that urban heat island effects lead to an increase in heat related death and illness in people [CDC, 2006]. Green infrastructure supported by stormwater reuse and wastewater recycling can provide microclimate benefits through increased shading and evapotranspiration to reduce urban heat island effects. Mitigating urban heat will have a positive effect on human health, reducing mortality and morbidity.

Green infrastructure such as sports fields, parks and gardens can have significant social and health benefits and the health benefits of exposure or access to nature within parks are well documented [*Maller et al.*, 2008]. The availability of these areas can lead to improved health of people participating in sport and recreation within these areas while irrigation of sports fields also reduces the risk of injury for players. There are also a range of social benefits from sport. While the prolonged drought and water restrictions have adversely impacted on sporting clubs and associated social structures, the use of non-potable sources can reduce the risk of recurrence of water restrictions.

2.0 Sources and demands

- Two wastewater treatment plants currently operate in Canberra
- The Lower Molonglo Water Quality Control Centre (LMWQCC) has sufficient supply to meet all current ACT non-potable water demands
- The LMWQCC discharges wastewater that is much lower in pollutants compared to typical wastewater, but higher in most pollutants than treated stormwater or natural catchment run-off
- Fyshwick wastewater treatment plant performs poorly but much of the effluent is reused
- Sewer mining is much more costly than using treated wastewater from the LMWQCC
- 14 existing ponds and wetlands and 47 proposed ponds in Canberra have the potential for stormwater harvesting
- One aquifer storage and recovery scheme is proposed

2.1 Sources

The potential sources of non-potable water within Canberra include recycled wastewater from treatment plants, stormwater stored in existing lakes and ponds, proposed stormwater wetlands and ponds and groundwater or aquifer storage transfer and recovery (ASTR). These sources have been quantified where possible using information from the CSIRO *Integrated Waterways* project [*Maheepala et al.*, 2009] and other sources as appropriate and incorporated into the preparation of the master plan to assess the supply reliability and cost of using them to service the non-potable demands.

The model is based on the best information available at the time of analysis. However it is recognised that several schemes are currently in development and the master plan can be updated in future as details of these are further refined.

2.1.1 Wastewater recycling

There are two sewage treatment plants operating in Canberra, while a third at Southwell Park has recently ceased operations. These plants currently supply some recycled water to meet limited demands. The quality of treated effluent and scale of operations vary between each of the respective treatment plants.

Lower Molonglo Water Quality Control Centre (LMWQCC)

The LMWQCC is a tertiary treatment plant treating 95% of Canberra's wastewater serving a population of 360,000. It currently treats a median of 34 GL/year with a 5^{th} to 95^{th} percentile range of 28-39 GL/year. The volume potentially available for reuse (based conservatively on the 5^{th} percentile flow) is approximately 28 GL/year and is expected to increase to 32.6 GL/year by 2060.

The LMWQCC discharges to the Molonglo River about 1.4 km upstream of the confluence with the Murrumbidgee River. During dry months, the effluent discharged from the LMWQCC constitutes as much as 30-40% of the total flow in the Molonglo and Murrumbidgee Rivers [*KBR*, 2010]. Therefore, it is important that a high quality of effluent is maintained to preserve water quality in the downstream rivers.

Relative to other sewage treatment plants in Australia, LMWQCC produces high quality effluent with very low concentrations of phosphorus, organic solids and coliforms [*ActewAGL*, 2010a]. It removes 99% of solids and 98% of total phosphorus. The water quality performance of the LMWQCC is summarised in Appendix C. While the treatment performance is relatively good, discharges of treated wastewater have higher pollutant loads than natural catchments and adversely impact on the ecological health of the Murrumbidgee River through high summer discharges and increases in nutrient loads as discussed in Section 1.1. LMWQCC currently supplies recycled water for internal plant uses, irrigation at the Belconnen Golf Course and Hardy's vineyard and for tanker supply.

For the purposes of this study it was assumed that potential wastewater recycling from LMWQCC was effectively unlimited since the volumes treated are significantly higher than the total demands identified and it is unlikely that this would become a constraint unless demands external to Canberra were considered. Consideration should be given to the seasonality of flows and also inter-annual variability during further detailed study of any scheme for the LMWQCC.

Fyshwick treatment plant and North Canberra Recycled Wastewater System (NCRWS)

Treated water from the Fyshwick treatment plant is recycled through the North Canberra Recycled Wastewater System (NCRWS). The plant has a number of operational issues resulting in poor performance of the plant. As a consequence, only a portion of the inflow water is available for reuse and the water quality is relatively poor, being closer to secondary than tertiary treated effluent and requires further treatment before reuse. Of the 4.2 ML/day of inflow, 1.6 ML/day is supplied to the reuse scheme and meets 60% of the demands. Further details of the water balance and water quality performance of the Fyshwick plant are summarised in Appendix C.

For the purposes of this study it was assumed that 1.6 ML/day would be available for use from the Fyshwick plant.

Southwell Park Sewer Mining Plant

Southwell Park was a local scale sewer mining plant supplying nearby irrigation needs. It ceased operation in 2010. Until that time it produced 20-40 ML/year of recycled water. On average 50% of the irrigation demand was met with the balance being supplied by potable water. The cost of operating the plant was considerably higher ($13-$15/kL) than the larger treatment plants due to efficiencies of scale and it would be significantly cheaper to supply recycled water from nearby Fyshwick (NCRWS) [*ActewAGL*, 2010a].

A summary of the sewage treatment plants and costs is provided in Appendix C for reference.

2.1.2 Stormwater harvesting

There are a number of existing ponds and lakes throughout Canberra that can potentially act as a storage for stormwater. Estimated capacities and inflows are shown below. These were generally based on information presented by CSIRO [*Maheepala et al.*, 2009] with updated information based on calibration or more recent reports used where available. Where systems occur in series in close proximity, they are combined within the model and represented as a single storage with multiple outlets. This has been done for Gungahlin and Yerrabi Ponds, Lake Tuggeranong, Isabella Pond and Tuggeranong Weir and the Inner North scheme which includes the Flemington Road Ponds, Dickson and Lyneham wetlands.

There are also numerous proposed ponds that can potentially be used for stormwater harvesting. The level of completeness of this information varies, with catchment areas, estimated inflows and storage capacity available for some storages and not others. Model analysis during master planning has supported the finding that most of these smaller ponds are less attractive for stormwater harvesting due to small storage volumes providing limited supplies at acceptable reliability levels. The data for the existing and proposed ponds and lakes for stormwater harvesting are summarised in Appendix C.

2.1.3 Aquifer Storage Transfer and Recovery (ASTR)

An ASTR scheme is proposed [Cardno Young, 2010; URS, 2011] to be constructed in conjunction with the Inner North stormwater reuse system to increase the storage available. Stormwater is sourced from Ponds P1 and P2 and also transferred from the Dickson and Lyneham wetlands. It is proposed that the ponds will supply a number of irrigation sources directly and also provide a source of water for injection into an aquifer at Kenny/EPIC. An injection rate of up to 70 L/s per bore and a total injection rate of 140 L/s was assumed. It is estimated that up to approximately 570 ML/year could be pumped into the aquifer and available for reuse.

Ongoing urbanisation can adversely impact groundwater reserves through reductions in the recharge of shallow unconfined aquifers and interflow to lowland streams. Deeper confined aquifers are subject to more complex hydrogeology with hydraulic connections dependent on local geology and often distant recharge mechanisms. Water quality within these deep aquifers is typically of a higher quality and therefore any water considered for injection into deep aquifers requires a high level of pre-treatment to protect beneficial uses and prevent contamination. This can be achieved through WSUD such as wetlands and disinfection treatment.

2.2 Demands

- Potential demands for alternative non-potable water include irrigation (sports fields, schools, golf courses, parks) and residential uses (toilet, laundry and irrigation).

Demands for non-potable water supplies in the ACT were identified by CSIRO for the Canberra Integrated Waterways Study [Maheepala et al., 2009]. These were confirmed through cross referencing with the Sports and Recreation database prepared by GHD. The earlier consultation undertaken by CSIRO with the project 'technical group' identified demands which were considered high priority for the purposes of providing alternative supplies. These demands are essentially those which are willing pay a premium for water during periods of water restrictions and typically apply for exemptions from stringent water restrictions. Priority end users included:

- Sports grounds
- School grounds
- Golf courses
- Bowling greens
- Parklands
- Tennis courts
- Other irrigation users such as racetracks, dog clubs and the National Zoo and Aquarium.

In addition, a number of future residential growth areas were included in the modelling. It was assumed that these areas could be provided with a 'third pipe' to supply non-potable water. In these residential development areas both seasonal irrigation demands and constant demands for toilet flushing were assumed. These residential areas represent good opportunities for increasing non-potable water use and reducing the use of potable water for non-potable demands through both the large volumes involved and the constant usage patterns for toilet flushing (high demands throughout the winter months).

It is recognised that the demands described above and assumed for this study do not represent the full range of demands that could potentially be met using non-potable sources. There is potential that laundry and even hot water demands could be met for future developments given appropriate treatment. For example, the combination of rainwater tanks for hot water combined with other non-potable sources for laundry, toilet and irrigation can significantly reduce potable demand. It is also recognised that there are many developments already in planning stages for which no information is yet available for the purposes of this study. There will be additional future opportunities which will arise as Canberra develops and its population grows. Therefore, the demands currently in the model simply represent what is currently readily identifiable and achievable. Additional demands or an expanded range of uses for new developments can potentially be incorporated into the master plan when it is reviewed and updated in future.

3.0 Master plan

- Non-potable water supplies are crucial to the vision of *Think water, act water* and to ensure the ongoing security of Canberra's water supply
- A master plan for non-potable water supply was developed for Canberra including all identified opportunities that were considered practical and economic at this time
- The master plan integrates the various individual schemes within one plan, allowing interactions between schemes and areas where they may be complementary or in competition to be resolved

A master plan for a non-potable water supply network has been prepared and is the main outcome of this study. The plan is based on potential non-potable water sources including wastewater treatment and sewer mining plants, existing and proposed ponds and lakes, groundwater and aquifer storage, transfer and recovery (ASTR) schemes. All identified demands that would use potable water in the absence of a non-potable supply were considered. These included priority public open space, sports and recreational areas that would likely apply for exemptions during periods of water restrictions, identified significant public and private users such as vineyards, horse racing and government facilities. Future development areas with potential for a third-pipe scheme to supply non-potable water for toilet flushing and irrigation were also considered.

A number of factors were taken into consideration during the decision making process in order to determine which demands should be supplied by which sources:

- The scheme should supply as much of the non-potable demand as is practical and economical
- The economic efficiency ($/kL) of the scheme for the utility and total cost
- The hierarchy of use outlined in Discussion Paper 1
- The flexibility of the system to respond to future growth
- Stakeholder comments and feedback

3.1 Non-potable master plan model

- It was recognised that a model was needed to support integrated evaluation of scenarios involving a range of non-potable water supply sources and demands
- A spreadsheet based model was developed to enable the rapid investigation of a range of scenarios for supply of non-potable demands.
- The model allows different types of sources including wastewater recycling, stormwater reuse and aquifer storage, transfer and recovery. Both irrigation and constant demands can be accommodated.
- The model provides preliminary estimates of infrastructure sizing and costs associated with storage, treatment and reticulation of non-potable water from various sources to demands.

A significant limitation of previous studies has been the focus on either stormwater reuse, recycled wastewater or on individual schemes considered in isolation. At the commencement of this study, it was recognised that there was a need for a model that would allow integrated evaluation of multiple alternative water sources of different types to allow consideration of the interactions and potential for cooperation and competition between schemes. Furthermore, there is a need to be able to compare individual schemes using a consistent set of base assumptions.

A water balance and costing model was developed to support the preparation of the master plan, see Figure 7. The model represents potential non-potable water sources, demands and the reticulation network. It allows a range of different scenarios to be considered where different sources of non-potable water and routing of the reticulation network are used to service the various demands. The model provides a preliminary estimate of infrastructure sizing requirements including pipes, treatment and storages and the potential costs associated with these. The model allows the balancing storage size to be varied for a simplified evaluation of different balancing storage and pipe sizing options, although it is recommended that this is confirmed with detailed hydraulic modelling. The strength of the model is that once input data has been provided, the reticulation network can be rapidly rearranged to consider various scenarios for servicing demands with instant feedback provided. This is achieved through the use of lookup tables to estimate reliability of stormwater schemes based on the estimated stormwater excess and storage size to avoid the need for lengthy model runs. This allows a range of scenarios to be rapidly 'gamed' and evaluated to gain an understanding of how the various schemes can potentially be implemented to determine an optimal master plan that provides the best outcomes in terms of financial costs, capacity to meet demands and flexibility for future expansion. Further details of the model and its calibration are provided in Appendix E.

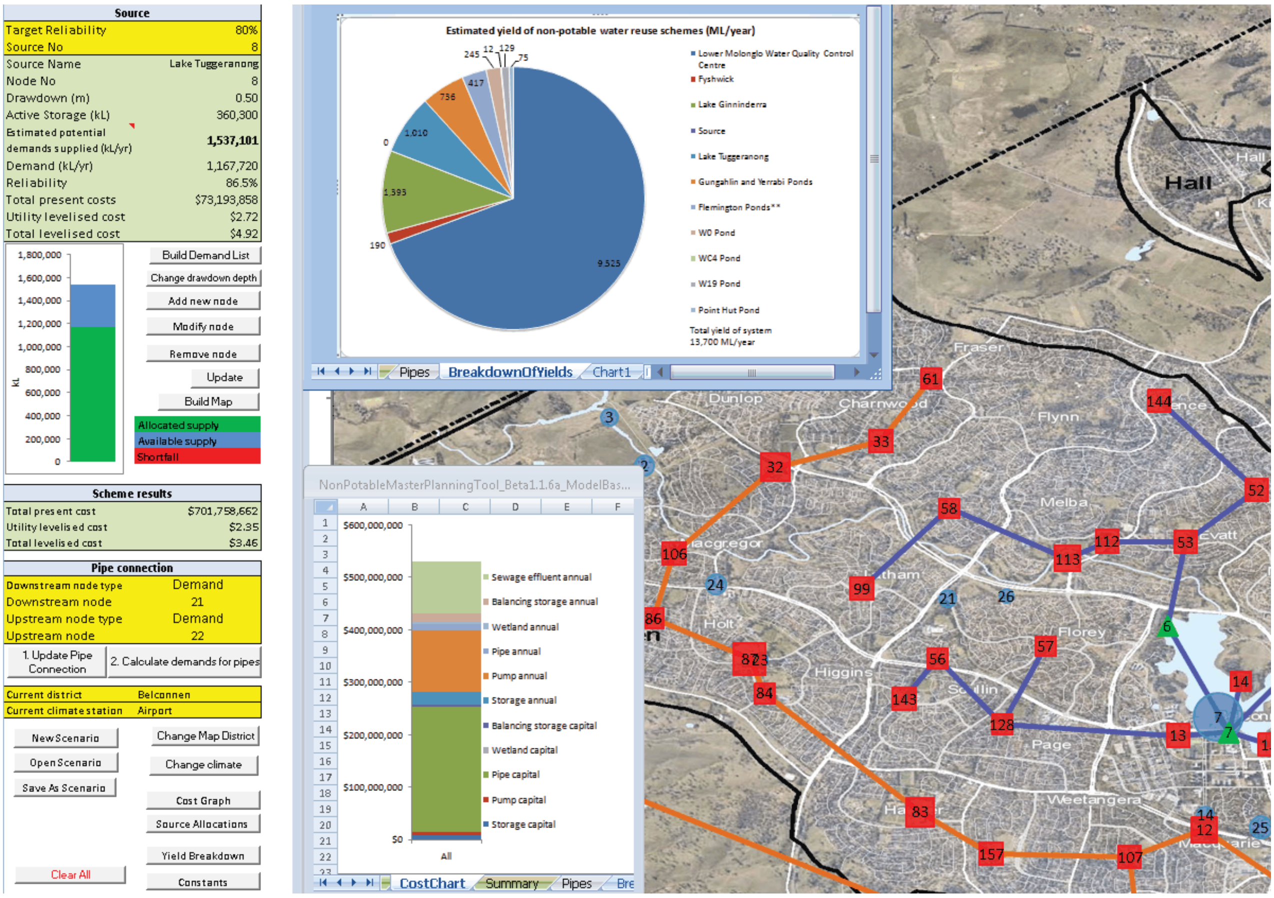


Figure 7 **The non-potable master plan model**

Showing: (left) the user interface with a summary for a source including size, potential and current supply, reliability and cost, the total present cost and levelised costs for the whole system and functionality to connect demands to sources; (top centre) the distribution of supply for the sources used; (bottom centre) a breakdown of present capital and operating costs and; (right) the map showing a source, Lake Ginninderra, connected to a range of surrounding demands while wastewater recycling from LMWQCC supplies demands to the south.

3.2 Development of master plan

– A range of scenarios were evaluated and presented at workshops during the development of the master plan

– An integrated approach incorporating a range of sources produces the most cost effective, flexible and resilient system

A master plan for North Canberra (north of Lake Burley Griffin) was prepared first and presented at a workshop for stakeholders on 2 February 2011. This was followed by a master plan for South Canberra which was presented at the second stakeholder workshop on 12 April 2011 along with an overview of the North Canberra master plan. For the second workshop, a range of scenarios was developed and evaluated to determine the preferred form of the master plan. Further details of these are included in Appendix F.

A number of broad observations were made from the development of the scenarios and master plans for North and South Canberra as follows:

- There is no one single optimal solution (neither stormwater reuse nor wastewater recycling) and integrated solutions involving a range of sources produce the most cost effective overall system as well as increasing resilience through the use of multiple sources.
- Available supply exceeds present demands, therefore most or all demands can be met and there will be available supply for future demands that have not yet been identified.
- The LMWQCC is a large potential supply, providing water that is already treated to a high standard at a low cost in close proximity to urban areas. As such, it will inevitably become the most significant part of any non-potable scheme for Canberra.
- Large scale schemes such as LMWQCC, Lake Ginninderra and Lake Tuggeranong were usually more cost effective than small scale schemes. The exception to this is for relatively isolated demands with sources in close proximity and in a few cases these were the best opportunity.
- Non-potable demands for future development (toilet flushing and irrigation) are substantial and improve the cost effectiveness of schemes for the utility by helping to achieve a critical mass of demands. The Molonglo Valley development is particularly significant.
- The differences between scenarios are not large due to a number of common elements, but they are significant, representing cost and efficiency savings in the order of 10% over the life of the scheme.

The merits of the various scenarios were considered with Scenario 3 being considered the best of the various options given its cost effectiveness and flexibility for potential future growth as well as providing a resilient solution with multiple sources. While Scenario 4 had an apparently better cost effectiveness, the set of demands that could be serviced was reduced and future growth of the system was more limited, making Scenario 3 preferable.

A non-potable water supply master plan for Canberra was created from Scenario 3 with further refinements, inclusion of additional demands and a number of adjustments where potential improvements were identified to produce the final master plan.

3.3 Outline of non-potable water supply master plan

- The proposed master plan will provide an estimated yield of 13.7 GL, more than 20% of Canberra's current water supply
- The system will comprise a network of schemes including recycled wastewater, stormwater reuse and aquifer storage and recovery
- A large proportion of the non –potable supply will be recycled wastewater from the Lower Molonglo Water Quality Control Centre
- The proposed plan results in a reduction in stormwater excess of 4.1 GL/year and reduction in treated wastewater discharge of 9.7 GL/year
- The master plan is intended to broadly set out how the various schemes can interact to create an integrated non-potable water supply system for Canberra. It is a living plan that can evolve and develop as new information becomes available

The proposed master plan is shown in the figures in Appendix H. Separate figures are included for overall context; Belconnen; North Canberra; Woden, Weston and Molonglo; South Canberra; and Tuggeranong.

The plan comprises several non-potable supply schemes with a variety of sources. It is emphasised that the master plan is intended to set out broadly how the various schemes can interact to create an integrated non-potable water supply system for Canberra. Further detailed investigations will be required (or may have already been conducted) for individual schemes to determine exactly which demands should be serviced, detailed infrastructure sizing and routing of pipes. As such, the master plan should not be seen as prescriptive, but rather a living plan that can evolve and develop as new information becomes available relating to specific opportunities and schemes. The model allows for continuous testing of variations and optimisation.

At this time it has been assumed that each scheme will operate independently. However, there is potential that schemes could be linked and wastewater reuse could be used to top-up supply for stormwater schemes as and when needed to maximise the proportion of supply derived from non-potable sources.

The sources summarised in Table 5 have been included within the master plan. While others have not presently been recommended for inclusion based on the information available, further information and investigations are likely to result in additional sources being incorporated over time.

Table 5 Sources of non-potable water included within master plan

Source	Demands	Yield supplied (ML/year)
Lower Molonglo Water Quality Control Centre*	9,420 + 110 for Fyshwick	9,420 + 110 for Fyshwick
Fyshwick*	300	190
Lake Ginninderra	1,630	1,390
Lake Tuggeranong	1,170	1,010
Gungahlin and Yerrabi Ponds	900	740
Inner North**	520	420
North Weston Creek Pond	270	250
W19 Pond (Woden East)	150	130
WC4 Pond (Weston Creek Pond)	10	10
Point Hut Pond	80	80
Total	**14,450**	**13,750**

*At present, Fyshwick supplies 190 ML/yr of the 300 ML/yr demand. It is assumed that LMWQCC may eventually be connected to the North Canberra Recycled Wastewater Scheme to supplement (or possibly replace) supply from the Fyshwick wastewater treatment plant. If so, the total supply from LMWQCC will increase to 9,530 ML/year.
**Does not include aquifer storage capacity

A breakdown of yields by scheme is shown in Figure 8. Approximately two thirds of the total non-potable yield is recycled wastewater from the Lower Molonglo Water Quality Control Centre while the contributions from the large stormwater reuse schemes for Lake Ginninderra and Lake Tuggeranong are also substantial.

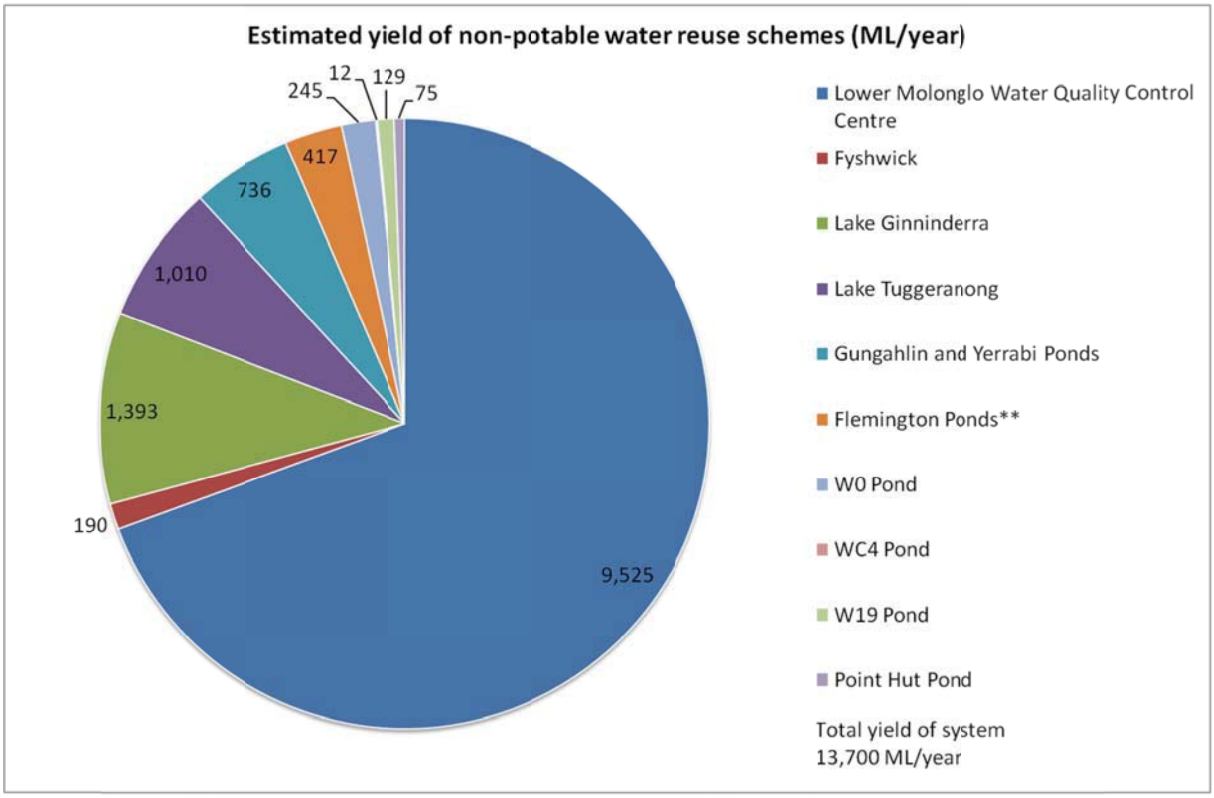


Figure 8 Breakdown of sources and estimated yields

3.4 Recommendations for specific schemes

- The LMWQCC wastewater recycling scheme is the single largest source and will need to be constructed in a series of stages building on the existing system
- This study confirms the recommendations of previous studies to connect the LMWQCC to the North Canberra Recycled Wastewater Scheme to supplement or replace supply from Fyshwick.
- Schemes for large lakes or involving ASTR including Lake Tuggeranong, Lake Ginninderra, Gungahlin and Yerrabi Ponds and Flemington Ponds are cost effective and should be progressed
- The timing of construction of schemes should be synchronised with planned development where possible

The master plan investigation has helped to provide a context for existing and proposed schemes and allows them to be evaluated and compared:

- The LMWQCC is the single largest source of non-potable water and will likely supply several areas across Canberra. Given the scale, these works will need to be staged over several decades to ensure that non-potable supplies continue to meet progressive targets. The staging should consider factors such as the rate of development in new developments such as the Molonglo Valley and Eastlake.
- The Fyshwick treatment plant has a number of operational issues and there is a need for the plant to be either upgraded or decommissioned depending on wastewater treatment needs. In terms of wastewater recycling, the scheme is already in place and should continue operation in the short-term. In the long-term, the connection of LMWQCC to the scheme would realise cost efficiencies allowing the existing infrastructure to be used in conjunction with a less costly source. If the plant is to be decommissioned, the potential to accelerate this connection should be considered. Removal of any wastewater infrastructure from upstream of Lake Burley Griffin could also be considered desirable from an environmental perspective. Alternatively, if the plant is upgraded then this would potentially provide a larger and more cost effective source and the

master plan could be adjusted to increase reliance on Fyshwick and reduce reliance on LMWQCC. In the long term this could reduce operational costs and energy use by reducing distribution distances.

- The Lake Tuggeranong scheme is both cost effective and relatively isolated with few practical alternatives. As such, it would be desirable to construct the scheme in the near future.
- The Flemington Ponds scheme provides significant reuse volumes and is cost effective given the use of wetlands for stormwater treatment, diversion of flow to Flemington Ponds and the use of ASTR.
- Gungahlin and Yerrabi Ponds already supply some demands, are cost effective and supply of additional demands to the north from these should be considered in the near to medium term.
- Lake Ginninderra is a large stormwater reuse opportunity. However it is also in close proximity to LMWQCC requiring close coordination of the allocation of demands between the two schemes. It is recommended that this scheme is implemented in stages through the near to medium term with the first stage being constructed to coincide with the adjacent Lawson development. An in-principle position to guide the balance between the use of recycled wastewater versus harvested stormwater is that where there is a storage (such as Lake Ginninderra), it would be environmentally desirable to use stormwater within the upstream catchment area.
- Connection of LMWQCC to the Molonglo Valley area should occur in tandem with development in the area and this presents a very substantial opportunity for non-potable reuse.
- A number of other stormwater opportunities exist that can progressively be implemented through the near to medium term

3.5 Staged implementation of master plan

- The master plan identified a set of projects that should commence immediately with completion by 2035 to ensure that the ACT continues to have a secure and reliable water supply
- The master plan is an essential part of the vision set out in *Think water, act water* for integrated water management for Canberra to provide social, environmental and economic benefits
- Most of the proposed works will be constructed between 2015 and 2025 and to allow for lead time planning and design of works should commence in 2012-2013

As previously discussed, *Think water, act water* sets out the overall strategy for water supply for Canberra [*Australian Capital Territory Government*, 2004]. The strategy involves several components including demand management and non-potable substitution and augmentation of the water supply system. The staging of works needs to enable progressive targets for non-potable reuse to be achieved.

It is likely that demand management can reduce potable demands by approximately 12% and based on *Think Water Act Water*, this should be achieved by 2013. A further 13% is expected to be obtained from non-potable sources. The supply targets to be met by non-potable sources was estimated based on estimated demands, population growth and assumed demand management reductions of 12% (as set out in Appendix B), see Appendix G.

The master plan was divided into five year stages with each stage to be completed by a specified year. 2035 represents completion of the entire system (as currently planned). A works program for each stage that would be sufficient to achieve the progressive target for that year was then identified, see Figure 9. Consideration was given in the selection of works to adopting those that were most cost effective, would provide the greatest flexibility, or were the most certain (due to lack of alternatives), as well as providing good coverage across different areas of the city.

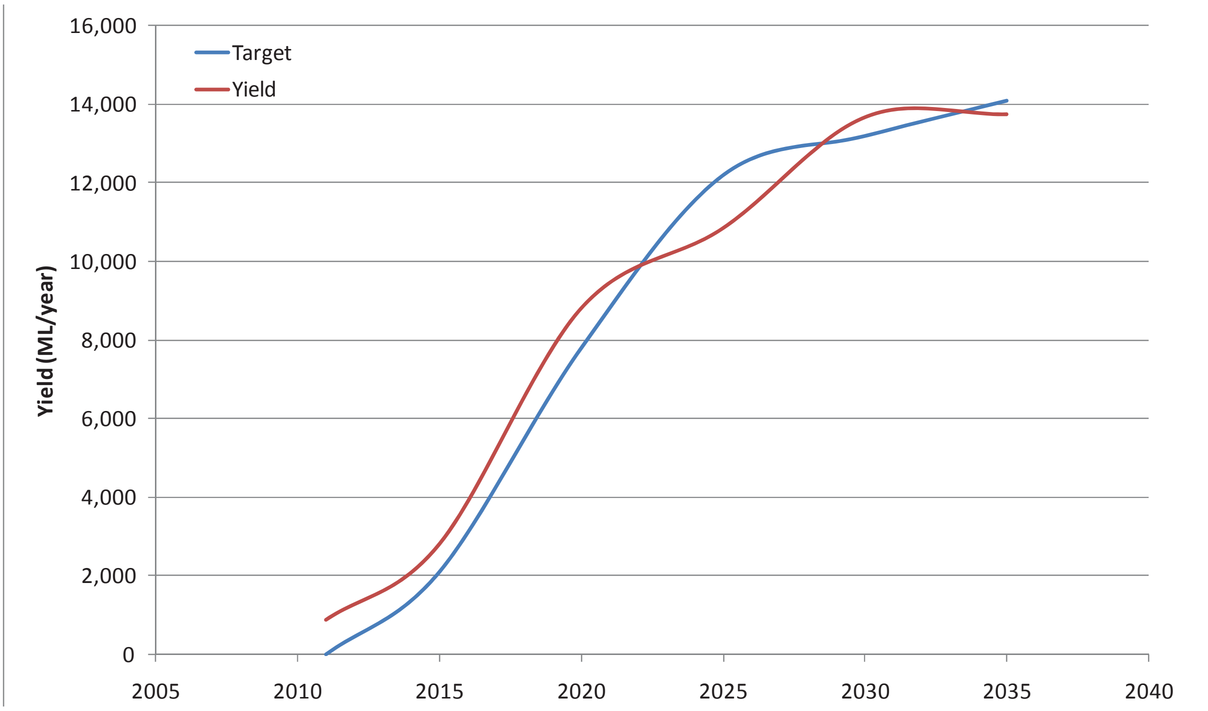


Figure 9 **Staged implementation of master plan to ensure target demand is continuously met**

A snapshot of the five-year action plans of the master plan is presented in Table 6.

Table 6 **Overview of the Non-potable Water Master Plan**

Period	Projects	Target[1] (GL/year)	Yield (GL/year)	Capital Costs ACT & Actew ($M)
2011-2015	Inner North (Flemington Ponds), Lake Tuggeranong, North Weston Creek Pond, LMWQCC-A, Lake Ginninderra-A	2.1	2.6	101
2016-2020	Gungahlin & Yerrabi, Lake Ginninderra-B, LMWQCC-B, LMWQCC-C	5.7	6.2	182
2020-2025	Fyshwick-A (and connection to LMWQCC), Lake Ginninderra-C, Lake Ginninderra-D, W19 Pond (Woden East), WC4 Pond (Weston Creek)	4.4	2.0	92
2025-2030	LMWQCC-E	1.0	2.8	73
2030-2035	Point Hut Pond	0.9	0.1	4
Total:		**14.1**	**13.7**	**$452**

[1]Estimated volume of water that should be met through non-potable sources to achieve the Think Water Act Water target of a 25% reduction in potable water demands (assuming 12% is achieved through water efficiency and 13% through non-potable sources)

[2]Include some water quality measures that may be required to satisfy ACT Government policies for new and re-development, irrespective of whether stormwater harvesting is carried out.

[3]Includes costs for contingency, investigations, design, supervision, capital cost insurance, administration and procurement. Refer to Appendix E, Table 2 for more information regarding these costs.

3.5.1 2011-2015

The target for non-potable supplies for 2015 is an increase of 2.1 GL/year. This is a relatively small and readily achievable target. This will be achieved largely through the schemes that have already been constructed and projects that are already planned or are in design and construction stages with the most significant being the Lake Tuggeranong scheme. The following works are proposed:

- Inner North (Flemington Ponds)
- Lake Tuggeranong
- North Weston Creek Pond
- LMWQCC A
- Lake Ginninderra A

It is estimated that these schemes will supply demands of up to 2,600 ML/year including new demands of 2,000 ML/year (internal use at LMWQCC was excluded). See Appendix J.

3.5.2 2016-2020

The 2020 target of 7.8 GL/year is the largest single increase and a substantial body of works needs to be completed within this period. This means that planning for these projects needs to commence soon and be completed over the next four years in preparation for an accelerated rate of delivery of projects providing about 1 GL/year of additional supply annually. These projects will establish the early stages of the LMWQCC supply pipelines, providing opportunity for connection to the Molonglo Valley development as growth occurs in this area and open the potential for connection through to the Fyshwick system if desired.

The following works are proposed:

- LMWQCC B
- LMWQCC C
- Lake Ginninderra B
- Gungahlin and Yerrabi

The works undertaken within these first two periods provide a variety of systems that will have inherent flexibility for future expansion and also provide a wealth of operational knowledge and understanding that can be used to inform and guide further development of non-potable reuse. See Appendix J.

3.5.3 2021-2025

The 2025 target of 12.2 GL/year again requires a significant increase with corresponding body of works required. By the end of this period most of the proposed works will need to be completed to ensure targets continue to be met. Delivery of projects providing capacity of about 800 ML/year of additional supply annually is required through this period. The following works are proposed:

- Fyshwick A
- Lake Ginninderra C
- Lake Ginninderra D
- W19 Pond (Woden East)
- WC4 Pond (Weston Creek)

The connection to South Canberra and the NCWRS at Fyshwick will increase the reliability of supply to demands on the NCWRS and possibly allow connection to the East Lake development. Alternatively, Actew may elect to upgrade the Fyshwick treatment plant to increase its capacity, in which case the master-plan can be revised to account for this. See Appendix J.

3.5.4 2025-2030

In later years, expansion will move into the highly urbanised areas of Canberra to the south of Lake Burley Griffin. These works have been left until later in the project as it is anticipated that costs may be higher in these areas and there is potential for demands in these areas to be serviced from Lake Burley Griffin in the interim. The following works are proposed, see Appendix J:

- LMWQCC E and connection of LMWQCC to Fyshwick

3.5.5 2031-2035

By 2035, it is expected that all currently identified works will need to have been completed to ensure that the broader ACT water supply system is able to deliver on the *Think Water Act Water* targets and that the augmentation works under construction, non-potable supplies and demand reductions together provide a secure supply through the next 25 years. The ACT will have a broad network of non-potable supplies delivering water to most areas of the city and this will create new opportunities. It is likely that climate change impacts will have reduced the available potable supply and non-potable sources will comprise an important part of Canberra's overall water supply system. The following works are proposed, see Appendix J:

- Point Hut Pond

3.5.6 Timing of staging

One of the significant benefits of the master plan is the potential for the timing of construction to be varied to account for differences in the anticipated and actual population growth, levels of development, effects of climate change and other factors. The timing of staging and the potential range over which the timing of individual schemes can likely be varied is shown in Figure 10.

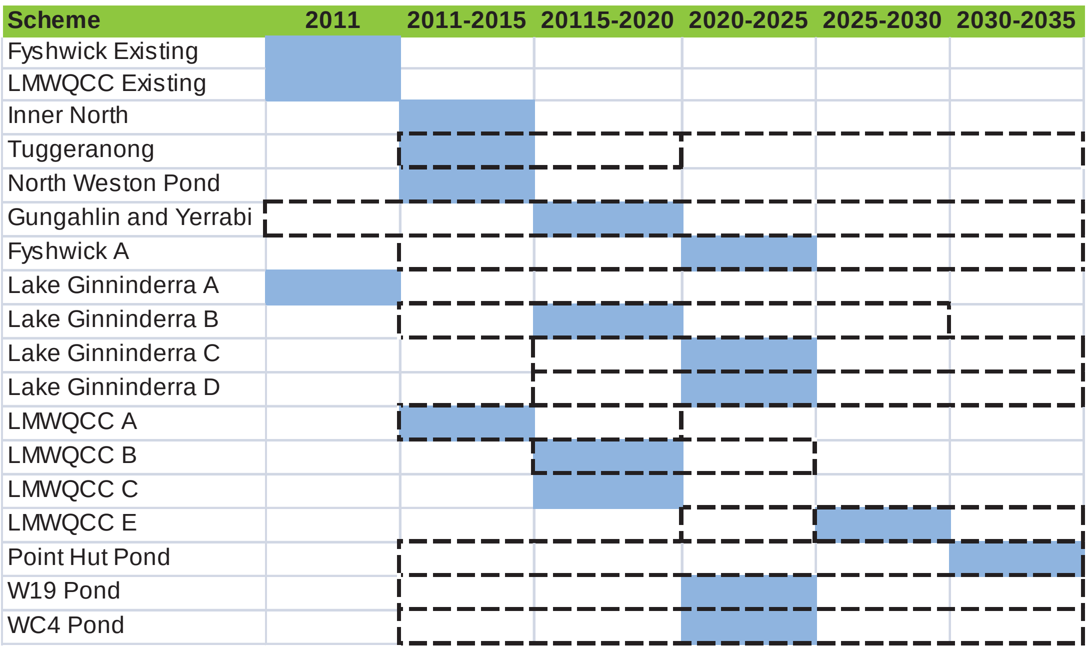


Figure 10 Scheme staging and potential variation of timing

3.6 Infrastructure Requirements

– It is expected that at least five existing and three new stormwater storages will provide water for non-potable use.

– 235 km of new reticulation pipes will be needed

– Balancing storages will be constructed by users to ensure a consistent supply at the required pressure.

– Stormwater will be treated in wetlands or other treatment measures either prior to entering storages as part of ongoing work to progressively implement WSUD for water quality or before reuse to reduce sediment and nutrient loads. Further UV disinfection will be provided (if required) at the point of use.

The proposed non-potable supply system will require a range of infrastructure including:

- Storage
- Pipes
- Pumps
- Balancing storage
- Treatment
- Bores for groundwater or ASTR

Stormwater storage – lakes and ponds

The dimensions of stormwater storages were based on available information for existing and proposed potential storages. Most of this was derived from the *Canberra Integrated Waterways* Study [*Maheepala et al.*, 2009], augmented by information from further investigations into specific schemes such as those for Lake Tuggeranong [*GHD*, 2010], the Inner North scheme (Flemington Ponds) [*Cardno Young*, 2010; *URS*, 2011] and North Weston Creek Pond [*Cardno*, 2010].

The sizing of these was estimated at a broad master-plan level. Further detailed analysis will be required to confirm these. Most of the proposed schemes will rely on existing ponds and lakes. It is anticipated that edge treatment works involving planting of macrophyte vegetation around exposed edges will be required to support drawdowns from normal water level of up to 0.5 m. Preliminary research at the University of Canberra (Pers. Comm. Fiona Dyer, 2011) indicates that drawdown of up to 0.6 m may be beneficial for water quality purposes.

The existing and potential new storages shown in Table 7 are proposed to be used to supply non-potable demands.

Table 7 Existing and proposed stormwater storages

Storage	Status	Active storage volume (ML)	Volume at full supply level (ML)
Lake Ginninderra	Existing	528	3,555
Lake Tuggeranong	Existing	360	2,768
Gungahlin and Yerrabi Ponds	Existing	252	998
Inner North (Flemington Ponds)	Existing	37	58
Point Hut Pond	Existing	84	336
North Weston Creek Pond	Under Construction	60	240
W19 Pond (Woden East)	Proposed	23	62
WC4 Pond (Weston Creek Pond)	Proposed	4	16

It is likely that the recycled wastewater reticulation network will need to include temporary holding storages. These have not been considered here due to the need to identify and design these on a case by case basis which would occur during further detailed design. Existing disused reservoirs can be integrated within the system where this is practical. As the supply of treated wastewater is relatively continuous, the storages are only required to supply one or two days of demand and can therefore be relatively small.

Pipes

The most significant and costly part of the system is the pipe reticulation network. It is estimated that some 235 km of pipes will be constructed throughout Canberra. Preliminary layouts of pipes for the schemes are shown in Appendix J.

Pumps

It has been assumed that each storage outlet will have a pump. Smaller storages typically only have one outlet while larger or combined systems (such as Gungahlin and Yerrabi Ponds) may have two or more. An initial estimate of pump sizes has been made based on anticipated peak month demands, assumed pumping hours per day and the number of days of balancing storage provided. It is recognised that these will likely be decreased by further design and refinement of operating rules and proposed pumps for detailed designs are generally smaller than these. It was assumed that pumps for recycled wastewater systems have already been constructed given the existing NCRWS and advice from Actew at workshops that the system at LMWQCC has substantial capacity available.

Table 8 Preliminary pump sizing

Storage	Estimated pump capacity (L/s)
Lake Ginninderra	640
Lake Tuggeranong	490
Point Hut Pond	30
Gungahlin & Yerrabi	380
Flemington Ponds A	210
North Weston Creek Pond	110
W19 Pond (Woden East)	60
WC4 Pond (Weston Creek Pond)	10

Balancing storages

Balancing storages at demand sites are required to manage flow and pressure at sites regardless of the source as previously advised by SRS [*GHD*, 2010] and confirmed at workshops. *These are required at SRS sites irrespective of stormwater harvesting as the potable system does not supply the flows required for efficient watering.* They also help to reduce the size of piped infrastructure and improve the overall efficiency and cost effectiveness of the system. Both this study and previous work [*GHD*, 2010], found that the use of balancing storages was preferable to instantaneous delivery to meet demands. Balancing storages sizes are summarised in Appendix D.

Treatment

Stormwater may contain a range of pollutants including sediment, nutrients (including nitrogen and phosphorus) and heavy metals. It is essential that appropriate treatment is provided prior to reuse with the level of treatment depending on the type of use as detailed in the Blueprint for Water Sensitive Cities [*CWSC*, 2011]. This includes treatment to remove gross pollutants, sediment and nutrients for restricted access use and additionally disinfection for unrestricted access or indoor use.

It is also recognised that there is a need for progressive implementation of WSUD, particularly for new urban developments, to protect urban and downstream waterways and water bodies, regardless of whether stormwater reuse occurs. This is required for all new developments to comply with the ACT's WSUD Guidelines [*ACTPLA*, 2009]. Where possible, treatment should be implemented upstream of storages and contribute towards both achieving treatment objectives to protect urban waterways and water bodies and for stormwater reuse.

For the purposes of this study, it was assumed the proportional cost of treatment borne by a proposed stormwater reuse scheme was the estimated cost of wetlands required to treat the volume reused with an average detention time of three days. This will be less than the cost of achieving best practice for the catchment overall. There is potential for a portion of treatment costs including any additional treatment to achieve best practice for catchments to be borne by other parties through the implementation of WSUD for the protection of urban waterways, ponds, lakes and the Molonglo and Murrumbidgee Rivers. The estimated size of wetlands for stormwater reuse schemes is summarised in Table 9.

A preliminary test for one scheme indicated the combined effect of a pond storage and wetland is likely to achieve best practice objectives. The more stringent regional guideline [*ACTPLA*, 2009] was achieved for total suspended solids (94% c.f. 85%) and total phosphorus (78% c.f. 60%) (pollutants of most concern for stormwater harvesting) while total nitrogen approached this guideline (56% c.f. 60% target).

Treatment system sizing and the precise locations for treatment systems should be determined for each scheme during functional and detailed design. Where there is opportunity, these will be located within the catchment and drainage lines upstream of the storage pond (for example the Inner North Scheme uses on-line treatment wetlands and pumping to the Flemington Ponds for storage). Where this is not practical, construction of a treatment wetland within the inlet area of the pond or lake itself should be considered. Finally, treatment can be provided using smaller rain garden systems at end user sites or an alternative location where this is found to be preferable.

It was assumed that disinfection treatment would be applied at the point of use if required to provide flexibility in the timing and type of irrigation. UV treatment (if required) was assumed and sizing was estimated based on peak daily use for each site. Alternatives could be adopted, particularly for large scale demands such as new development areas. End users that are able to restrict access and/or use subsurface irrigation may adopt a risk based management approach and not require disinfection.

Table 9 Wetland treatment

Storage	Wetland area (m^2)
Lake Ginninderra	30,800
Lake Tuggeranong	21,300
Point Hut Pond	1,400
Gungahlin & Yerrabi	16,500
Flemington Ponds A	3,600
North Weston Creek Pond	4,900
W19 Pond (Woden East)	2,700
WC4 Pond (Weston Creek Pond)	400
Total	81,600

3.7 Performance of master plan

- The master plan will provide an average net yield of 13.7 GL/year of non-potable water with a reliability of 95% and allow the same volume of potable substitution.
- The master plan will provide up to 20% of the ACT's current water supply. Inflows to Canberra's dams have been 60% below average over the past decade and the master plan will ensure that a range of sources are available, reducing the vulnerability of the overall system to climate change and bushfire.
- The substitution of potable supply with non-potable sources will allow the release of high quality water for environmental flows to improve the environmental health of the rivers and the quality of water reaching downstream irrigation storages.
- The proposed master plan will reduce wastewater and stormwater discharges by 26% and 6% respectively and could potentially reduce pollutant loads to downstream receiving waters by 620 tonnes/year of sediment, 2,840 kg/year of phosphorus and 25,300 kg/year of nitrogen through treatment and source substitution.

The master plan will provide an estimated yield of 13,750 ML/year to supply non-potable demands throughout Canberra with a reliability of 95%. The demands identified consist of sports fields that would apply for exemptions during periods of water restrictions, new developments and other facilities that would otherwise rely on the potable water supply. Therefore implementation of the master plan will reduce the demand for potable water by the same amount. This represents approximately 20% of Canberra's current demand. While this apparently decreases over time, as development occurs new opportunities and demands will be identified.

Most of Canberra's water supply is presently derived from the catchments of the Cotter, Murrumbidgee and Queanbeyan Rivers. The diversion of flows from these rivers reduces natural flows in the upper reaches with most of the flow potentially allocated for urban water supply. The substitution of 13,750 ML/year of potable water will allow this water to be retained within the dams and released at appropriate times to provide increased environmental flows or retained to provide greater security during times of drought. This could be achieved by revising dam management and environmental flow guidelines to account for the reduced overall demand on potable supplies and also some reduction in the reserves required to ensure reliability through drought periods given the increased diversity and dry period resilience of the overall water supply system. In the long term, non-potable supplies will need to be incorporated into modelling of Canberra's water supply system.

The master plan will also substantially reduce pollutant loads discharged to Canberra's urban waterways and the Molonglo and Murrumbidgee Rivers. An initial estimate was made of the pollutant loads potentially removed through treatment and reuse and these are summarised in Table 10. It is recognised that some of these will return to waterways through increased infiltration and runoff from irrigated areas or return flows to the wastewater treatment plants and further investigation would be needed to estimate these. The reductions in sediment and nutrient loadings will reduce the pressure on aquatic ecosystems and algal growth within the reaches of the Molonglo and Murrumbidgee Rivers immediately downstream of Canberra and loads discharged into Lake Burrinjuck. The reductions in phosphorus (TP) loads are also potentially significant for operation of the wastewater treatment plants, being equivalent to about 20% of the daily load limit for LMWQCC which may help to achieve targets in future as the population grows.

There is potential to increase the performance of the master plan through future improvements. This could include the connection of wastewater recycling to stormwater harvesting schemes to provide 'top-up' in place of potable water supplies, further increasing the potential for source substitution and increasing the reliability and cost effectiveness that can be achieved. There is also potential to expand the scheme to supply other uses as community understanding of and confidence in non-potable water sources develops with time.

Table 10 Pollutant loads redirected for reuse and recycling

	Stormwater reuse	Recycled wastewater	Total
Flow volume (ML/year)	4,000	9,700	13,700
TSS Load (kg/year)	620,000	-	620,000
TP Load (kg/year)	900	1940	2,840
TN Load (kg/year)	10,700	14,600	25,300

3.8 Cost of master plan

- Preliminary cost estimates were made using unit rates and cost curves
- The present value of cost for the system was estimated at approximately $726 M, comprising $452 M of capital costs and $275 M of annual costs. This includes both ACT Government and Actew Corporation costs. The division of these costs will be explored in detail as the project is progressed.
- The levelised costs of the system were estimated at $2.49 for the utility or $3.57 for the total cost (which includes costs of wetlands for treatment and balancing storages). Some of these treatment measures may be required to satisfy ACT Government policies for new and re-development, irrespective of whether stormwater harvesting is carried out.
- The staged implementation of the plan allows the costs to be spread over a period of time and risks related to timing of infrastructure more effectively managed than is possible with a one-off project

The costs[7] of the proposed works have been estimated based on the required infrastructure and cost assumptions built into the model, which are documented in Appendix E. Capital and operating costs are estimated using unit rates and cost curves for the various infrastructure to allow a large number of calculations to be quickly undertaken. It is noted that these cost estimates are approximate and further work is required to evaluate detailed infrastructure and costs for individual schemes.

A discount rate of 6.5% and an assumed lifespan for the scheme of 50 years was adopted.

The costs for the master plan are shown in the following tables with capital, annual and present value of annual costs in Table 11, and a summary of the present costs for the utility and the total cost including consideration of user and third party costs is included in Table 12.

- **Utility costs**: Direct utility costs for wastewater recycling and stormwater reuse were estimated based on the costs of pipe, pump, ASTR and disinfection infrastructure and costs of supply of treated wastewater.
- **Total costs**: The costs of infrastructure associated with storage ponds, balancing storages for end users and stormwater treatment for water quality are assumed to be borne by the user or other parties and are included in the estimate of total levelised cost in addition to the above utility costs.

Within the total cost, there is allowance for wetlands to provide treatment of stormwater. Regardless of whether any stormwater harvesting is undertaken, it could be expected that there will be significant expenditure in future on WSUD measures including wetland and also rain gardens, swales and other measures to protect urban waterways and existing water-bodies from the increased flow frequencies, volumes and pollutant loads caused by urbanisation. Therefore, this cost has been excluded from the utility cost.

[7] ***Disclaimer:*** *AECOM has prepared this cost estimate using information available to AECOM and where required, based on assumptions made by AECOM. Prices and quantities in the cost estimate may change. AECOM does not represent, warrant or guarantee that the master plan can be completed for the cost estimates provided.*

Balancing storages are required to allow for differences in the timing of supply and demand. Sports and Recreation Services have indicated these are required at sports fields, primarily to meet pressure requirements, even with potable supply, and are being progressively constructed. As such, it could be expected that much of the substantial $158 M required for balancing storages will derive from Sports and Recreation Services, sporting bodies and other customers in order to ensure a reliable and consistent supply that meets their pressure needs. These costs are assumed to be borne by the user and have been excluded from the utility cost.

No consideration has been made of the effect of staging on the present costs. A detailed breakdown of capital and annual costs for each scheme is provided in Appendix G.

Table 11 Capital and annual costs

Item	Utility cost	Capital cost ($ M)	Annual cost ($ M)	Present annual cost ($ M)
Storage		7.9	1.6	23.3
Pump	Y	6.4	8.0	117.9
Pipe	Y	262.9	0.9	13.4
Wetland		12.0	0.3	3.8
Balancing storage		158.0	1.1	15.6
Groundwater	Y	0.2	0.003	0.04
Disinfection	Y	4.6	0.043	0.64
Sewage effluent supply	Y	-	6.8	100
Utility cost		**275**	**15.8**	**232**
Total cost		**452**	**18.7**	**275**

Table 12 Summary of present and levelised costs

Item	Present cost ($ M)
Capital costs	452
Annual costs	18.7
Present value of annual costs	$274.8
Utility present value of costs	$506.1
Total present value of costs	$726.7
Present yield (ML)	203,000
Utility Levelised Cost ($/kL)	**$2.49**
Total Levelised Cost ($/kL)	**$3.57**

The cost estimates indicate that the cost for the utility to deliver non-potable water to users would be approximately $2.50 per kL. The total cost including all end user and third party costs would be $3.57 per kL. This total cost is somewhat lower than the present retail cost of water greater than 540 litres per day of $4.66 per kL. As such, it would appear that the proposed non-potable master plan has the potential to be cost effective and allow non-potable water to be delivered to customers for a comparable or reduced price, although it is recognised that the retail cost necessarily includes allowance for additional costs and profit for the water authority and the cost would be higher than the average cost of producing potable water using the existing water supply system.

A significant potential benefit in relation to the costs is the flexibility of timing and layout. The layout can be varied to some extent to fit with changes in the focus of development areas. This is limited as trunk systems near the source are only marginally oversized to allow for flexibility for future networks. However there are significant opportunities in terms of timing. Managers of water supplies are facing increasing uncertainty in terms of supplies due to the unknown effects and rate of climate change and the risk of bushfire while the rate of development and population growth may vary due to social, economic and other factors. With the construction of larger centralised supplies, there is a risk that construction of a new supply may not occur until it is too late, or conversely that a large and expensive system will be constructed but not required for a number of years. Both can result in significant costs to the community. The proposed non-potable reuse master plan is proposed to be implemented progressively over a period of 25 years on a 'just-in-time' basis to meet current demands. The timing of implementation of schemes proposed within the master-plan can be brought forward or delayed as required to meet these uncertainties. *The master plan therefore provides the water authority with a valuable means of cost effectively managing future uncertainty associated with climate change, development and other factors.*

3.9 Future investigations

It is recommended that further work be undertaken in the following areas:

- Develop concept and functional designs for all proposed schemes. This should occur prior to the 5 year period when each scheme is expected to commence.
- Review the source and demand opportunities at least once every 3 years. The model allows the master plan to be readily updated to incorporate new and improved data and information. It is recommended that this takes place to ensure that the master plan remains current and relevant into the future.
- Undertake further analysis of costs and benefits including environmental, social, energy and other considerations. While these issues have been covered at a higher level in the Discussion Papers (Appendix K) and also in the previous CSIRO study [*Maheepala et al.*, 2009], further in-depth analysis of the range of benefits and multi-criteria analysis would support future decision making with regard to non-potable water supplies.
- While the impacts of urbanisation on waterways are broadly understood, there would be benefit in undertaking a focussed study of Canberra to evaluate the extent of directly connected impervious areas and their relationship to water quality in ponds and waterways and to waterway health. A literature review to synthesise the available information specific to Canberra would be useful.

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5.0 References

ACT Government (2007), Think water, act water, Strategy for sustainable water resource management in the ACT: 2005-2006 Progress Report, Canberra.

ACTEW (2008), Future Water Planning - Recycled Water Strategy for Canberra.

ACTEW Corporation (2010), ACTEW Corporation Annual Report 2010.

ActewAGL (2010a), Draft Canberra Sewerage Strategy 2010-2060 - Stage 1 Options Report, ActewAGL, Canberra.

ActewAGL (2010b), 2010 Review of Planning Variables for Water Supply and Demand Assessment, ACTEW Corporation, Canberra.

ACTPLA (2009), Waterways - Water Sensitive Urban Design - General Code, ACT Planning & Land Authority, Canberra.

Arnold Jr, C. L., and C. J. Gibbons (1996), Impervious surface coverage: The emergence of a key environmental indicator, *Journal of the American Planning Association*, *62*(2), 243-258.

Australian Capital Territory Government (2004), Think water, act water, Canberra.

Booth, D. B., and C. R. Jackson (1997), Urbanization of aquatic systems: Degradation thresholds, stormwater detection, and the limits of mitigation, *Journal of the American Water Resources Association*, *33*(5), 1077-1090.

Cardno (2010), Design for North Weston Creek Pond, Water Reticulation Scheme, Water Balance Modelling, ACTPLA, Procurement Solutions.

Cardno Young (2010), Flemington Road Pond Reticulation Network, Preliminary Sketch Plan Report, prepared for ACTPLA, Symonston.

CDC (2006), Extreme Heat: A Prevention Guide to Promote Your Personal Health and Safety, edited, Centers for Disease Control and Prevention.

CSIRO, and BoM (2007), Climate Change in Australia, CSIRO & BoM.

CSIRO (2008), Water Availability in the Murray-Darling Basin. A report to the Australian Government from CSIRO Murray-Darling Basin Sustainable Yields Project, 67 pp, CSIRO, Australia.

CWSC (2011), Blueprint, Centre for Water Sensitive Cities.

Duncan, H. P. (1999), Urban stormwater quality: A statistical overview, 80 pp, Cooperative Research Centre for Catchment Hydrology, Melbourne.

GHD (2010), Draft Canberra Integrated Waterways - Preliminary Sketch Plan Design Report - Part B, Stage 1 ACT Procurement Solutions.

Institute for Sustainable Futures (2003), ACT Water Strategy: Preliminary Demand Management and Least Cost Planning Assessment.

KBR (2005), Reclaimed Water Projects Sustainability Report.

KBR (2010), Strategic Review of Sewerage Services – Effluent Reuse Options for Canberra.

Maheepala, S., et al. (2009), Canberra Integrated Waterways: Feasibility Study. Report for Territory and Municipal Services, ACT, CSIRO: Water for a Healthy Country National Research Flagship, Black Mountain, Canberra, Australia.

Maller, C., et al. (2008), Healthy parks, healthy people: The health benefits of contact with nature in a park context, School of Health and Social Development, Faculty of Health, Medicie, Nursing and Behavioural Sciences, Deakin University, Burwood, Melbourne.

MDBA (2010), Summary of Murrumbidgee Region, from the Guide to the proposed Basin Plan, Murray-Darling Basin Authority.

MDBC (2008), Murray-Darling Basin Rivers: Ecosystem Health Check, 2004-2007. A summary report based on the Independent Sustainable Rivers Audit Group's SRA Report 1: A report on the Ecological Health of Rivers in the Murray-Darling Basin, 2004-2007, submitted to the Murray-Darling Basin Ministerial Council in May 2008.

Mitchell, V. G., et al. (2002), Utilising Stormwater and Wastewater Resources in Urban Areas, *Australian Journal of Water Resources*, *6*(1), 31-44.

Murray-Darling Basin Authority (2010), Guide to the proposed Basin Plan: overview, Murray-Darling Basin Authority, Canberra.

Murray-Darling Basin Authority (2011), Proposed Basin Plan

National Water Commission (2011), Urban water in Australia: future directions, April 2011, ISBN 978-1-921853-06-7.

Paul, M. J., and J. L. Meyer (2001), Streams in the urban landscape, *Annual Review of Ecology and Systematics*, *32*, 333-365.

PB (2009), Water Management Plan for ACT Sportsgrounds.

Prime Minister's Science, Engineering and Innovation Council Working Group (2007), Water for Our Cities: building resilience in a climate of uncertainty, a report of the PMSEIC Working Group, June 2007.

Productivity Commission 2011, Australia's Urban Water Sector, Report No. 55, Final Inquiry Report, Canberra

Purves, T., et al. (2011), Trends in Canberra & Queanbeyan Water Consumption, in *ACT Water Matters Conference*, edited, Canberra.

URS (2010), Final Report for Design Acceptance, Canberra Integrated Urban Waterways: Dickson and Lyneham Ponds, ACT Procurement Solutions, Canberra.

URS (2011), Final Sketch Plan. Canberra Urban Waterways: Flemington Road Pond Reticulation Network, prepared for ACT Procurement Solutions, Melbourne.

Walsh, C. J., et al. (2004a), Urban stormwater and the ecology of streams, Monash University (CRC for Freshwater Ecology, Water Studies Centre, CRC for Catchment Hydrology and Institute for Sustainable Water Resources, Department of Civil Engineering), Melbourne, Australia.

Wong, T. H. F. (2006), Australian Runoff Quality, 231 pp, Engineers Australia

National Committee for Water Engineering, Sydney.

Wong, T. H. F., et al. (2011), blueprint 2011 - Stormwater Management in a Water Sensitive City, The Centre for Water Sensitive Cities.

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