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Canberra Integrated Waterways: Feasibility Study

Report for Territory and Municipal Services, ACT

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ABBREVIATIONS AND NOTATION

ACTEW: Australian Capital Territory Electricity and Water Corporation is a government owned company which owns the water and wastewater assets and business in the ACT, and is a 50% owner of ActewAGL.

ActewAGL: a utility joint venture of ACTEW and Australian Gas Light Company, supplying electricity, natural gas, water and wastewater services to the ACT.

ACTPLA: Australian Capital Territory Planning and Land Authority.

ASR: Aquifer storage and recovery or managed aquifer recharge (see below) using one well or well field for both injection and recovery.

ASTR: aquifer storage, transfer and recovery or managed aquifer recharge (see below) using one well or well field for injection and another well or well field for recovery. It allows simultaneous injection and extraction.

DMCE: deliberative multi-criteria evaluation is a decision-aiding process combining multi-criteria evaluation with deliberation and stakeholder interaction (Citizens' Jury)

Hydrogeological province: area of soil/rock formation with similar groundwater distribution and movement characteristics. The province is a key (large-scale) determinant of the potential aquifer injection and extraction rates.

Levelised cost: the unit cost of an item (in this case $ /kL) and is defined as the present value of costs (capital, operational, maintenance and replacement) divided by the present value of units supplied. The denominator is discounted in the same manner as the numerator to reflect the present value of revenue flows. Levelised cost therefore represents an estimation of the price required, in present day terms, to recoup costs over the analysis period.

MAR: managed aquifer recharge or the storage of water in aquifers for later recovery and use.

MCE: multi-criteria evaluation is a decision-making tool to assess performance of a proposal against multiple objectives such as triple bottom line reporting.

Net present value / present value: total present value of a time series of a cash flow or the difference between the present value of cash inflows and the present value of cash outflows.

Reclaimed water: treated wastewater reclaimed from waste stream for re-use.

Sewer mining: local treatment and re-use of wastewater direct from sewer mains (within a sewershed) before reaching a regional wastewater treatment plant.

Sportsground aquifers: small-scale aquifers in coarse gravelly material regularly found beneath sportsgrounds, originally formed due to overwatering but with potential for stormwater storage.

TaMS: Australian Capital Territory Department of Territory and Municipal Services.

TBL: triple bottom line or the implication of a proposal in economic, social and environmental dimensions.

Volumetric reliability: reliability of supply in terms of the ratio of volume supplied to volume demanded over a period of time. This is usually set as a planning objective.

WSUD: water-sensitive urban design or integration of urban water cycle management into urban planning and design. A key element of WSUD is management of stormwater both as a resource and to protect receiving water environments.

EXECUTIVE SUMMARY

Context and Purpose

The ACT Government is committed to sustainable urban water management in Canberra. The Government aims to reduce demand on the mains water supply by 12% by 2013 and by 25% by 2023. This study has examined stormwater harvesting for irrigation purposes in urban Canberra; as well as reducing demand on the potable water supply, stormwater harvesting has the potential to provide stormwater quality improvements, flood mitigation, urban habitat for native birds and wildlife, and improve aesthetics and recreation value of urban parks.

The aim of the study is to identify stormwater harvesting opportunities that collectively have the potential to save 3 GL per year of potable water for Canberra, to assess financial cost of preferred harvesting options and to identify social acceptance, ecological impacts, stakeholder views and potential risks of stormwater harvesting in Canberra.

Research & Method

The criterion of least financial cost was used to identify the preferred harvesting schemes. To determine which type of scheme was of the least cost, a range of stormwater harvesting scenarios was developed:

- Scenario A: Stand-alone stormwater ponds
- Scenario B: Stormwater ponds with Aquifer Storage and Recharge (ASR)
- Scenario C: Stormwater ponds with Aquifer Storage Transfer and Recharge (ASTR)
- Scenario D: Ponds with stormwater and reclaimed water inflow
- Scenario E: Ponds with ASTR and stormwater and reclaimed water inflow.

These scenarios were developed into a generic range of hypothetical options by varying inflows, volumetric reliabilities, demands and distances and heights between demand and supply.

Infrastructure requirements for collection, storage, treatment and distribution of stormwater for each option were determined using appropriate hydrological, storage-behaviour and hydraulic analyses. The pond volume of each option was optimised so it was the minimum required to meet the specified volumetric reliability. Each of the options was then costed in present value (PV) terms and converted to cost per kilolitre using the levelised cost method. This allowed direct comparison between options and provided an indication of which style of harvesting scheme, for a variety of circumstances, was likely to be cheapest.

The next task was to move from hypothetical options to real options and determine which 'real world' supply–demand options were likely to be cheapest. New stormwater ponds, existing lakes and ponds, and ASTR were considered in this analysis. Sewer mining was not included at this stage because any substantive sewer mining planning should be coordinated with ActewAGL's strategy for recycled water schemes (ActewAGL, 2008), which is beyond the scope of the study. ASR was also not further considered, because ASTR outperformed ASR in all options. (Note: this is partly due to the broad assumptions in the modelling and costing; those undertaking detailed design should also consider ASR).

Using the knowledge gained from the stand alone pond (Scenario A) and pond-ASTR (Scenario C) hypothetical options, a database containing 63 supply and 312 demand options (which translates to tens of thousands of potential supply–demand options) was interrogated. Those options (~1000) most closely matching the cheaper options in Scenario A and Scenario C were identified.

Each of these options was then designed for least cost. Each option was modelled with data specific to that option (rather than generalised data as used for the hypothetical options) such as catchment area, fraction impervious, and distance between supply and demand.

A range of options for existing lakes and ponds were modelled and costed. As the lakes already exist, there was no need to optimise volume for least cost for each supply–demand option. Instead, a range of supply–demand options were modelled and costed based directly on existing supplies and demands. (Note that Lake Burley Griffin was not included in the analysis as it is under Commonwealth rather than Territory control and is currently over allocated).

A short-list (or a portfolio) of stormwater harvesting options was developed using actual, on-the-ground, cheapest stormwater supply-demand options that had the ability to supply stormwater to urban irrigators with at least 95% volumetric supply reliability. This portfolio was considered as the preferred portfolio. It comprises with a number of ponds and lakes, some existing, some proposed, and some in combination with aquifer storage and recovery. We named this portfolio as 'Master Plan A'. Since it was considered as the preferred portfolio of stormwater harvesting, TBL performance assessment was undertaken for Master Plan A (results are presented in chapters 8 to 11).

However, on completion of the TBL performance assessment, new information on the potential end users was emerged. New information included significant changes to some potential end users. For example, many end users considered in developing Master Plan A, were found to be met by non-potable water supplies such as Lake Burley Griffin, groundwater or the proposed effluent reuse schemes. Emergence of changes to the potential end users had meant that Master Plan A was no longer valid. Hence, Master Plan B and C were developed using the new information on end users.

The Master Plan B supersedes Master Plan A. Both Master Plans A and B include stormwater harvesting schemes with at least 95% volumetric supply reliability. Like Master Plan B, Master Plan C uses new information on end users, but includes stormwater harvesting schemes with at least 85% volumetric supply reliability. Due to limitations in availability of time and resources, further analysis of TBL performance assessment of Master Plans B and C could not be undertaken. Chapters 8 to 11 can be used to gauge these impacts related to the new master plans, however caution should be used because drawdown levels, pond volumes and demands placed upon the ponds have changed, which will influence these impacts (particularly ecological impacts).

Key Findings

The overall key finding of the study is the development of two portfolios of stormwater harvesting options at two different volumetric reliabilities: 95% or greater (i.e. Master Plan B) and 85% or greater (i.e. Master Plan C), and establishment of detailed financial and general ecological impacts, social impacts, stakeholder views and project risks for harvesting stormwater in Canberra. Both master plans have the potential to save 3 GL/yr of potable water.

Financial findings

Total present value cost of the 95% reliability master plan (i.e. Master Plan B) is $177M, which comprises of $141M capital, $33M operation and maintenance and $3M replacement costs. The collective average annual supply of harvesting options included in this master plan is 3.3 GL/yr, which equates to a levelised cost of $3.67 per kL.

Total present value cost of the 85% reliability master plan (i.e. Master Plan C) is $150M, which comprises of $120M capital, $27M operation and maintenance and $3M replacement costs. The collective average annual supply of harvesting options included in this master plan is 3.5 GL/yr, which equates to a levelised cost of $2.94 per kL. The 85% reliability master plan was cheaper because the required pond volume is much less compared to pond volumes of the 95% reliability master plan.

The above-mentioned financial cost figures include construction costs for new ponds and ‘add-on’ costs for contingency, administration, procurement, insurance, site investigations and consultant design and supervision. The levelised cost of harvesting without pond construction costs, for 95% and 85% reliability cases (i.e. Master Plan B and C) are $1.70/kL and $1.61/kL respectively.

Ecological findings

For the stormwater harvesting options included in the master plans, new ponds tend to be relatively small compared to their catchment size in order to maximise the volumetric reliability and minimise the cost. Significant volumes of nutrients are removed, however this is largely attributed to harvesting rather than treatment, as the turnover rate of the pond is very high. The high turnover rate ensures the risk of algal bloom is low, but it also means there is minimal detention volume for flood mitigation. Velocities and flow rates in downstream channels are therefore largely unaffected in large storm events, but the reverse is true for small storm events, especially in summer when there tends to be a greater proportion of flow detained in the pond (as the water level is typically lower). In some cases downstream sections had prolonged zero flows and this has the potential to be detrimental to macroinvertebrate communities that rely upon summer low flows to survive.

The risk of adverse impact upon downstream macroinvertebrate communities is less pronounced for stormwater harvesting from existing ponds, because the change to the low flow regime is far less. The most significant change due to harvesting is on water levels within the ponds themselves. They will fluctuate further than previously, which is likely to improve aquatic vegetation diversity on the edge of the pond as diversity in most existing ponds is currently constrained by constant water levels.

The ecological impact upon the Murrumbidgee and Molonglo Rivers downstream of the urban area from implementing the master plans was found to be negligible. If fully implemented, each master plan would remove discharges up to 3.5 GL/yr from the Murrumbidgee River, and less than this from the Molonglo (as not all harvesting options are connected to the Molonglo). It is likely that reductions in flow will be much less than this or neutral as stormwater harvesting will reduce demand on the Cotter, Bendora, Corin and Googong dams, which would most likely result in increases in environmental flow releases. Regardless of the potential increases in environmental flows, up to 3.5 GL/yr potential reduction in flows is relatively minor in the context of total flow in the Murrumbidgee and Molonglo Rivers, and is therefore unlikely to have any ecological impact as flow volumes and velocities will be largely unchanged.

Social findings and stakeholder views

The social impact of stormwater harvesting was examined using focus groups, web-based surveys and community workshops. Outcomes of the social analysis indicated a strong preference for considering school grounds and sports grounds as high priority users of harvested stormwater, especially during time of water shortages. Golf courses, residential gardens and public parks were not considered as high priority users of the harvested stormwater during times of water shortages, but they were considered as appropriate users of harvested stormwater in all other times. In addition, the community in the ACT regarded aesthetic appearance and potential for recreation as prominent amenity values of stormwater harvesting. Accordingly, there is a strong preference for ‘natural’ looking stormwater collection and transmission measures over storages and floodways made out of concrete.

Deliberative Multi Criteria Evaluation (DMCE) was used to explore decision criteria to be used for assessing the impact of stormwater harvesting in social, environmental and economic dimensions and to understand stakeholder preferences. Outcomes revealed a 38% weight to economic criteria, 47% weight to social criteria and 15% weight to environmental criteria, which indicates that in the ACT, there is greater preference for considering impacts of stormwater harvesting in social and economic dimensions than the impacts in the environmental dimension.

Risk assessment

The study included a preliminary assessment of risks associated with stormwater harvesting. It offers guidance on risk issues that should be considered in the future work, rather than a detailed risk assessment of options included in the master plan. Key areas of risk considered in the study were: supply security risk associated with a specified volumetric reliability; public health and safety risks associated with drowning and other immediate hazards such as drinking of stormwater and mosquito breeding; and environmental risks such as possibility of algal blooms and changes to flow habitats. The risk assessment indicated that nearly all the risks that were assessed can be evaluated as low. Risks can be managed through improved design features.

Conclusions & Recommendations

This study has generated a considerable amount of new knowledge on hydrological, financial, ecological and social (including stakeholder preferences on decision criteria and key risk areas) aspects of stormwater harvesting, which will inform decision makers to make better planning decisions on stormwater harvesting at city scale. However, value judgements will still be required in planning stormwater harvesting in Canberra.

This study has developed two portfolios of stormwater harvesting schemes (named as Master Plans B and C) by considering 95% or greater volumetric supply reliability and 85% or greater volumetric supply reliability. Detailed financial costs for both master plans have been estimated, but social and ecological aspects of each master plan have not been assessed due to time and resource limitations of the study. Hence this report provides a comparative assessment of the two master plans in financial terms only, which indicates that 85% reliability master plan can supply stormwater at a cheaper cost than the 95% reliability master plan. To broaden planning options, it is recommended further portfolios are developed using different criteria, and then ranked using triple bottom line (TBL) assessment or cost benefit analysis (CBA). The TBL and CBA analyses require detailed analysis of social, ecological and economic aspects of each portfolio.

To further build upon this study, it is also recommended that trial projects involving aquifer storage and recovery are developed. The costs and assumptions used to assess aquifer storage and recovery in this study were based on limited data. Trial projects would provide greater confidence of the likely success of such schemes in Canberra. Hydrogeological experts should be engaged to further assess the feasibility of regional aquifer storage and recovery.

Further work to improve planning outcomes could also involve coordinating stormwater harvesting planning with ActewAGL's recycled water strategy (ActewAGL, 2008) and further investigating the possibility of potable water backup. This would improve financial, ecological and social outcomes, compared to developing a stormwater harvesting plan in isolation.

To enhance quantification of both ecological and economic aspects of stormwater harvesting, analysis of the whole-of-urban water system could be undertaken. Such an analysis will enable quantification of economic impacts of delays in augmentations and water restrictions due to stormwater harvesting, changes to environmental flow releases from supply storages due to potential increases in storage levels as a result of stormwater harvesting, interactions of environmental flow releases in waterways with reductions in stormwater discharges due to stormwater harvesting and the ecological implications of changes to flow and nutrient discharges to waterways.

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1 INTRODUCTION

This chapter describes the background, objectives, and methodology of the study and outlines the structure of this report.

1.1 Background

The Canberra Integrated Urban Waterways Project was announced in November 2006 and is funded by the Australian Government ($10.2M) and ACT Government ($6.8M). The project is funded by the National Water Commission under the Water Smart Program, and is now administered by the Commonwealth Department of Environment, Water, Heritage and the Arts.

The aim of the Canberra Integrated Urban Waterways project is to provide integrated management of urban waterways by investigating opportunities for investment in stormwater harvesting, and aquifer storage and recovery. The objective of the project is to replace 1.5 GL of potable water by 2010 with alternative water sources for irrigation. The project is also aiming to meet a longer term target of 3 GL/yr of potable water displacement by 2015.

The context for the Canberra Integrated Urban Waterways project is embedded in three major policy initiatives:

1. *Think water, act water*, released in April 2004, sets a number of targets that the ACT Government is committed to achieving. These targets are:

    - a 12% reduction in mains water usage per capita by 2013, and a 25% reduction by 2023 (compared with 2003), achieved through water efficiency, sustainable water recycling and use of stormwater and rainwater

    - by 2013, increase in use of treated wastewater (reclaimed water) from 5% to 20%

    - a level of nutrients and sediments entering ACT waterways no greater than from a well-managed rural landscape and

    - reduction in the peak flow and volume of urban stormwater flows so that the run-off event that occurs, on average, once every three months, is no larger than it was prior to development.

2. The Where Will We Play strategy was publicly announced by the ACT Minister for Sport and Recreation at the Sustaining Sport in a Drought Environment Symposium on 23 October 2007. This strategy details the ACT Government's commitment to developing and implementing a sportsground master plan to deliver the vision that by 2013 no sportsground in public or private ownership in the ACT will rely solely on the use of potable water to guarantee sporting operations.

3. The *Waterways Water Sensitive Urban Design General Code*, incorporating principles of water-sensitive urban design, became effective in March 2007. The code requires a 40% reduction of potable water use in all new developments.

In addition, in October 2007, the ACT Government announced a water security program with an aim to increase water supply to ensure a supply reliability of 95% so that temporary water restrictions would not need to be applied for more than 5% of the time – equivalent to one year in 20. A range of new water supply projects, now being implemented by ACTEW, has been proposed as part of this program. The major projects currently underway include the enlarged Cotter Dam, the Murrumbidgee to Googong water transfer, water transfer from the Tantangara Dam to the ACT and a demonstration water purification plant.

1.2 Study Objectives

The overall objective of the study is to assess the feasibility of achieving a 3 GL/yr water saving target by 2015, primarily by the use of stormwater as a potable water substitute. Harvesting from existing lakes and ponds is to be considered, as is construction of new stormwater harvesting ponds. Aquifer storage and sewer mining are also to be considered, but only in combination with the construction of new stormwater ponds (i.e. aquifers are used mainly for stormwater storage but reclaimed water may be mixed with the stormwater). The study area covers the entire urban area of the ACT.

The detailed objectives of the study are to:

1. quantify the amount of stormwater that can be harvested by considering various harvesting options (e.g. new ponds, existing ponds and lakes and managed aquifer recharge or MAR) and possible mixing of stormwater with locally treated wastewater obtained through sewer mining

2. identify potential end users of stormwater

3. identify the best stormwater harvesting options that collectively have the potential to achieve 3 GL/yr potable water savings in triple bottom line terms (i.e. by considering implications of stormwater harvesting in economic, social and environmental dimensions).

1.3 Overall Methodology

The approach developed to identify the best stormwater harvesting options in TBL terms, consists of seven steps:

- Step 1: Identify key study parameters, including climate, study area boundary and urban land use and development patterns

- Step 2: Identify potential end users of stormwater (e.g. private and public sports and recreational organisations)

- Step 3: Identify potential harvesting options, including existing lakes and ponds suitable for drawing extra volumes of water, suitable locations and areas available for new ponds, and aquifers suitable for storing stormwater for later recovery (i.e. managed aquifer recharge or MAR).

- Step 4: Develop guiding principles to identify least-cost harvesting options at the required supply reliability – cost calculated according to the net present value of infrastructure life cycle costs

- Step 5: Identify all feasible stormwater supply–demand options and screen them using the guiding principles developed in Step 4, to develop portfolios of stormwater harvesting options (e.g. '95% volumetric reliability, least-cost portfolio' comprises a set of stormwater supply–demand options that collectively have the potential to achieve 3 GL/yr supply by 2015 at 95% volumetric reliability with least infrastructure lifecycle costs)

- Step 6: Assess social, ecological and risk implications of stormwater harvesting in general and for each portfolio – this generic assessment identifies criteria for assessing performance of portfolios

- Step 7: Conduct a multi-criteria assessment (MCA) of portfolios to provide an indication of which portfolio is likely to have greatest ecological, life cycle cost or social impact (i.e. TBL performance). MCA may also be used for identifying relative benefits of individual options in a particular portfolio.

Steps 1 to 7 were undertaken in close association with a group of key stakeholders who provided local knowledge, assist in identifying key parameters and constraints of the study, and provide input to establish criteria for assessing portfolios.

Steps 1 to 7 can be carried out in two stages:

- Stage 1 encompasses Steps 1 to 5 and will result in identification of feasible portfolios of stormwater supply–demand options

- Stage 2 encompasses Steps 6 and 7 and will result in identification of preferred portfolios or 'Master Plans'.

The overall generic methodology is illustrated in Figure 1. This methodology is transferable to any location.

The above-mentioned generic methodology was applied to study. Application of Steps 1 to 6 resulted in developing a portfolio of stormwater harvesting options (Portfolio A or Master Plan A) and a set of assessment criteria for evaluating the performance of portfolios. Master Plan A was developed to include a set of least-cost (in financial terms) stormwater supply–demand options with 95% or greater volumetric supply reliability. The key stakeholders of the study agreed to consider that portfolio as the preferred portfolio. Hence Step 7 (i.e. social and ecological aspects, and MCA) was performed on individual options included in Master Plan A. Chapters 2 to 11 of this report describe the process followed to develop Master Plan A and outcomes of the analysis.

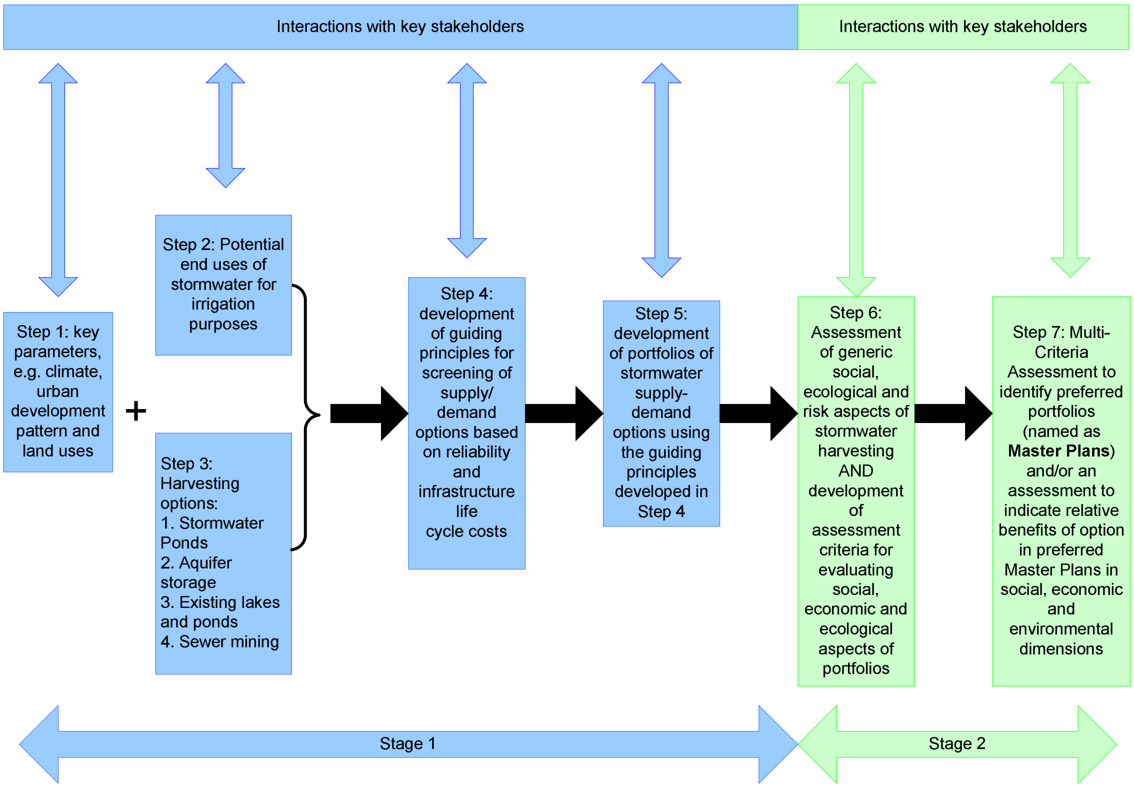


Figure 1: Overall methodology

Although Steps 1–7 were completed in mid 2008, new information regarding potential end users of the harvested water became available on completion. It was discovered that many end users considered in the analysis included those whose needs were already met by non-potable water supplies such as Lake Burley Griffin, groundwater and the proposed North Canberra Effluent Reuse Scheme. This information was not available at the commencement of the study.

In light of this new information, a review of potential end users considered for the analysis was undertaken in mid 2008 by the project team and Technical Working Group of the project and a revised list of potential end users of stormwater harvesting was compiled (see Appendix V).

The most sensitive variables of the methodology described in Steps 1–5 for identifying the cheapest-cost stormwater harvesting options are location of end users and the volume of water needed to meet each end use to a specified volumetric reliability. Therefore, any changes to end users in terms of their location and the demand water volume has a considerable impact on the levelised cost of individual options and the options selected to be included in a portfolio. Consequently, the revised list of end users and demand volumes meant the stormwater harvesting options included in Master Plan A may no longer have represented the cheapest financial cost options at 95% volumetric reliability.

To incorporate the new information into the study, Steps 1–5 were repeated and two new portfolios were developed (named as Portfolio B and Portfolio C or Master Plan B and Master Plan C). Master Plan B was similar to Master Plan A in terms of volumetric supply reliability (i.e. 95%), but included new information on potential users of stormwater. Master Plan C included least-cost stormwater harvesting options with a minimum of 85% volumetric supply reliability. The new portfolios are described in Chapter 7 along with Master Plan A.

Master Plan B supersedes Master Plan A. Master Plans B and C should be treated as outcomes of this study.

Due to limitations in availability of time and resources, no further analysis of ecological impact, social impact and MCA of Master Plans B and C was undertaken (i.e. Steps 6 and 7 were not repeated for these Master Plans). Although Chapters 8 to 11 can be used to gauge the impacts related to the new Master Plans, caution should be used because drawdown levels, pond volumes and demands placed upon the ponds which will influence these impacts (particularly ecological impacts) have changed.

As part of the study, HydroPlanner (Maheepala et al. 2005; Grant et al. 2006; Maheepala et al. 2007), a software tool for integrated modelling of water quantity and quality of the total water cycle at city scale, was further developed and applied to Canberra using the data available. The purpose of this task was to demonstrate how HydroPlanner could be used to quantify implications of stormwater harvesting on supply-side dynamics such as system yield, storage levels and triggering of restriction regimes, as well as changes to flow characteristics in urban and downstream waterways and rivers. Since the task of developing HydroPlanner was undertaken in parallel with Steps 1–7, analysis described in this report was carried out using existing models where available, and new, spreadsheet-based models. Modelling outputs were used to verify the outputs of HydroPlanner. Development of the HydroPlanner model for Canberra is described in a separate report (Maheepala et al. 2009). Enhancements to the HydroPlanner application will commence in January 2009 as part of eWater ACT Focus Catchment Study.

1.4 Structure of the Report

Chapter 2 describes key parameters of the study including the climate series and study boundaries. Chapter 3 describes potential users of the harvested water. Irrigation is the only type of end use considered. Chapter 4 describes the harvesting approaches considered in this study (i.e. existing ponds/lakes, new stormwater ponds, aquifer storage and sewer mining) and lists the potential new pond sites, existing lakes/ponds and hydrogeological provinces.

Chapter 5 describes the methodology used to quantify life cycle costs of infrastructure. The method described in Chapter 6 involves the development of a large number of hypothetical supply and demand options, and estimation of their costs and supply reliability. This chapter informs the reader of the stormwater supply–demand options that are preferable in Canberra and the circumstances in which they should be employed (these have been named ‘guiding principles’). Guiding principles are used to inform the development of portfolios or Master Plans of harvesting options for Canberra in Chapter 7.

Chapters 8 and 9 describe ecological and social implications of stormwater harvesting in the ACT. In Chapter 10, deliberative multi-criteria assessment is used to identify relative benefits of the options in the Master Plan. Generic risk assessment of stormwater harvesting in the ACT is described in Chapter 11.

Chapter 12 concludes with the outcomes of the study and Chapter 13 details a series of recommendations for developing a capital works program for stormwater harvesting in the ACT.

2 KEY PARAMETERS

The technical advisory and stakeholders groups met on several occasions to discuss the guiding principles and key parameters of the study. In summary, they are:

i. Year of analysis is 2015 because the purpose of the study is to examine achievability of 3GL/yr potable water savings by 2015.

ii. Climate projections for Canberra in 2015 are not available and the study used a 2030 climate scenario developed in accordance with ACTEW's *Future Water Options* report (ACTEW 2006).

iii. Stormwater use was considered for irrigation purposes only. Although it could be used for other non-potable applications, these have not been considered in this study.

iv. Both existing and future potential end uses were considered although knowledge of potential future end uses is limited.

v. Rainwater tanks are not part of the study.

vi. Mixing of stormwater with greywater was not considered.

vii. Mixing of stormwater with locally treated wastewater (obtained through sewer mining) was considered although current regulations do not allow treated wastewater to be stored in aquifers.

viii. A master plan for supplies with volumetric reliability of 95% or greater was developed, however the potential of 85% volumetric reliability options was also assessed.

ix. Existing lakes and ponds were modelled with an allowable drawdown level of 1 m. Although this is well beyond the 200 mm drawdown limit of the Water Resources Act, a 1 m value was chosen to test the potential of stormwater harvesting and the likely environmental/ecological impact.

x. Lake Burley Griffin (managed by the National Capital Authority [NCA]) was not considered as a harvesting option, although it is understood that further harvesting is being investigated by the NCA.

xi. Proposed ponds were modelled with an assumed average depth of 2 m and an allowable drawdown level of 1 m.

xii. Environmental flows were not required for urban waterways.

Although the target was for 3 GL/yr of stormwater harvesting by 2015, a Master Plan greater than this (4.4 GL/yr, Chapter 7) was developed because some projects may not proceed due to planning approvals, community support, adverse environmental impact, competing land use, existing services and unforseen costs (including excavation costs). The assumption that users are willing to pay may also not hold in every case.

2.1 Climate Series

A daily climate sequence for Canberra was obtained from the SILO Data Drill <www.bom.gov.au/silo/> using the coordinates of 35 18’ S and 149 18’ E. SILO data drill uses interpolation from closest climate stations to estimate a variety of parameters (Jeffrey et al. 2001). A climate series of 1940–2004 with an average annual rainfall of 651 mm and pan evaporation of 1405 mm was used. This compares to the Bureau of Meteorology record for Canberra Airport <www.bom.gov.au/climate/averages/tables/cw_070014.shtml> which records annual rainfall of 619 mm. A monthly rainfall comparison is shown in Figure 2.

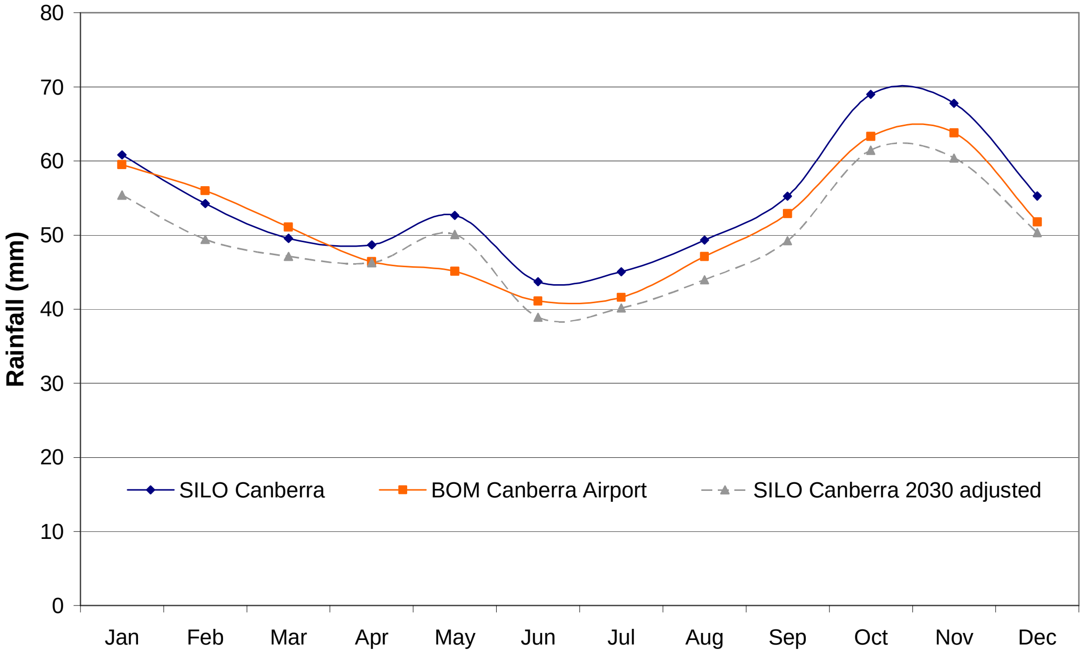


Figure 2: Comparison of SILO Canberra and BOM Canberra Airport average monthly rainfall

To align with climate predictions (see Key Parameter ii), a 2030 climate series was developed (see ACTEW 2006) by linearly scaling the historical climate sequence using factors representing seasonal predicted impact of climate change (Table 1) relative to current (1990) climate. These correspond to a ‘worst case’ or conservative climate change scenario based on projections of seasonal range of change from a suite of 13 global and regional climate models. These were developed by the CSIRO (Bates et al. 2003) over a 100 km grid square centred on the ACT (35.5ºS 149.0º E).

The resultant climate series had an average annual rainfall of 593 mm and pan evaporation of 1533 mm (see Figure 2 for average monthly rainfall and Figure 3 for average monthly evaporation). This climate series was used for all rainfall run-off modelling in the study.

Instead of pan data, estimates of pond and lake evaporation used monthly point potential evaporation data from Wang et al. (2001) (1480 mm/yr) and the evaporation scaling values in Table 1 to convert to a 2030 climate sequence (1641 mm/yr).

Table 1: Modelled climate change impact for 2030 climate sequence compared to historical record (1990) (ACTEW 2006)

	Rainfall (%)	Evaporation (%)
Summer	-8.9	8.7
Autumn	-4.9	8.5
Winter	-10.9	10.5
Spring	-10.9	9.7

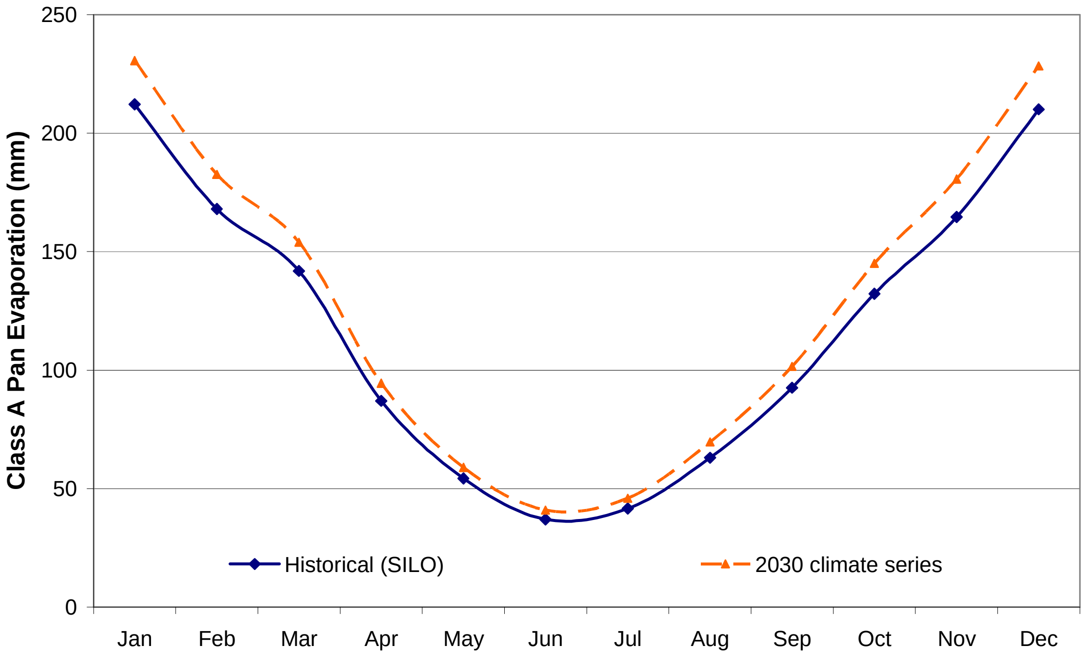


Figure 3: Comparison of adjusted evaporation (2030 series) with historical evaporation

2.2 Extent of Study Area

The project team met with key stakeholders – representatives of ACTEW, ActewAGL, TaMS and ACTPLA – to define the study area boundary (see Figure 4). The study area included catchments of Parkwood, Gungahlin, Lake Ginninderra, Sullivan’s creek, Lake Burley Griffin, Fyshwick, Woden, Weston, Kambah, Jerrabomberra, Tuggeragong and Tharwa.

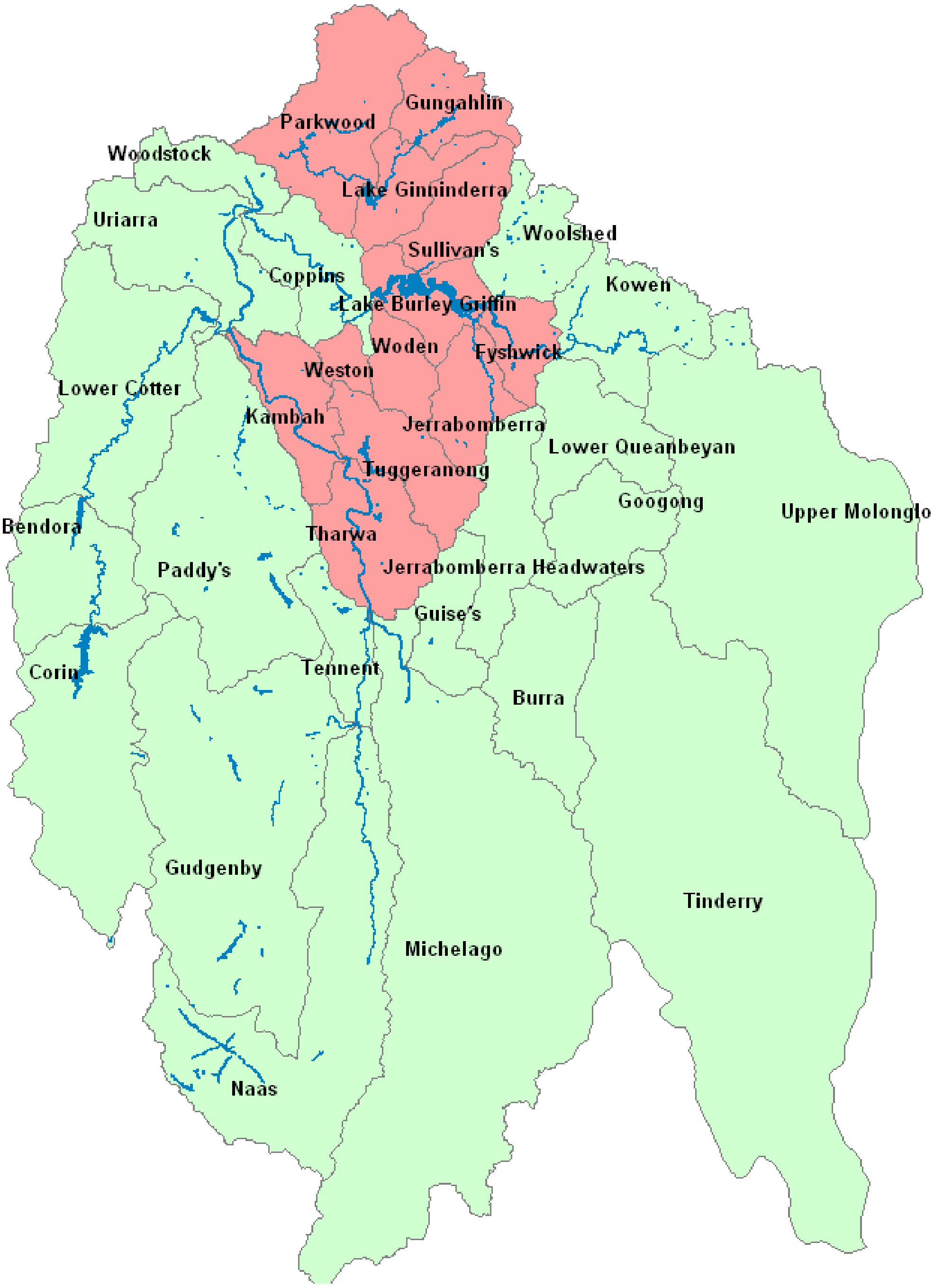


Figure 4: Study area (shown in light red) and major hydrological sub-catchments in Canberra

3 POTENTIAL USERS OF STORMWATER

3.1 End Users

Potential users of stormwater were identified in collaboration with ACT Planning and Land Authority (ACTPLA) and ACT Territory and Municipal Services (TaMS). Sources of information were:

- TaMS and ACTPLA staff
- TaMS Facility Audit of sportsgrounds
- aerial and topographic maps
- meter data for urban parklands.

These were further classified into either priority or non-priority end uses based on end use type. Those end users with a ‘willingness to pay’ (as determined by the technical group) were classified ‘priority’. Only the ‘priority’ end uses were considered in the development of supply–demand options. Priority end uses included:

- sportsgrounds
- school grounds
- golf courses
- bowling greens
- parklands
- tennis courts and
- various other club irrigation or commercial uses of non-potable water (e.g. racetracks, dog clubs, the National Zoo).

Non-priority end uses included:

- swimming pools (due to more stringent water quality requirements)
- sportsgrounds and school grounds not seeking exemptions under Stage 4 water restrictions as per the TaMS Facility Audit of sports grounds.

A list of the end uses considered in this study is shown in Appendix A.

3.2 Demand

Irrigation demand was determined from the rainfall–pan evaporation deficit using the method outlined for water allocation by the ACT Government (2007) – roughly set 500 mm or 5 ML/ha/yr. As the rainfall–pan evaporation deficit is greater under the 2030 climate series used in this study, demand was adjusted to 6.35 ML/ha/yr. This value has been adopted for all end uses considered in this study.

Supply and demand were calculated on a daily time-step (see Appendix K). Daily demand was assumed to be the average difference between rainfall and pan evaporation for that month in the year, divided by the number of days in the month. Demand was assumed to vary only from month to month – not from year to year – resulting in demand on 31 January 2008 is the same as demand on the 31 January 2009, but different to demand on 1 February 2008.

All end users were assumed to require the same volume of water per hectare. This is an appropriate assumption for the purposes of this project (i.e. determining which schemes are likely to be preferable), but the same assumption should not be made for detailed design. Demand will vary from site to site based on factors such as irrigation practices, irrigation infrastructure, soil type, grass type and end use. For example, a horse racing track may require more irrigation than average to ensure the ground is suitably soft (and safe), while a public park may require less water than average. Many approaches are available for end users to ensure demand is minimised – fore example, selection of appropriate grass type, revision of irrigation practices and upgrading of irrigation infrastructure. None of these practices have been considered in this project – a single value of 6.35 ML/ha/yr has been adopted for all potential end users.

3.3 Demand Clusters

Demands were clustered in order to simplify development of supply–demand options (see Chapter 7). Adjacent demands were grouped when they fell wholly or partly within a 400 m radius (a distance selected following sample testing). The centre of this circle was based around the average of the points of highest elevation of each end use, determined to be a conservative estimate of pipe distance and a likely point to which the water will be supplied (to permit easy on-site dispersal).

Once the clusters were mapped in geographic information systems (GIS), the maximum elevation, geometrical coordinates, water volume and area were recorded in a spreadsheet prepared for comparison with potential supply options.

Non-priority end uses were not included as part of the clusters (see Appendix A for a list of priority end uses and clusters; and Appendix B for a map of the demand clusters).

4 POTENTIAL HARVESTING SITES

In consultation with key stakeholders and the technical working group, the following stormwater harvesting schemes were considered:

- capture in **'stormwater' ponds**
- recovery from deep aquifers using either **ASR** (i.e. aquifer storage and recovery: one well or well field for both injection and recovery) or **ASTR** (i.e. aquifer storage transfer and recovery: one well or well field for injection and another well or well field for recovery)
- **existing lakes** and ponds, with an allowable 1 m drawdown
- stormwater mixed with locally treated wastewater obtained using an appropriate sewer mining method to create **reclaimed water** with end users supplied directly from ponds
- stormwater mixed with locally treated wastewater obtained using an appropriate sewer mining method with end users supplied from aquifers (**sewer mining with aquifer storage** – not yet approved under legislation)
- stormwater recovered from shallow **sportsground aquifers** confined to the alluvial-gravel material typically found under sportsgrounds for application to sportsgrounds.

Potential sites for stormwater ponds and the appropriateness of Canberra’s hydrogeological provinces for aquifer storage were identified, and existing ponds and lakes to be included in the analysis were also chosen in consultation with the technical working group.

Potential sites for sportsground aquifers **were not** identified. Although this form of capture and storage is technically feasible (see Chapter 4.2.5 & Chapter 6.6), geotechnical information is required prior to sites being able to be identified.

Potential sites for sewer mining were also **not** identified. Stormwater harvesting is generally cheaper than a combined sewer mining – stormwater harvesting, or stand-alone sewer mining schemes (see Chapter 4.4), however there are many circumstances where this is not the case. This report recommends further investigation into sewer mining by development of a sewer mining plan similar to the stormwater harvesting ‘master plan’ outlined in this study (Chapter 7). A further step would be to then integrate the planning of stormwater harvesting and sewer mining into a single ‘master plan’. Given the time constraints of this project, it was not possible to undertake such detailed investigations. It should also be noted that ActewAGL have completed a study into recycling water from the Lower Molonglo Wastewater Treatment plant (ActewAGL 2008).

4.1 Stormwater Ponds

Using corporate knowledge of ACTPLA and TaMS and the Sullivans Creek report (Bill Guy & Partners 2003), potential stormwater sites were identified. The technical working group reviewed these sites, removing those that were either too small, had an insufficient catchment area or were otherwise unsuitable for stormwater harvesting.

Catchment areas for each of the ponds were determined using GIS contour and stormwater drainage network information supplied by ACTPLA. Fraction impervious values were determined by assigning fraction impervious areas to various land uses (Table 2) and then calculating a weighted average for each catchment. Although values in Table 2 were used as a guide, adjustments were made according to unique circumstances in some catchments. These catchment area and fraction impervious values were input to the rainfall run-off models (Appendix C) that were used to model the harvesting schemes (Chapter 7).

The list of sites investigated in this study, together with their estimated catchment area and fraction impervious values are shown in Table 3 and by maps in Appendix D.

Table 2: Adopted fraction impervious values

Land use	**Details**	**Adopted Value**
National Capital Plan	Australian Government land: including nature reserves, forest, Capital Hill, embassies, some horse paddocks & golf courses	0.00
Residential		0.35
Commercial		0.70
Industrial		0.70
Community facility	Schools, churches, hospitals, historic sites	0.30
Restricted access recreation	Some sports grounds (ovals, archery range, golf course, tennis, leisure centre)	0.05
Water feature		0.00
Municipal services	Electrical substation, ambulance station, council offices, bmx park, reservoir, train line	0.50
Entertainment, accommodation & leisure	Includes some sports clubs, horse paddocks	0.40
Urban open space		0.00
Broadacre	Some mixed use, schools, residential, parks, raceways	0.10
Rural		0.05
Hills, ridges and buffer areas		0.00
River corridor		0.00
Plantation forestry		0.00
Major roads	Includes nature strips	0.75

Table 3: Potential pond sites, available area for pond construction, catchment area and fraction impervious values

District	Wetland / pond ID	Suburb	Section / block	Available area (m^2)	Catchment area (ha)	Fraction impervious (ratio)
Belconnen	B1	Kaleen	147/1	117 200	263.9	0.26
	B14	Florey	114/2	20 000	766.7	0.35
	B2	Giralang	84/10	97 040	2 016	0.23
	B24	Holt	50/52	101 849	235.3	0.34
	B28	Latham	129/1	52 223	298.2	0.35
	B3	Belconnen	150/2	37 384	325.9	0.33
	B37	Melba	67/3	143 533	137.8	0.36
Gungahlin	G23	Kenny	0/775		1 107	0.18
	G25	Throsby	0/733		370.2	0.08
North Canberra	NC1	Acton	63/1	4 000	12.0	0.66
	NC12	Lyneham	41/19	18 000	8.9	0.34
	NC12A	Lyneham	59/43	9 600	88.7	0.27
	NC13	Lyneham	41/17 and 47/2	11 000	64.9	0.41
	NC14	Dickson	76/4	35 000	523.8	0.18
	NC18	Mitchell	76/1	45 000	1863.0	0.20
	NC2	Turner	25/2	3 000	13.5	0.30
	NC3	Turner	25/6	6 000	7.0	0.45
	NC4	Turner	65/3	8 000	107.7	0.26
	NC5	Turner	66/19	8 000	104.3	0.22
	NC6	Braddon	14/1	5 500	39.0	0.16
	NC7A	Turner	67/16	5 000	92.1	0.38
	NC8	O'Connor	24/22	5 000	50.0	0.32
	NC9-11	Lyneham	46/27-30	18 000	895.7	0.21
Tuggeranong	T1	Kambah	353/10		237.1	0.19
	T2	Fadden	353/10	38 900	500.0	0.24
	T3	Calwell	788/2	47 500	1 610	0.11
	T4	Richardson	450/1	250 000	1 980	0.14
Woden Valley	W0	–	0/677		3 352	0.28
	W19	Phillip	131/7	132 626	1 078	0.22
	W2	Curtin	121/9	44 648	3 059	0.28

District	Wetland / pond ID	Suburb	Section / block	Available area (m^2)	Catchment area (ha)	Fraction impervious (ratio)
	W26	Mawson	47/25	48 366	263.6	0.27
	W27	Mawson	–	35 782	565.7	0.30
Weston Creek	WC0	–	1 179/0		1 770	0.30
	WC13	Weston	58/4	7 314	486.7	0.32
	WC14/15	Duffy	58/1 and 56/3		338.5	0.29
	WC17	Waramanga	47/1	21 073	449.9	0.29
	WC19	Waramanga	46/7	98 546	207.1	0.22
	WC2	Holder	48/1	190 558	1 674	0.31
	WC20-1	Stirling	24/88		176.9	0.24
	WC20-2	Stirling	24/88		48.9	0.27
	WC20-3	Stirling	24/88		35.7	0.33
	WC23	Fisher	13/9	11 333	58.4	0.27
	WC3	Holder	45/18	37 081	1 252	0.31
	WC4	Holder	45/19	31 885	1 235	0.31
	WC9	Weston	74/9	35 444	610.7	0.31

4.2 Aquifer Storage

Managed aquifer recharge (MAR) via methods such as aquifer storage and recovery (ASR) can only be established in Canberra if technical, economic, institutional and management barriers are overcome. This study, together with the accompanying report *Aquifer Storage and Recovery Investigations, Canberra Urban Area* (Evans 2008), addresses some of the technical and economic issues. Essentially, this study provides a first-pass, pre-feasibility technical and economic assessment of the opportunities for MAR in Canberra where stormwater run-off is harvested for non-potable irrigation supplies. Institutional and management issues are not addressed.

MAR can be partitioned into two distinct scales: regional and local. Regional aquifers can be either shallow (in alluvial material) or deep (in fractured rock) and can store and transport water. Water could be injected via wells or infiltration basins adjacent to a water source and transported using the groundwater system to the demand point (see Chapter 4.2.4). Local aquifers are distinct from regional aquifers as they transport water through pipes from the supply source to a local aquifer adjacent to a demand centre. They can be either shallow or deep are further described in Chapters 4.2.2 (deep fractured rock) and 4.2.3 (shallow alluvial).

A distinct type of local aquifer – a 'sportsground aquifer' – where coarse gravelly material regularly found beneath sportsgrounds are used to store water, was also investigated in this study (see Chapter 4.2.5 and Chapter 6.6).

4.2.1 Injection/extraction rates for hydrogeological provinces

The likely injection and extraction rates for an aquifer are important for determining feasibility for storage and recovery of water. The higher the injection/extraction rate, the less infrastructure per litre of water is required and the lesser the requirement to treat water. The primary determining factor of injection/extraction rate is the hydrogeological province where an aquifer is to be located.

Hydrogeological provinces across the ACT and recommendations to their applicability for aquifer storage are sourced from Evans (2008) and are presented in Appendix E and summarised in Table 4. Only those provinces with potential classified as ‘moderate to high’ or better were considered for aquifer storage (i.e. only fractured rock aquifers in the Mt Painter Volcanics, Ordovician and Canberra Formation provinces were considered). Unfortunately, numerical probabilities of intersecting such aquifers during drilling could not be determined as the understanding of aquifer potential in each geological province is not as precisely known (see Evans 2008).

Bore extraction and injection rates for each province (with the exception of Alluvium, which was assumed) were developed from drilling tests reported in Evans (2008). The values adopted roughly equate to the 75th percentile bore yield result and are then increased by a further 50%. The 75th percentile was adopted rather than the median because it was assumed searching would be undertaken to find a favourable site. An increase of 50% was adopted because the drilling test in Evans (2008) relates to 100 mm diameter bores and in this study it is assumed 200 mm diameter bores are used.

Injection rates were assumed to be 25% less than extraction rates due to clogging effects around the borehole/aquifer interface associated with injection. However by use of filter/bio-filters, and backwash in ASR schemes clogging may be minimised.

Table 4: Hydrogeological provinces and their potential for aquifer storage

Hydrogeological province	Aquifer storage potential	Assumed extraction rate (L/s)	Assumed injection rate (L/s)
Mt Painter Volcanics	High	4.0	3.0
Ordovician	Moderate to high	3.5	2.6
Canberra Formation	Moderate to high	3.5	2.6
Alluvium	Moderate	2.0	n/a
Middle Silurian Volcanics	Low to moderate	1.5	1.1
Granites	Low to moderate	1.5	1.1
Upper Silurian Volcanics	Low	1.5	1.1

4.2.2 Fractured rock aquifers (local)

Fractured rock was identified as the ideal target aquifer for MAR. Injection rates are likely to be greater than for aquifers in shallow alluvium soils, and water logging is less likely to be an issue. In fractured rock aquifers, groundwater is stored primarily within the fractures, joints, bedding planes and cavities of the rock mass, rather than the primary porosity as is the case in sedimentary aquifers. The well yield of fractured rock is dependent on the nature of the fractures and their degree of interconnection. Cook (2003) gives a detailed explanation of fractured rock aquifers and classifies them into different forms. Fractured rock aquifers are found in the Mt Painter Volcanics, Ordovician, Canberra Formation, Middle Silurian, Granites and Upper Silurian hydrogeological provinces (Evans 2008).

Fractures in Canberra are typically open to depths of 100 m and most of the bore yield is obtained in the top 40 to 60 m where the aquifer is most heavily weathered (Evans 2008). It was assumed the thickness of the unsaturated zone above the watertable in the case of fractured rock aquifers is at least 15 m and the MAR is situated at least 30 m above the valley floor.

ASR was only considered in detail in the Mt Painter Volcanics, Ordovician and Canberra Formation provinces. Likely injection rates in other provinces (< 2 l/s), which were derived from Evans (2008), are generally too low for economically viable ASR schemes as the cost of water treatment would be too great (in the order of $3.50 /kL, pers. comm. Taylor 2008; Pavelic 2008).

Aquifers with lower injection rates require greater treatment since they are characteristic of lower transmissivities and hence lower fracture apertures or pore sizes which are more susceptible to clogging by filtration of injected particulates, chemical precipitation or biomass growth. This makes aquifers with lower injection rates exponentially less appropriate since lower injection and storage capacity requires higher treatment costs, making the unit cost of the injected water very high. Due to their assumed low injection rate potential, aquifer storage in Middle Silurian, Granites and Upper Silurian provinces was not considered any further in this study.

The Mt Painter Volcanics hydrogeological province is assumed to have the highest extraction rates and bore yield. For the purposes of this study, 4.0 L/s has been used for calculations and 3.5 L/s for Ordovician and Canberra Formation provinces based on Evans (2008). It should be noted that rates can vary significantly within provinces and values of up to 24 L/s using a 100 mm bore have been recorded (Evans 2008).

Two types of aquifer storage were considered – aquifer storage and recovery (ASR) and aquifer storage transfer and recovery (ASTR). Simply put, the difference between the two schemes is that ASR uses one well for both injection and extraction whilst ASTR relies on two or more wells (dedicated well for injection and dedicated well for extraction) (Dillon 2005). ASR schemes generally require less water quality treatment because each time water is extracted the aquifer is partially flushed. Because ASTR is drawing water from a separate well to which it is injecting, it does not have this advantage. On the other hand, ASTR can be assumed to lose less water to surrounding groundwater, because water can be injected all year round. This means the average time water is stored is much less than for ASR. For this study, a recovery efficiency of 75% was assumed for ASTR and 50% for ASR systems.

A great deal of variation in recovery efficiency occurs between aquifers (Pavelic et al. 2002), however 75% is considered a reasonable conservative expectation for ASTR systems over the longer term. In some circumstances, an ASR scheme will have a similar or better recovery volume to an ASTR scheme due to water being transported over shorter distances. Therefore, the recovery efficiency assumptions used in this report are subject to a high degree of uncertainty and the estimated costs for ASR/ASTR schemes are also subject to a high degree of uncertainty. Further investigations into MAR in Canberra would be beneficial in determining this parameter.

Despite such uncertainties, fractured rock aquifers offer genuine potential for cost-competitive storage and supply of water. Estimated costs will be cheaper for a well-designed pond-aquifer scheme than for a similar stand-alone pond scheme (see Chapter 5). The challenge will be to undertake further hydrogeological/geotechnical assessment and trial projects to test the assumptions used in this report. A detailed explanation of the modelling and costing of an ASTR example is given in Appendix F.

4.2.3 Shallow alluvium aquifers (local)

Alluvium hydrogeological provinces are generally associated with major drainage lines and are thus located in valley floors, directly connected to streams and generally composed of coarse gravelly material. Potential exists to locate shallow alluvium aquifers in these provinces however, since these deposits can be highly heterogeneous, investigation costs to identify appropriate locations to site ASR wells could be substantial (Evans 2008).

ASR in shallow alluvium soils, based on Evans (2008), are assumed to have an extraction rate of 2 L/s and are considered to have moderate potential (Table 4).

No further investigation into alluvium aquifers was undertaken (with the exception of ‘sportsground aquifers’). Fractured rock aquifers offer greater potential due to their higher injection and extraction rates. It is recommended that trial projects be undertaken to test the potential of fractured rock aquifers and sportsground aquifers. If these projects prove successful, consideration can then be given to shallow alluvium aquifers.

4.2.4 Regional aquifers

Regional aquifers could potentially be used for transporting water from a supply source to a demand site. Water could be injected into an aquifer, perhaps through infiltration trenches or through a bed of ponds, and extracted using a well at the demand site. Such aquifers are relatively large in scale and could involve tens to hundreds of hectares, or hundreds to over 1000 ML of storage.

Shallow aquifer systems which contain pedoderms (i.e. deposited sand and gravel material) that are ideal for storage of water are already identified. These pedoderms are known to exist in the catchments of Ginninderra Creek, Gungaderra Creek, Sullivans Creek, Jerrabomberra Creek, Yarralumla Creek, Tuggeranong Creek, Point Hut Creek and Lanyon Creek. Treated stormwater (or reclaimed water) could potentially be stored in these pedoderms and extracted via a well for irrigation purposes.

Potential also exists to restore aquifers that have impaired replenishment rates as they are currently covered by channels. Restoration would require redirecting stormwater into the aquifer, rather than transportation via stormwater pipes and concrete channels. To do so, connections between residential properties and stormwater drains would need to be decoupled, concrete channels removed and replaced by ponds and weirs, and where possible, drainage water diverted from pipes towards aquifers. Any works of this nature would require accompanying hydrological studies to ensure the risk of flooding is not increased and the water table is not increased to unacceptable levels.

The potential for regional shallow aquifers, including preliminary costing and conceptual hydraulic design formulae, are further described in a short report by Ian Lawrence (eWater CRC) and Ray Evans (Salient Solutions) which has been included in Appendix G. Evans (2008) also discusses them in greater detail.

The potential to use regional aquifers for transfer and storage of water is difficult to quantify given the limited information available. It has therefore not been further considered as part of this study. To include regional aquifers in this study requires detailed investigation of specific sites which is beyond the resources of this project. Further investigations in the form of collation of geotechnical data and engagement of hydrogeological / MAR experts is recommended.

4.2.5 Sportsground aquifers

Sportsground aquifers are a concept that has legitimate potential for cost-effective water storage and supply in Canberra. A sportsground aquifer is essentially a local aquifer where water is extracted from a nearby creek (or any water source) and stored in the sand / gravel sub-base typical of sportsgrounds. They are relatively small in scale and are likely to require subsurface storage over 1–2 ha (roughly 5–10 ML).

The concept of sportsground aquifers emanates from Canberra University following a review of water use practices during the late 1990s that led to the discovery of significant overwatering of sportsgrounds, and hence to development of groundwater mounds in the surficial aquifers. This led to the idea of injecting stormwater into the sand / gravel subbase during wet periods and extract it for irrigation use at a later date.

Sportsground aquifers have the potential to be economically feasible (see Chapter 6.6). However suitable sites across Canberra would need to be found. A suitable site requires a suitable aquifer, plentiful creek flows, sportsground/s located adjacent to a creek and demand for the water (i.e. a sportsground requiring irrigation).

Some sites with these requirements will exist, especially considering sportsgrounds do not require large volumes of water for irrigation and they are often located in floodplains that are adjacent to creeks and commonly contain alluvial material which may be suitable for water storage.

Many of the details regarding sportsground aquifers emanate from a short note by Ian Lawrence (eWater CRC) and Ray Evans (Salient Solutions) (see Appendix H). Design and costing of an example sportsground aquifer can be found in Chapter 6.6 and Appendix I.

Due to lack of information, data and resources, specific application sites could not be identified or recommended by this study.

4.3 Lakes

Existing ponds and lakes to be considered as part of this study (Table 5, map in Appendix D) were chosen by the technical working group.

Table 5: Existing lakes/ponds considered in this study (see accompanying map in Appendix D)

Lake/Pond	Surface area (ha)	Volume (ML)	Unique catchment area (ha)	Fraction impervious (portion)
David St Wetland	0.3	3	309	0.15
Jarramlee (Dunlop 1)	0.7	11	79	0.30
Fassifern (Dunlop 2)	0.7	11	35	0.33
Gordon Pond	0.6	9	20	0.29
Gungahlin Pond	23.8	600	3 028	0.24
Isabella Pond	5.7	70	3 088	0.23
Lake Ginninderra	105	3 700	4 652	0.25
Lake Tuggeranong	57.1	2 600	2 088	0.28
Lower Stranger Pd	4.1	80	115	0.34
Nicholls Pond	3.6	40	150	0.19
Point Hut Pond	16.7	350	1 479	0.17
Tuggeranong Weir	7.5	110	70	0.51
Upper Stranger Pd	4.4	43	474	0.33
West Belconnen Pond	9.9	150	162	0.31
Yerrabi Pond	26.4	600	1 906	0.14

Lake Burley Griffin was not considered because it is under Australian Government rather than ACT Government control, and this study relates to harvesting options that can be adopted by the ACT Government.

Catchment areas and fraction impervious values were calculated based on contour, land use and stormwater drainage network information provided by ACTPLA (see Table 5). Fraction impervious values were assigned to various land uses (Table 2) and a weighted average fraction impervious value adopted for each catchment (similar to the process used for stormwater pond catchments). These values were input to rainfall run-off models (Appendix C) that were used to inform the harvesting models (Chapter 5 & 7).

Further information regarding lakes, including computation of hypsometric curves, are included in Appendix J.

4.4 Sewer Mining

Specific sewer mining sites were not considered for this project due to lack of information available to the technical working group, and time and resource constraints. Despite this, the potential of combining sewer mining with stormwater harvesting and aquifer storage was investigated by undertaking conceptual modelling, design and costing (see Chapters 6.3 and 6.4).

It should be noted that ActewAGL (2008) recommended centralised (non-potable) wastewater recycling in preference to sewer mining due to operating and capital costs. This report concludes stormwater harvesting schemes *may* be able to reduce their capital and operating costs in *some* circumstances by inclusion of a sewer mining scheme (see Chapters 6.3 and 6.4). However, it should be noted this conclusion is based on hypothetical modelling; no specific sewer mining schemes have been investigated.

5 FINANCIAL COST ESTIMATION METHODOLOGY

The objective of the financial analysis was to compare costs of increasing water supply through harvesting water from new stormwater ponds, aquifer storage and recovery (ASR/ASTR) and existing lakes and ponds. The outcomes of the financial analysis were used to develop a portfolio of least-cost supply–demand options (see Chapter 6). The potential for combining sewer mining with stormwater harvesting and ASR/ASTR was also investigated, however only from a hypothetical/conceptual viewpoint; no specific schemes were analysed (see Chapters 6.3 and 6.4).

The term 'financial analysis' is used in preference to 'economic analysis', because only the financial aspects such as construction, operation, maintenance and replacement costs of the harvesting schemes are considered. A true economic analysis would include a broader range of costs and benefits such as:

- water quality improvements
- impact on property values
- community attitudes
- aesthetic / landscape value
- land opportunity costs
- flood mitigation and potential for a more natural flow to receiving waterways
- micro-climatic effects
- secure supply to sporting grounds and associated benefits (human health, community engagement) and
- habitat creation for native wildlife (including migratory birds).

Such costs and benefits are addressed by the multi-criteria analysis (Chapter 10). A cost–benefit analysis (CBA) was not undertaken as part of this study.

The reported financial costs in this study **cannot be directly compared to potable water costs (or prices) or costs of other supplies of water**, due to:

- differences in how unit cost is calculated – this study uses the 'levelised cost' method to estimate the unit cost of water; comparison with any other studies needs to ensure the same method is used
- different actual costs (e.g. this study includes 'add-on' costs – contingency, design, administration, procurement – whereas other studies may not include them or may use different values)

- externalities such as water quality improvements, flood mitigation benefits, land opportunity costs etc. not being included in the cost and
- the quality of the product will be different since volumetric reliabilities and the quality of the water will vary between different schemes and supply sources.

Any meaningful comparison with prices or costs of other supplies requires a detailed understanding of how they were developed and would include methods, data, and which costs and benefits were included and excluded.

5.1 Methodology of Estimating Costs and Benefits

5.1.1 Cost estimation

Increase in water supply typically requires an initial investment to fund construction and money for ongoing maintenance and operations of the infrastructure. It can also provide benefits in the form of saved water for some number of years. This means that the costs of urban water supply include both capital instalment costs (e.g. construction and land) and annual costs (e.g. operating or maintenance costs). The first category of costs will occur in the year when major investment or a major reinvestment to continue the required supply takes place. The second category of costs may occur yearly throughout the life of the supply system.

In this section, a summary of the procedure used to collect data to assess the different costs categories in the ACT is presented. Given that structural stormwater supply costs (i.e. initial capital investment and annual operating costs) depend on the sizes, technical feasibility, volume of supplying water and reliability, the cost of these options will often vary considerably over time.

With an expected life of several years and financial realities such as inflation and the time value of money, the life-cycle cost of saving or increasing a unit (kL) of water is an appropriate cost measure to be determined. Net present value (NPV) analysis (in combination with the calculation of annuity equivalents), is a commonly used methodology because of its capability of integrating expected life with related annual costs and outputs, as well as other financial realities into a comprehensive life-cycle cost ($ /kL/yr).

NPV requires the appropriate choice of discount rate. The discount rate can reflect the opportunity cost of investment (money today can be invested elsewhere to achieve a return over time) and time preference (the lower value placed on the consumption of goods and services in the future compared with goods and services today) (Pickering 2006). The appropriate discount rate is critical to reflect society’s true preferences for allocating a resource over time. However, determining the social discount rate is controversial, and the choice of discount rate can have a large effect in determining NPV and on the results of a cost-effectiveness analysis or cost–benefit analysis. A larger discount rate gives more weight to the present in relation to the future, and thus benefits to the current generation are given more weight than benefits to future generations. In business, the opportunity cost of investment is relevant to decisions about the optimum use of capital funds. The discount rate for private investment reflects the company’s strategy for achieving return to shareholders. In regulated industries, the discount rate typically reflects the industry weighted average cost of capital (WACC). The WACC has been applied as a discount rate for water investment widely throughout Australia since the 1990s. Recent determinations by economic regulators have seen a number of water industry WACC determinations emerge between 5% and 8% in real, pre-tax terms. This is because water is a fairly stable commodity with steady income streams compared to other high risk industries (such as land development) that might aim for returns as high as 20–30% (Pickering 2006). This study adopted a discount rate of 6.5%.

Levelised cost is used when a comparison is needed for different options with different quantities on cost minimisation basis and is widely used in the water industry. Levelised cost is essential for pricing, particularly for calculating long run marginal cost for volumetric tariffs. It is also commonly used to compare options as it gives a coarse understanding of relative cost of different sized options. Levelised cost is typically calculated as the present value of costs divided by the present value of water demand (in kilolitres, for example). The demand is discounted to represent falling utility over time rather than any inherent loss in the water itself (Pickering 2006).

In this analysis, the stream of costs was discounted and annualised so that the various water supply options of different useful lives can be compared on a ‘like to like' basis. Cost of less reliable water supply options are also inflated and volume of water supply is deflated (compared to a 100% reliability option) to account for impact of reliability on $ /unit of water supply. In the calculations and methodology, zero net salvage values (for the infrastructure) and a continual replacement of such capital items into perpetuity are assumed. The present value of cost approach is used for this purpose.

The results can be compared with an externally compared-specified economic value of water to easily provide for implications of a complete cost–benefit analysis. If the same methodology and factors are used, comparisons can be made with other capital projects that increase the region’s water supply (including on-farm and municipal water conservation measures, seawater desalination, rainwater harvesting, rehabilitation of water conveyance systems as well as retaining stormwater options). Obtaining comparable costs for alternatives that can increase region’s water supply will also provide useful information for prioritising projects in the event of limited and other varying circumstances (Sturdivant et al. 2007). However, **caution should be applied when comparing with potable water supply cost (or any other water supply cost)** because there are likely to be significant differences in how costs are calculated and there are many costs and benefits that have not been included in the financial analysis results (Chapters 5 and 7) presented in this study.

5.1.2 Construction costs

Data on construction costs were collected by references to literature and from expert local knowledge (see Appendix L for details).

5.1.3 Maintenance costs

All water supply options require inspection and periodic maintenance to prevent or overcome problems, such as pipe failure, weed infestation (ponds) or clogging (ASR). Maintenance costs for some options are higher than for others. Maintenance costs were collected by references to literature and from expert local knowledge (see Appendix L for details).

5.1.4 Land opportunity costs

A continuous trade-off exists between building stormwater pond and other land commitments. Pond construction may reduce the availability or the size of a (re-) development site, and this could be a concern for real estate interests. Land opportunity costs recognise the foregone opportunity of using the land for other commitments. In highly urbanised areas, dedicating land to stormwater ponds involves a loss of development profit, and this loss is likely to be an important cost item of a stormwater pond option. Opportunity cost of land will depend on size of land (surface area), adjacent properties and current and future (predicted) price of the land.

Opportunity cost of land has not been included in the financial analysis in this study.

5.1.5 Cost in the form of reduced flows downstream

Stormwater retention and use for urban supply means less run-off and water available for downstream uses (especially for irrigation). This cost will depend on how much water is retained as a result of building a pond and how much would have been available downstream (after accounting for conveyance / evaporative losses) if there was no retention. This requires a comprehensive assessment of the water inflow and outflow at each point.

These costs were accounted for within the urban area of Canberra when developing the master plan (Chapter 7). The effect of constructing / harvesting from a pond on downstream flows and hence the cost of downstream harvesting projects was accounted for.

No effort was made to account for these costs outside of the urban area due to lack of data.

5.1.6 Benefit estimation

Key benefit elements include increase in water supply and the value associated to increased supply either in the form of price it attracts in the market, revenue in the form of tariffs or reduction in costs due to enhanced reliability in water supply and/or due to less stringent regulations and their associated costs. In case of stormwater supply options, other benefits may include reduction in stormwater pollution in the aquatic environment or reduction in drainage infrastructure load. In the case of greenfield sites or peri-urban use for agricultural production, it may be sold at a price less than or equal to its contribution in the agricultural revenue. Stormwater retention in the form of lakes may increase local recreational/tourism values along with increasing property values adjacent to the lake/s and enhance benefits of supplying water through that option (among other benefits).

Such benefits have not been accounted for in dollar terms in the analysis (i.e. for inclusion in a cost-benefit-analysis) but they are accounted for in the triple bottom line multi-criteria analysis (Chapter 10).

5.1.7 Price (benefits of water supply)

The price of water or charges on greenfield sites or for agricultural water users where stormwater will be used depends on the rate at which water will be supplied after deducting costs. Alternatively, a shadow price of water can be estimated by examining the existing water market and how much water users are paying. In the case of agriculture, a temporary water market price can be considered as a benefit of water. The temporary water market price in the agricultural sector varied from a $200 to approximately a $1000 /ML (or approximately 20^c to $1 /kL) while the annualised price in permanent water market prices increased to $200 /ML (or $0.2 /kL). In Canberra, ActewAGL applies a three-block discriminatory pricing system varying from $0.75 /kL for the first 100 kL to $1.67 /kL for 100–300 kL to $2.57 /kL (Hughes et al. 2008).

No attempt has been made to determine the appropriate price of harvested stormwater in this study.

5.1.8 Increase in reliability

Increase in water supply reliability reduces chances of stringent water regulations and restrictions. Water users are willing to pay a high or premium price for greater water security. However, water security may not be possible at a price – either financial or non-monetary – that water consumers would willingly pay.

The precise nature of the trade-off between level of water security and willingness to pay varies from user to user and most households and firms will choose a level of water security that involves some degree of rationing some of the time rather than paying a substantially higher water price all the time for a water supply that always met their demand (PC 2008).

Since December 2002, the ACT (Canberra) has been under Stage 1 restrictions for five months, Stage 2 restrictions for 11 months and Stage 3 restrictions for 11 months. Studies assessing the cost of the restrictions have shown that their continuation will incur significant cost to the ACT region. Costs were assessed for household, commercial, recreational, tourism and transaction (i.e. cost of implementation) in current terms and for 2055 (expressed in real terms). They were approximately $71 million. Hensher, Shore and Train (2006) estimated Canberra households' willingness to pay to avoid water restrictions and found respondents were unwilling to pay to avoid low-level restrictions, including restrictions that allowed watering only on alternative days. To have stage 1 or 2 restrictions rather than stage 3, 4 or 5 restrictions, respondents were willing to pay an average amount of $109, $130 and $268 per year, respectively, given that restrictions were applied once in every ten years.

The increase in benefit that results from a more secure supply must be accounted for in assessing the water supply option.

This study does not determine how stormwater harvesting will impact upon the reliability of the mains system or how it will impact on the frequency or severity of water restrictions.

5.1.9 Increase in local property and recreational/tourism values

Stormwater ponds can impact on the values of adjacent land and other properties. Anecdotal evidence suggests that land adjacent to a lake or pond attracts greater price compared to a block where there was no lake. Establishment of stormwater ponds is also seen as critical in increasing local recreational and tourism values. However, these values and benefits attributed to a particular option must be considered on an incremental basis – i.e. the difference between the values when there was no stormwater pond (status quo) and when there was a pond should only be accounted for in the analysis. Potential negative values such as bad odour or mosquitoes also need to be taken into account when proposing pond development.

No attempt was made in quantifying these impacts in financial terms because no local recreational and tourism values specific to the local site were available, however they are accounted for in the TBL-MCA analysis (Chapter 10).

5.2 Alternative Approaches in Addressing Costs and Benefits of Harvesting Options

Some of the values discussed above are subjective and qualitative in nature. Their elusive and non-market nature mean that determining the associated cost–benefit implications of different options to society is particularly difficult. Non-market valuation techniques such as ‘revealed preference’ and ‘stated preference’ have recently been applied to estimate the value of goods and services that are not commonly bought and sold in markets.

Revealed preference is an approach that is used to identify the underlying preferences, and thus demands of individuals, based upon the choices each reveals in their consumption. Revealed preference methods include travel cost method and hedonic price method. These methods are generally preferred as they rely on real actions that people make and do not rely on hypothetical situations (through subjective judgements) that can be directly observed. However, these methods can only be used where related market data exists. Further, they can only be used to estimate ‘use values’ and they are retrospective which limits their usefulness for a comprehensive cost–benefit analysis that typically requires valuation of options that do not yet exist, and of non-use values.

Stated preference methods are employed when the actual data on behaviour with regards to certain environmental goods or services does not exist, or where it is not possible to obtain these values. This method is used to estimate the 'existence value' that individuals ascribe to resources that they will never see. In this method, individuals are typically provided with hypothetical scenarios, based on plausible outcomes and options, and their choices are used to determine the value of the environmental goods or services in question. The contingent valuation method and choice modelling are the key examples of this method. However, these methods require carefully designed survey and sampling procedures and the employment of sophisticated data analysis. Obtaining reliable information requires a substantial investment of time and resources and makes these methods very expensive. The mere fact that these methods are based on asking people questions, as opposed to observing their actual behaviour is also a source of controversy and creates doubts about reliability of the estimated values.

6 IDENTIFYING LEAST COST SUPPLY-DEMAND OPTIONS

Identifying the optimal supply–demand combinations across Canberra is a very complex problem. The number of possible supply–demand combinations is most likely in the order of tens of thousands, if not more. This is because there are so many variables:

- 63 potential supply sites and 312 potential demand sites have been identified
- a supply could be constructed to meet any number of demands, including portions of demands
- a supply–demand option could also include mixing of reclaimed water with stormwater and/or aquifer storage
- the portions of reclaimed water / stormwater can vary, as does the style of aquifer storage
- often the supplies are in series, meaning they will impact upon each other, and often a demand could be met by multiple supplies
- a pond could also be constructed to a variety of sizes depending upon the volume of demand to be met and the volumetric reliability required.

With so many competing variables, it is very difficult to determine which supply–demand combinations are best.

To help solve this problem, a process of modelling and costing ‘generic scenarios’ was adopted (Figure 5). The first step was to develop ‘generic scenarios’. Initially, they were limited to:

- Scenario A: Stormwater ponds
- Scenario B: Stormwater ponds with ASR
- Scenario C: Stormwater ponds with ASTR
- Scenario D: Ponds with stormwater and reclaimed water inflow
- Scenario E: Ponds with ASTR and stormwater and reclaimed water inflow.

Lakes were not included as a scenario because identifying optimal supply–demand options involving lakes was a much simpler process. As the lakes already exist, there was no need to optimise lake volume for each supply–demand option, nor was it necessary to assume a required volumetric reliability. Instead, a range of supply–demand options were modelled and costed based directly on existing supplies and demands across Canberra (see Chapter 6.5).

ASR and ASTR are considered independently since ASR offers season injection, whilst ASTR offers opportunities for year-round injection, making more productive use of Canberra’s relatively uniform rainfall distribution.

Sportsground aquifers were not included as a scenario because the limited geotechnical information available means it is very difficult to identify potential sites. To overcome this, a generic scenario was designed and costed (see Chapter 6.6).

For the remaining supply options, the scenario list was expanded to incorporate scenarios with volumetric reliabilities of 85% and 95%, and mixed stormwater-reclaimed water scenarios where reclaimed water comprised 25% and 50% of inflows. The resultant list was:

- Scenario A1: Stormwater ponds with 85% volumetric reliability
- Scenario A2: Stormwater ponds with 95% volumetric reliability
- Scenario B1: Stormwater ponds and ASR with 85% volumetric reliability
- Scenario B2: Stormwater ponds and ASR with 95% volumetric reliability
- Scenario C1: Stormwater ponds and ASTR with 85% volumetric reliability
- Scenario C2: Stormwater ponds and ASTR with 95% volumetric reliability
- Scenario D1: Pond with 75% inflow from stormwater, 25% inflow from sewer mining and 85% volumetric reliability
- Scenario D2: Pond with 75% inflow from stormwater, 25% inflow from sewer mining and 95% volumetric reliability
- Scenario D3: Pond with 50% inflow from stormwater, 50% inflow from sewer mining and 85% volumetric reliability
- Scenario D4: Pond with 50% inflow from stormwater, 50% inflow from sewer mining and 95% volumetric reliability
- Scenario E1: Pond and ASTR with 75% inflow from stormwater, 25% inflow from sewer mining and 85% volumetric reliability
- Scenario E2: Pond and ASTR with 75% inflow from stormwater, 25% inflow from sewer mining and 95% volumetric reliability
- Scenario E3: Pond and ASTR with 50% inflow from stormwater, 50% inflow from sewer mining and 85% volumetric reliability
- Scenario E4: Pond and ASTR with 50% inflow from stormwater, 50% inflow from sewer mining and 95% volumetric reliability

Each of these scenarios was then modelled for a range of options (Figure 5) that adjusted:

- inflow
- demand

- demand clusters (i.e. the number of demands being supplied, see Chapter 3.3 for how ‘demand clusters’ were specified)
- distance between demand and supply
- height differential between demand and supply.

Information on the harvesting models, life cycle costing method and costing data are outlined in Appendix K and Appendix L. A rainfall run-off model with a fraction impervious value of 0.3 was used (see Appendix C).

The values chosen for inflow and demand were loosely based on the distribution of values across Canberra. For example, the inflows of 80, 350, 700 and 1400 ML/yr (i.e. 60, 250, 500 and 1000 hectares) roughly equates to the 20th, 50th, 80th and 95th percentiles of inflow into the potential pond sites. The options for number of demand clusters (1–20), distances (up to 4000 m) and height (20–100 m) differential were developed in consultation with the technical working group and based on sampling of real examples and preliminary assessment of economic feasibility.

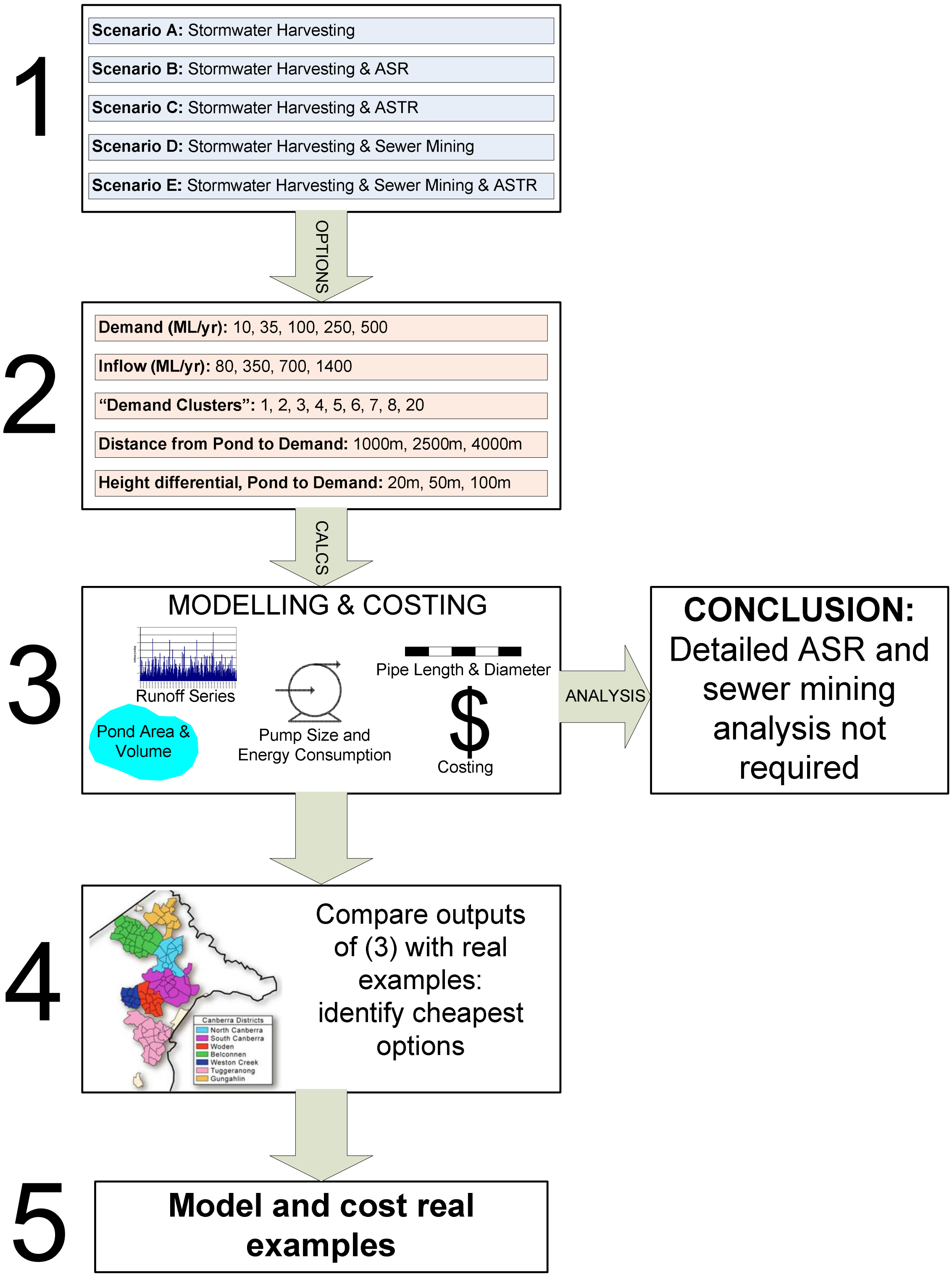


Figure 5: Generic scenario analysis process

Scenarios A1, A2, C1 and C2 were shown to be the cheaper style of supply (see later this chapter and Appendix N). Mixing stormwater and reclaimed water (scenarios D1-4, E1-4) was shown to be cost effective where demand was larger. In all circumstances ASTR was shown to be preferable to ASR due to the assumptions regarding recovery efficiency and the ability to inject water all year round for ASTR and only during the non-irrigation season for ASR. The Mt Painter hydrogeological province injection and extraction rates were used for the generic scenario modelling.

In order to determine which specific supply–demand options across Canberra were cheapest, the outputs of the A2 and C2 generic scenario modelling were compared to information on real schemes. Outputs from scenarios D1-D4 and E1-E4 were not compared to information of potential schemes due to time constraints and lack of information regarding the sewer network.

The A1 and C1 outputs were also not chosen because the technical working group decided a reliability of 95% was appropriate given there was no guarantee the schemes would be backed up by mains water and a high reliability is required to maintain the sportsgrounds. A scheme with 95% reliability provides a much more secure supply during drought years (see Appendix O), however even at this reliability, many grass types could not be sustained. A reliability higher than 95% was not considered as this can lead to excessive pond volumes and excessive costs.

The first step in determining which actual real schemes are likely to be cheapest was to develop a database of ‘supplies’ and ‘demands’. The ‘supplies’ in the database contained information such as average annual inflow, available area for pond, elevation level (in metres AHD) and grid coordinates. The ‘demands’ in the database contained information such as average annual demand, elevation level and grid coordinates.

The database was then used to filter which of the cheaper ‘generic options’ corresponded to real examples. For example, stormwater ponds for Scenario A2 are shown to cost between $3.22 /kL and $3.41 /kL to supply a demand ranging from 10 ML/yr to 35 ML/yr where the inflow is greater than 1400 ML/yr, the difference from demand to supply less than 1000 m in distance and 20 m in height (see table in Appendix N). Options fitting these criteria were identified and their indicative cost recorded. This process was repeated until a sufficient list of supply–demand options was obtained to easily meet the 3 GL/yr target.

This resultant list of supply–demand options was then remodelled and costed using specific information, rather than the general values used in the ‘generic scenario’ process (e.g. specific catchment areas, fraction impervious values, demand volumes). A list of specific supply–demand options, with their estimated cost was then developed (a sample of results are shown in Table 6 and Table 7).

This costing information was then compared with the lake costing information (a sample is shown in Table 9) and a range of supply–demand portfolios to meet 3 GL/yr were developed. Further details on this process are provided in Chapter 7.

6.1 Stormwater Ponds

Stormwater ponds were shown to be a potentially cheap source of water. Costs of ‘generic’ options were as low as $1.90 /kL in levelised cost terms. Options where the inflow / demand ratio is high are the cheapest options (with the proviso that the demand is high enough for economies of scale to come into play). High inflow and low demand allows a small storage pond while still achieving a high volumetric reliability. Stormwater becomes more expensive as a supply when the inflow is low and the demand is high. A very large storage, and hence, very large cost is then required to supply water. This concept is demonstrated by Figure 6 which shows levelised costs increasing as demand increases. The 2030 climate series as described in Chapter 2.1 was used for developing this graph and costs include add-ons as described by the example stormwater pond calculation in Appendix P.

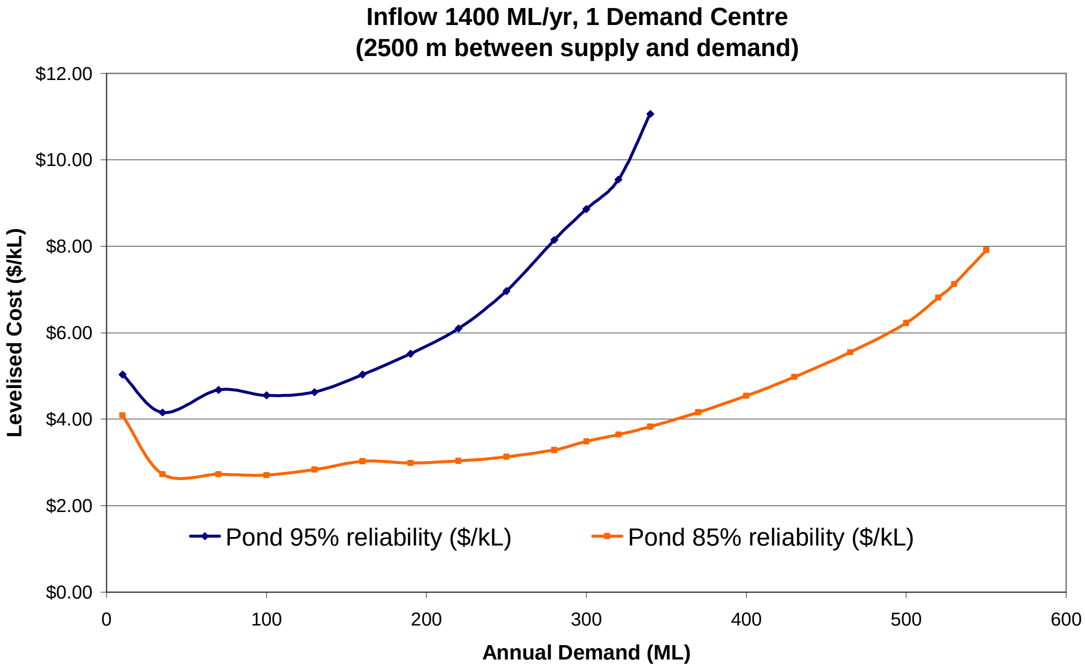


Figure 6: Pond costs with varying demand

Stormwater pond volumes, and hence cost, can be significantly reduced by reducing volumetric reliability. Figure 6 shows levelised cost versus demand for two ponds – one with a requirement for 95% volumetric reliability and the other for 85% volumetric reliability. The 85% volumetric reliability is significantly cheaper regardless of the demand volume and is also capable of meeting a much larger demand overall. This is significant when considering whether mains water should be used to back up stormwater ponds. A reliability of 85% is probably unacceptable to end users (such as sportsgrounds or racecourses) because the grass will die very frequently with such a low reliability. However, if the stormwater system were backed up by the mains:

- reliability to the end user would be much higher
- the cost of the stormwater system would be significantly less
- the total amount of water supplied by the stormwater system has the potential to be greater because a larger number of end users can be supplied (see Figure 6 – the 85% reliability option can supply a maximum of 550 ML/yr whilst the 95% reliability option can supply a maximum of only 340 ML/yr).

If the stormwater harvesting schemes in Canberra can be backed up by the mains system, the feasibility of stormwater harvesting is significantly enhanced.

To determine which specific stormwater harvesting schemes could be developed in Canberra, the cheaper options of scenario A2 were compared to the potential supply–demand options sites using the supply and demand options identified in Chapters 3 and 4 (see Table 6 for some of the cheaper possible options – without considering interactions between the supplies). An example costing of a stormwater pond option is shown in Appendix P.

Table 6: Cheapest stormwater pond supply–demand options for 95% volumetric reliability

Supply	Demand cluster	Demand (ML/yr)	Levelised cost ($/kL)[1]
W2	Curtin 1	41.7	2.51
WC4	Holder/Weston	12.7	2.58
W0	Government House	127.0	2.92
	Curtin 1	41.7	
WC0	North Weston	34.3	3.16
W2	Deakin 3	88.9	3.19
W0	National Zoo	317.5	3.23
WC4	Weston	17.2	3.29
	Holder/Weston	12.7	
B14	Florey 1	12.3	3.36
WC3	Weston	17.2	3.36
	Holder/Weston	12.7	
B2	Giralang	50.2	3.53
	University of Canberra	28.6	
B2	Giralang	50.2	3.60
	McKellar	19.0	
B2	Giralang	50.2	3.60
	Crace	31.8	
WC2	Holder/Weston	12.7	3.60
B14	Latham	25.4	3.74
WC9	Holder/Weston	12.7	3.87

Note #1: Cost figures include construction cost for new ponds

6.2 Stormwater Ponds and Aquifer Storage

Stormwater ponds in combination with aquifer storage were shown to be a comparatively cheap source of water. ASTR, which in this case is assumed to comprise of one extraction well, was shown to be preferable to ASR (one well for both injection and extraction) in almost all circumstances. Stormwater ponds and ASTR in combination are generally more cost effective than stand-alone stormwater ponds for scenarios with 95% volumetric reliability and vice versa for scenarios with 85% volumetric reliability (see tables in Appendix N for more information).

Aquifer storage also has a likely environmental benefit over pond storage. Whereas ponds lose water through evaporation, an aquifer harvesting scheme 'loses' water to the surrounding groundwater table (through mixing and/or advective flow). Advice has been provided (personal communication, Ray Evans) that there is no loss to deep groundwater in the Canberra region – the only 'losses' that occur are to the surrounding groundwater table. This study assumes ASTR 'loses' 25% of water to the surrounding groundwater and ASR 50%. However, a well designed system in appropriate geology may not lose any water at all. Even if there are 'losses', they are much more likely to appear somewhere else in the system compared to evaporative losses from ponds.

Ponds and ASTR in combination were shown to be as cheap as $2.11/kL in life cycle costing terms (Appendix N). Similar to stormwater ponds, ponds-ASTR was shown to be most cost effective at times of high inflows and low demands as this reduced the required size of the pond (see Figure 7 below, which also shows the pond-ASTR outperforming stand-alone ponds for almost all demand volumes for this scenario – inflow 1400 ML/yr, volumetric reliability 95% and one demand centre). Figure 7 was developed using an injection rate of 3 L/s and extraction rate of 4 L/s as for the Mt Painter Volcanics hydrogeological province.

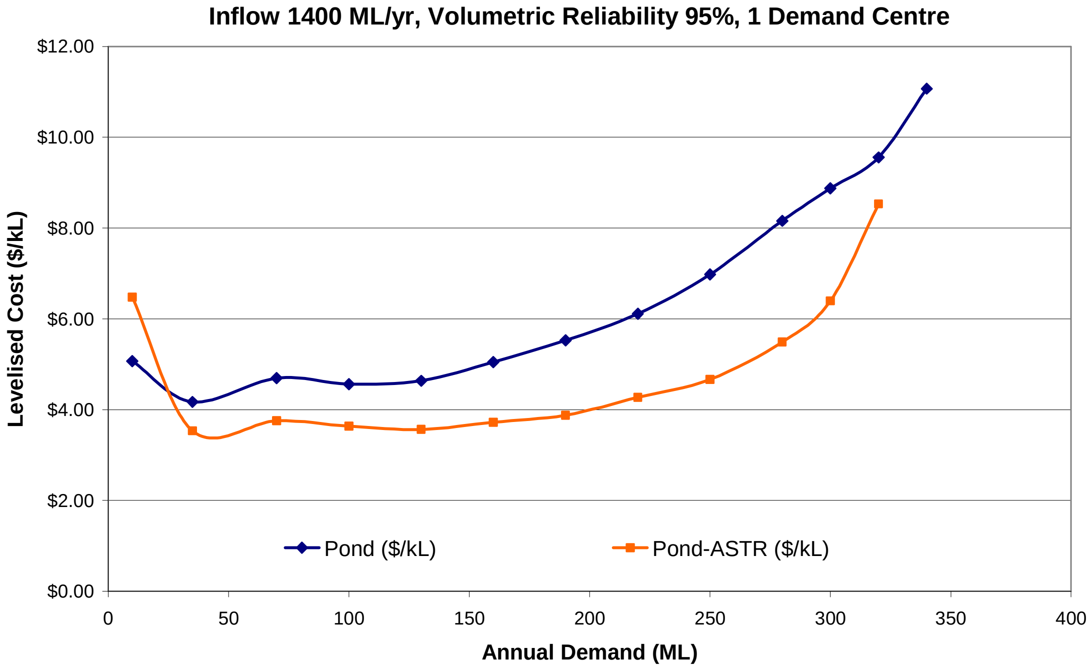


Figure 7: Pond-ASTR costs with varying demand

Although the pond-ASTR is cheaper than the stand-alone pond, a stand-alone pond has a greater maximum supply for a given inflow (see Figure 7 where the pond-ASTR option can supply a maximum of 320 ML/yr and the stand-alone pond option can supply a maximum of 340 ML/yr). The stand-alone pond option can provide a greater volume because a pond-ASTR option requires water in addition to demand at the end use to account for losses in the aquifer (25%). It has also been assumed that all aquifer options will supply 100% reliability to the end use, as the operator will be unsure at any given moment in time whether they are drawing from injected water or 'natural' groundwater. To ensure there is no net loss of natural groundwater over the modelling period, extra water must be supplied from the pond to the aquifer to account for the less than 100% volumetric reliability between pond and aquifer. Under these assumptions, the stormwater pond can therefore provide a greater demand for a given inflow. It must be noted that given different assumptions, such as 0% losses from the aquifer, this statement will not hold.

The reason a pond can provide more water for a given demand than pond-ASTR, given the assumptions of this study, is probably best explained by the following example. If a user is requesting 10 ML/yr for irrigation the demand at the end point, $D_{\text{end point}}$, is therefore:

$$D_{\text{end point}} = \text{Demand of end user} = 10 \text{ ML/yr}$$

Given an assumed 25% loss from the aquifer, the minimum amount of water flowing from an aquifer annually, $Q_{aquifer}$, is:

$Q_{aquifer}$ = Amount of water extracted from aquifer annually

$Q_{aquifer} = D_{end\ point} / (1-0.25) = 13.3$ ML/yr

If the volumetric reliability between the pond and aquifer is 85%, the average annual volume of water to be delivered from the pond to the aquifer needs to be:

$Q_{pond\text{-}aquifer}$ = Amount of water extracted from pond and injected into aquifer annually

$Q_{pond\text{-}aquifer} = Q_{aquifer}/(0.85) = 15.7$ ML/yr

The above equations show why a stormwater pond can supply more demand than a pond-ASTR combination for a given inflow. For a 10 ML/yr demand, the pond is required to supply 15.7 ML/yr for a pond-ASTR option, but only 10 ML/yr for a stand-alone pond option.

The reasons ASTR outperforms ASR is perhaps best described by Figure 8. It shows the components of a present value cost for an example of two demand clusters, 700 ML/yr inflow and 35 ML/yr demand. The primary reason ASTR performs best is the cost of the pond. ASTR (scenarios C1 & C2) can manage with a smaller pond because it is assumed water can be pumped continually from the pond to the aquifer throughout each year. This compares to pond-ASR (scenarios B1 & B2), where it is assumed water cannot be pumped from pond to aquifer during the irrigation season. Consequently, a large pond is required to ensure reliability targets are met. Stand-alone ponds (scenarios A1 & A2) also perform better than pond-ASR because they can pump directly from the pond during the irrigation season.

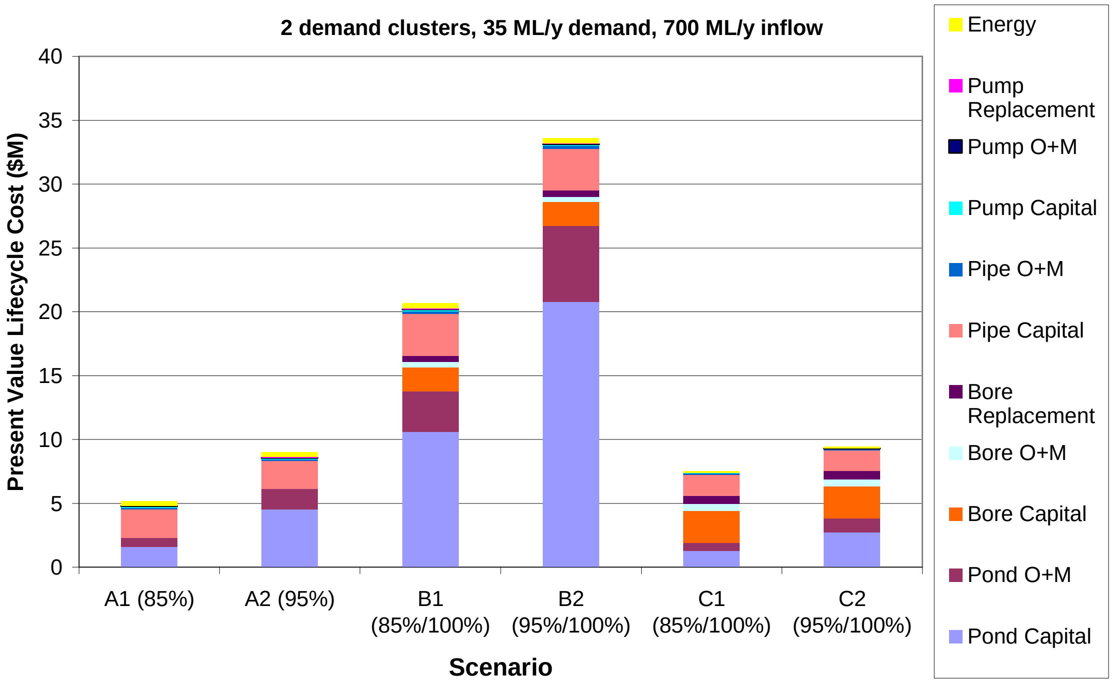


Figure 8: Comparison of present value costs between pond and pond-aquifer scenarios

Pond-ASTR also has an advantage over stand-alone ponds from a pond size, energy, pipe and pump cost perspective. Pond-ASTR has a constant pumping rate from pond to aquifer – this limits the size of peak flows and the pipes, pumps and energy costs are consequently less than for stand-alone ponds. Pond size is also reduced because the aquifer is charged all year round, whereas in the case of stand-alone ponds, pumping only occurs during the irrigation season. In effect, the pond-ASTR scheme is advantaged by the aquifer being a cheap storage in comparison to a pond.

Stand-alone ponds can provide the necessary storage to harvest water and make it available, particularly in a climate such as that found in Canberra. The advantage that subsurface storage via ASTR provides is that it diminishes the size of the pond, while maintaining reliability of supply. This comes at the cost of bore infrastructure and means stand-alone ponds are cheaper in circumstances where only a small pond is required (e.g. high ratio of inflow to demand or low volumetric reliability) or where there are many demand clusters (and hence, many bore sites). In other circumstances, pond-ASTR will be cheaper. In the example shown in Figure 8, the stand-alone pond option (A1) outperforms the pond-ASTR option (C1) at a low reliability (85%), but at a high reliability (95%) the reverse is true (C2 outperforms A2).

Each of the pond-ASTR options (C1 & C2) have no net loss of 'natural' groundwater over the modelling period, however C2 uses 'natural' groundwater less frequently. The only difference between the options is that the volumetric reliability from pond to aquifer is 85% in C1 and 95% in C2. A larger pond and therefore greater pond capital, operation and maintenance costs are required for C2.

Table 7: Cheapest stormwater pond-ASTR supply–demand options for 95% volumetric reliability

Supply	Demand cluster	Potential for aquifer storage	Demand (ML/yr)	Levelised cost[1] ($/kL)
W2	Curtin 1	High	41.7	2.41
W0	Yarralumla 5	High	295.3	2.55
B2	Giralang	Moderate to high	50.2	2.65
W0	Government House	High	127.0	2.75
	National Zoo	High	317.5	
W0	Government House	High	127.0	2.78
	Yarralumla 5	High	295.3	
W2	Curtin 1	High	41.7	2.92
	Curtin 2	High	15.6	
NC9-11	Ainslie	Moderate to high	41.3	3.33
B2	Giralang	Moderate to high	50.2	3.46
	Crace	Moderate to high	31.8	
WC0	National Zoo	High	317.5	3.53
NC18	Lyneham 1	Moderate to high	40.6	3.74
	Gungahlin Cemetery	Moderate to high	95.3	

Note #1: Cost figures include construction cost for new ponds

Without considering interactions of options (i.e. whether or not supplies are in series or whether demands could be met by multiple supplies), some of the cheaper pond-ASTR options can be seen in Table 7. An example modelling, design and costing of a stormwater pond is shown in Appendix P and an ASTR option in Appendix F. It should be noted that the breadth of options for ponds-ASTR was less than stand-alone ponds because in some areas the hydrogeology is considered unsuitable for ASTR.

6.3 Stormwater Ponds and Sewer Mining

Stormwater ponds in combination with reclaimed water from sewer mining were shown to be favourable in circumstances where the ratio of inflow to demand was low. In circumstances where this ratio is high, the extra infrastructure required (i.e. a sewer mining plant) does not produce enough benefits. When this ratio is low, the benefit of steady, secure inflow outweighs the extra cost of the infrastructure. The cheapest generic options modelled were $4.32/kL in levelised cost terms, which compares to the cheaper pond and pond-ASTR options of ~$2.40/kL (Table 6 and Table 7) (see Appendix L for the method and data used to estimate cost).

Mixing reclaimed water with stormwater is unfavourable when demand is low because the cost of reclaimed water is similar or more expensive than stormwater (Table 8). Favourable economies of scale (i.e. large quantities of water) are required for sewer mining to be a similar price to the cheapest stormwater options. The highest plant flow considered in this study, 4 ML/day (1.5 GL/yr), is required to produce similar costs to the cheapest stormwater options (Table 8).

Table 8: Estimated cost of providing reclaimed water from sewer mining (source: Wayne Harris courtesy of Aquatech Maxicon)

Plant flow (kL/day)	Levelised cost ($/kL)
100	6.04
300	4.24
1000	3.09
4000	2.17

When inflow is high and demand low, much of the water produced by sewer mining in a combined sewer mining-stormwater scheme will become redundant. Despite costs as low as $2.17 /kL for producing the reclaimed water (Table 8), much of it will accumulate in the harvesting pond and either evaporate or spill into the downstream waterway. Only a portion of that water will actually be used to supply an irrigation scheme. In order for a combined sewer mining and stormwater scheme to be cost competitive, a high ratio of demand compared to inflow is required.

Reclaimed water has the advantage over stormwater of constant supply, which means it can more easily meet higher volumetric reliabilities. If the user requires a highly reliable supply, or the ratio of inflow to demand is low, reclaimed water may become more cost-effective than stormwater (see Figure 9 which shows that stormwater is cheaper for lower demands, but combined sewer mining-stormwater schemes are cheaper for higher demands).

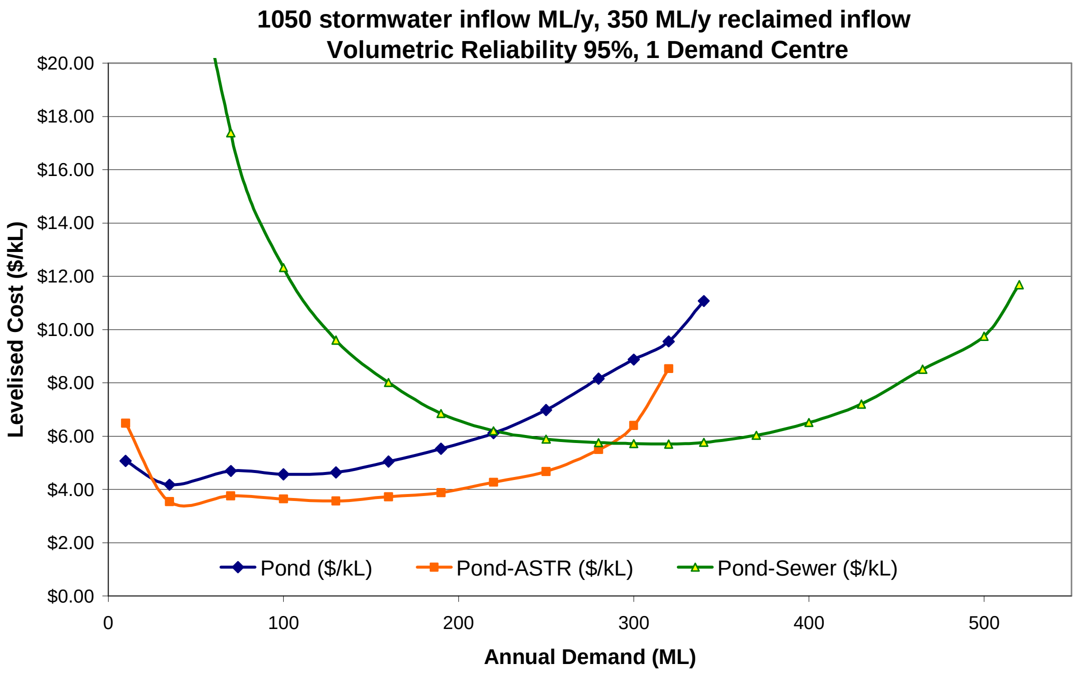


Figure 9: Comparison of stormwater-reclaimed water mixing with other supply options

Costs for sewer mining in this study do not remove the 'necessary' cost of treating reclaimed water further downstream. Presumably, treating sewage at a sewer mining plant will reduce the load on the Lower Molonglo treatment plant and hence reduce its operational costs and delay the need for an upgrade. It is arguable whether this cost (which has not been quantified in this study) should be removed from the sewer mining cost. This benefit needs to be taken into account before conclusions are drawn. It could also be argued there is a similar 'necessary' cost for stormwater harvesting (i.e. the function stormwater ponds perform in improving water quality that alleviates the need for further water-sensitive urban design measures.)

Although some potential exists for mixing stormwater and reclaimed water and storing it in ponds, no further investigation has been undertaken for this study. This was primarily due to time constraints, lack of resources and lack of data, rather than because it lacks potential. The generic costing options indicate it is more expensive than stormwater options in circumstances of low demand and high inflow, but that it is much cheaper in circumstances of high demand and low inflow. The concept could also be adopted to allow marginal or borderline stormwater schemes to become viable.

Sewer mining also has the potential to reach demands that are not feasible or very expensive to reach from stormwater or lake harvesting schemes. Stormwater harvesting is only feasible where there are sufficient inflows and land available for capture and storage. Sewer mining may therefore be feasible in some locations where stormwater harvesting is not.

It is recommended that further investigations are undertaken to coordinate the planning of stormwater harvesting and recycled water schemes. ActewAGL has already developed a recycled water strategy for Canberra (ActewAGL 2008) which recommended centralised recycling from Lower Molonglo Water Quality Control Centre and Fyshwick Sewage Treatment Plant in preference to sewer mining plants. ActewAGL stated that sewer mining plants, *although feasible ….*, have …*substantially higher capital and operating costs than the network of pipes and a single source of recycled water*.

Notwithstanding the recommendations of ActewAGL (2008), this report is suggesting sewer mining *may* have potential in Canberra. The above analysis shows that in *limited* circumstances, a stormwater harvesting scheme could reduce costs by combining with a sewer mining scheme. Whether these limited circumstances present themselves is unknown, because the modelling and costing involving sewer mining in this study was limited to hypothetical examples.

6.4 Stormwater Ponds, Sewer Mining and Aquifer Storage

Similar to stormwater-sewer mining (SSM) schemes, stormwater-sewer mining-ASTR (SSMA) schemes were also shown to be favourable where demand is high and inflow is low. In such circumstances, SSMA schemes comfortably outperformed SSM schemes. The cheapest levelised cost from the generic scenarios was $3.55 /kL which compares to $4.32 /kL for SSM and around $2 /kL for the generic stormwater and stormwater pond-ASTR options.

Schemes that have large demands and low inflows are appropriate applications for combined stormwater-sewer mining-ASTR schemes (see Figure 10 for an example of 1400 ML/yr inflow (25% from sewer mining), one demand centre and a volumetric reliability of 95%, the cost SSMA is cheaper than SSM for all demands). Stand-alone stormwater or pond-ASTR schemes are cheaper for lower demands.

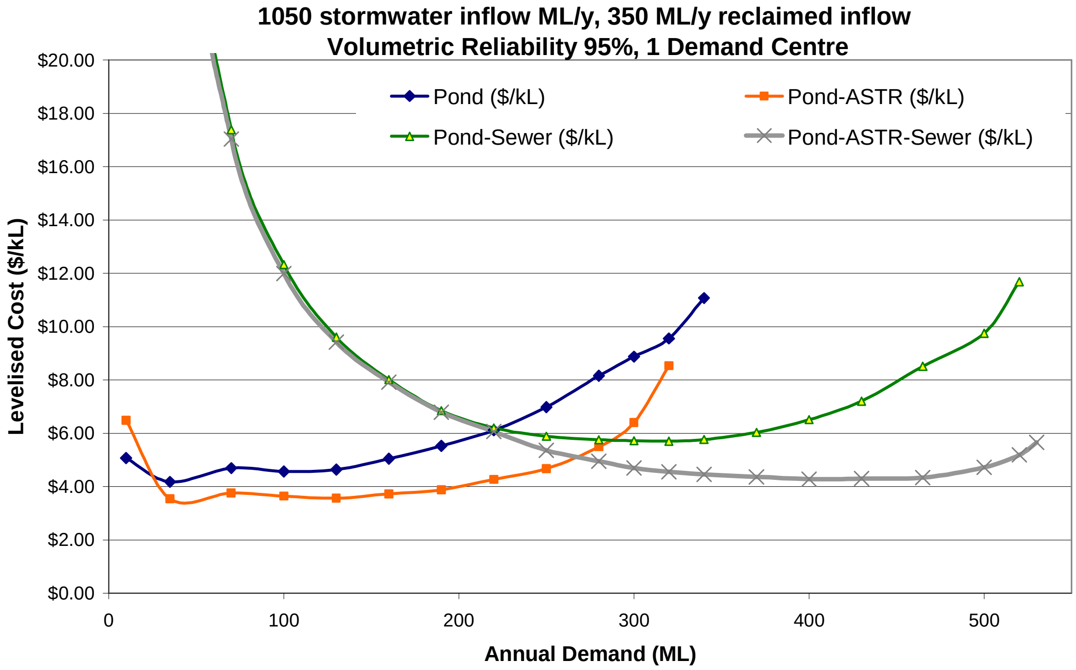


Figure 10: Comparison of stormwater-ASTR-reclaimed water with other supply options

Combining stormwater, sewer mining and ASTR offers genuine potential for least-cost water harvesting in urban Canberra. It will not be the cheapest supply option in all circumstances, but it will be very cost-competitive in circumstances of:

- high demand and low inflow
- high volumetric reliability requirement and
- limited pond area.

Storing reclaimed water in an underground aquifer is not possible at this time in the ACT because existing legislation and proposed legislation changes make no provision for reclaimed water to be injected into aquifers. Future legislation changes may consider this aspect when more detailed science addresses real and perceived risks.

Sewer mining *may* have potential in Canberra (see also Chapter 6.3). The above analysis shows that in *limited* circumstances, a stormwater harvesting scheme could reduce costs by combining with a sewer mining scheme. Whether these limited circumstances present themselves is unknown, because the modelling and costing involving sewer mining in this study is limited to hypothetical examples.

This study has investigated hypothetical rather than specific schemes involving a combination of stormwater harvesting, sewer mining and aquifer storage. Sewer mining *may* have potential in Canberra (see also Chapter 6.3), however further investigations are required. ActewAGL (2008) suggested centralised recycling would be cheaper than sewer mining, but the potential of combining sewer mining with stormwater harvesting schemes was not considered. This study is recommending a further study be undertaken to coordinate planning of stormwater harvesting and recycled water schemes. Such a study should also consider stormwater-sewer mining-ASTR options.

6.5 Lakes

Many supply–demand options were considered where an existing pond or lake was the supply. Generally, any demand located within 4 km of a pond/lake was modelled and costed (see Appendix C and Appendix K for a description of the modelling models and data). An allowable drawdown limit of 1 m was assumed. Life cycle costing was undertaken as per Appendix L.

Existing ponds and lakes were shown to be a very cheap source of water in comparison to stormwater ponds. This is largely due to pond costs (construction, operation and maintenance) not being included in the cost of harvesting as they already exist. The only costs included in this analysis are piping and pumping. Some lakes also benefit from very large inflows, often from beyond the urban area, and are also very large storages. Lakes such as Ginninderra and Tuggeranong can almost be considered as mini-reservoirs. Given they have plentiful inflows, plentiful storage and no costs associated with storage they are much cheaper in comparison to new stormwater ponds.

Without considering interactions of options, some of the cheaper possibilities for lakes supplying demands are shown in Table 9.

Remediation works on the edge of lakes may be required if lakes are allowed to be drawn down by 1 m. Plants that are capable of withstanding ephemeral conditions may be required, as may works on jetties and landscaping. Costs of such ‘edge-works’ have not been included in this analysis, following technical working group discussions. These costs are difficult to estimate at the conceptual design stage but are likely to be minor.

Table 9: Cheapest lake options (greater than 95% volumetric reliability)

Supply name	Demand cluster	Levelised cost ($/kL)	Irrigation area (ha)	Demand (ML/yr)
Yerrabi Pond	Gungahlin Lakes (pipe 1)	0.24	22.5	142.9
David St Wetland	O'Connor/Turner	0.34	3.9	24.5
Yerrabi Pond	Gungahlin Lakes (pipe 2)	0.48	22.5	142.9
Lake Ginninderra	Belconnen 2	0.51	3.5	22.2
Lake Ginninderra	Belconnen 3	0.58	1.6	10.2
Nicholls Pond	Gold Creek (meet partial demand)	0.61	5.2	30.8
Lake Tuggeranong	Greenway 1	0.65	8.5	53.9
Lake Ginninderra	Belconnen 1	0.68	2.8	17.8
Gungahlin Pond	Gungahlin Lakes (pipe 1)	0.78	22.5	142.9
Lake Ginninderra	McKellar	0.78	3	19.1
Lake Ginninderra	Giralang	0.92	7.9	50.2
Point Hut Pond	Gordon	1.09	4.3	27.3
Lake Tuggeranong	Kambah 4	1.12	14	88.9

To provide an indication of the expected changes in lake levels, an example involving Lake Ginninderra is presented. The current regime where Lake Ginninderra is not used for harvesting was modelled. This was compared to using Lake Ginninderra to supply 1 GL/yr to surrounding demands and using a number of ponds upstream to supply 650 ML/yr of demands (as per the master plan developed in Chapter 7). The 2030 climate series (see Chapter 2.1) was used, as were the rainfall run-off and harvesting models (see Appendix C and Appendix K).

Under the current regime of no harvesting, the average water level is 0.06 m below top water level; the minimum level over the 65-year simulation period is 0.76 m below top water level and the daily standard deviation is 0.1 m. Under the ‘proposed regime’, the corresponding numbers are 0.18 m and 1.32 m below top water level with a standard deviation of 0.27 m. Water levels will therefore drop on average 0.12 m under the proposed regime, and the lowest anticipated level will be 0.56 m less. Discussions with those responsible for maintaining the lakes are required to determine whether this necessitates edge-works.

6.6 Sportsground Aquifers

To demonstrate the potential of sportsground aquifers, a scheme (Figure 11) was conceptualised, designed and costed. The scheme comprises:

- diversion weir and pump
- pipe to transfer water from weir to infiltration trench
- infiltration trench covered by a swale
- recovery pump and
- pipe from well to fields.

Design and costing details are shown in Appendix I. The principles for sportsground aquifer design could also be applied to ‘shallow alluvial aquifers’ as they are essentially the same concept.

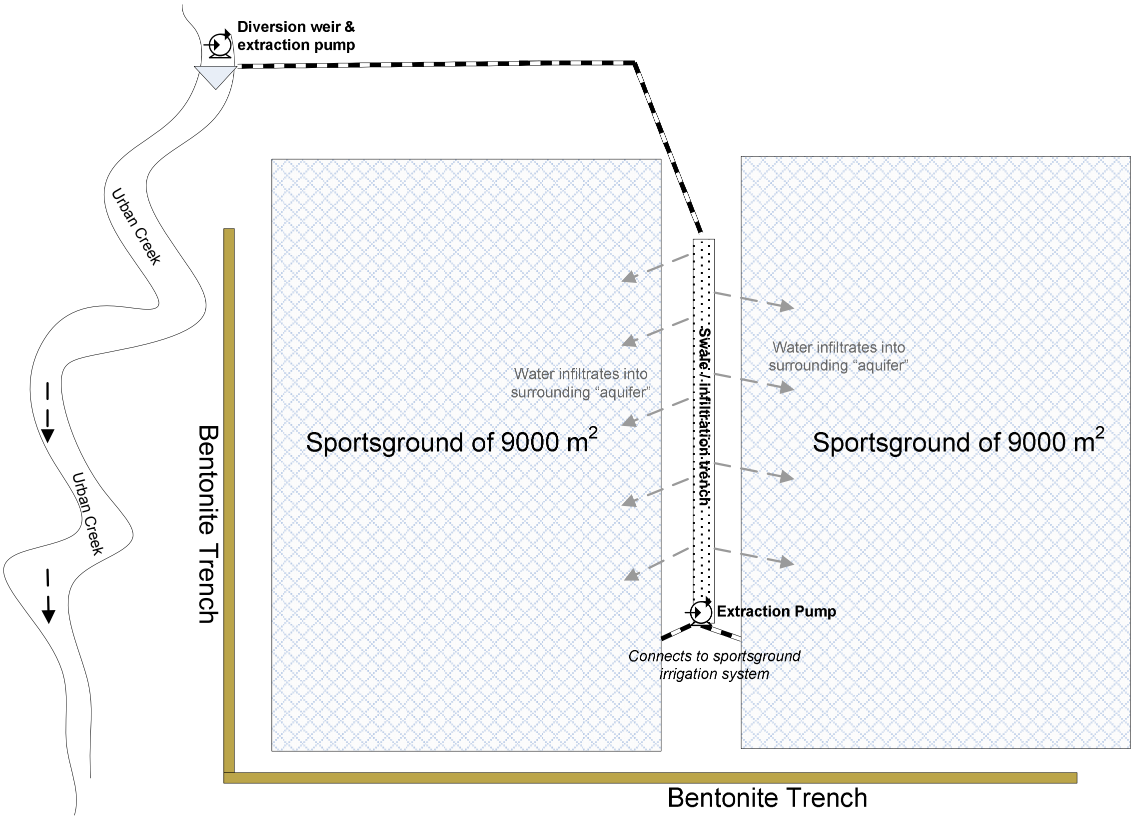


Figure 11: Sportsground aquifer example

The present value cost for a sportsground aquifer scheme is anticipated to be $310 000 which equates to a levelised cost of $2.34 /kL (Table 10). Capital costs, not including contingencies and other add-on costs, are estimated to be $125 000. Loam soils were assumed. This is a conservative assumption as soils with greater hydraulic conductivity (e.g. sandy gravel, sandy loam) would require a lesser trench size. The costs of the pipes and pumps are also conservative as they are based on ACTEW's estimations for pressurised residential water supplies rather than irrigation systems.

Table 10: Indicative costs for sportsground aquifer

CAPITAL CONSTRUCTION COST	**Allowance (%)**	**Cost ($)**
Weir structure and litter screen / pumping well		5 000
Pump from diversion		8 000
Rising main / transfer pipe		10 875
Infiltration swale (80 m, 2 m wide, 3 m deep)		84 469
Recovery pump		12 556
Pipe from well to fields		3 625
Subtotal		**125 000**
Including allowances	**Allowance (%)**	
Contingency	30	37 500
Consultant design & supervision	20	25 000
Special investigations	20	25 000
Subtotal		**212 500**
Insurance	0.6	1 275
Administration-procurement solutions	4	8 500
TOTAL		222 275
Total capital cost (rounded) ($)		**220 000**
REPLACEMENT COSTS		
Diversion pump		4 790
Swale		32 844
Recovery pump		7 518
Subtotal		**45 153**
Contingency, administration & procurement	30	13 546
Total PV replacement cost		**58 698**
OPERATION & MAINTENANCE COST		
Annual pump cost (assumed 1.5% of capital)		308
Annual weir and litter screen cost (assumed 1.5% of capital)		75
Annual infiltration swale cost		401
Annual energy cost		516
Subtotal		**1 300**
Allowances (contingency 10%, design & supervision 12%, administration & procurement 8%)	30	390
Total annual O+M		**1 689**
Total PV O+M cost		**24 876**
TOTAL PV PROJECT COST		**305 849**
ROUNDED TOTAL ($PV)		**310 000**
LEVELISED COST ($ /kL)		**2.34 per kL**

Given the affordable life cycle cost and conservative approach used in costing, sportsground aquifers can be considered feasible as water storage and supply options. The challenge now is to find appropriate sites.

No further analysis has been undertaken into sportsground aquifers as part of this study, as the resources for doing so are not available.

A short report prepared by Ian Lawrence (eWater CRC) and Ray Evans (Salient Solutions) which was used for informing this report is included in Appendix H.

6.7 Summary

Modelling hypothetical supply options provided clear cut conclusions:

i. existing ponds and lakes are the cheapest way to harvest water in urban Canberra

ii. stormwater harvesting is generally cheaper than stormwater-ASTR options for 85% volumetric reliability

iii. stormwater harvesting-ASTR is generally cheaper than stand-alone stormwater ponds for 95% volumetric reliability

iv. ASTR is preferable to ASR given the assumptions adopted for this study (it should be remembered there will be significant variation in recovery efficiency on a case-by-case basis, so in some cases, ASR may be preferable)

v. combining sewer mining and stormwater harvesting schemes is preferable where demand is high and inflow low; adding reclaimed water from sewer mining is also capable of making marginal stormwater harvesting schemes viable but, injecting reclaimed water into aquifers in the ACT requires enabling legislation; further work is required to quantify risks / management measures that may enable treated effluent ‘reclaimed water’ being stored in aquifers

vi. a combined stormwater-ASTR-sewer mining scheme has potential to be cheaper in life cycle cost terms than a stormwater-sewer mining scheme

vii. combined reclaimed water-stormwater schemes (including those with aquifer storage) are much more capable of meeting very large demands in comparison to stand-alone stormwater schemes

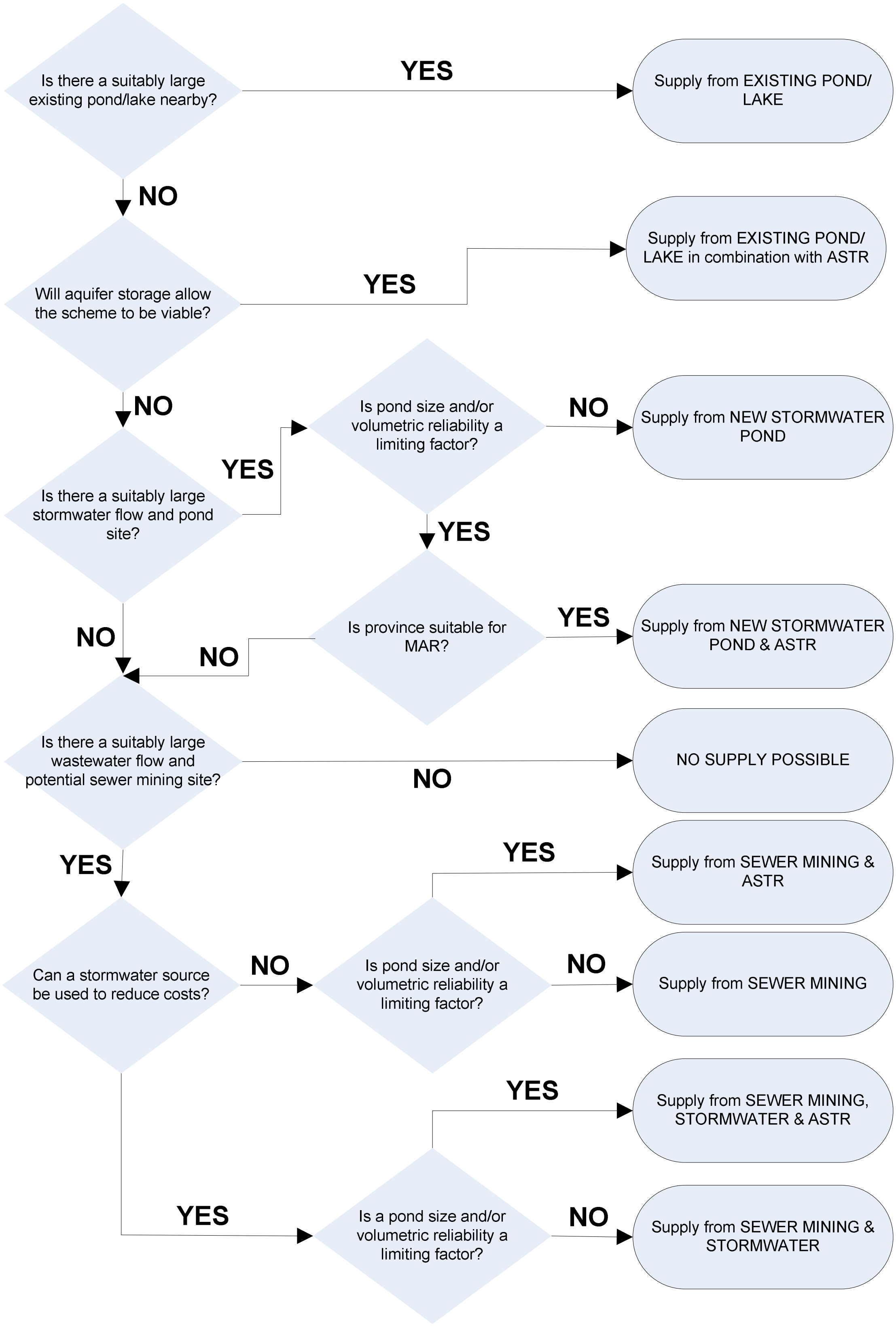
viii. sportsground aquifers have the potential to be a comparatively cheap storage and supply option.

It can be concluded that the ideal harvesting solution for urban Canberra will involve a mixture of existing lakes, new stormwater ponds, aquifer storage and sewer mining. In some cases, combining sewer mining with stormwater harvesting will be beneficial.

The outputs of this modelling process have been developed into a decision-making tree (Figure 12). This decision-making tree is another way of representing the modelling results shown in

Appendix N. It shows that there is no single solution that will be cheapest in every circumstance, but rather all options need to be considered. Use of existing lakes and ponds should first be considered as they are potentially the cheapest solution, however if supplying a demand is constrained by lack of nearby stormwater flows or an appropriate pond site, sewer mining and aquifer storage will need to be considered.

The results emanating from the modelling described in this chapter were used to develop a master plan of supply–demand options to achieve at least 3 GL/yr (Chapter 7). The master plan considered new stormwater ponds, aquifer storage and existing lakes / ponds. Sewer mining was not considered due to lack of resources and time constraints.



Note: This is only a guide. A decision making tree will vary depending upon site specific factors such as required reliability and hydrogeological province

Figure 12: Least-cost decision making tree

7 DEVELOPMENT OF MASTER PLANS

'Master plans' are preferred portfolios of stormwater supply-demand options. The study has developed three master plans: Master Plan A, Master Plan B and Master Plan C. This chapter describes development of all three master plans.

7.1 Master Plan Development Methodology

Master Plan A was developed first, using aquifer storage, new stormwater ponds and existing lakes/ponds as supply options, subject to the following constraints:

- distance between supply and demand being less than 4 km (as outlined in Chapter 6)
- volumetric reliability being 95% or greater (parameter viii, Chapter 2 and discussed in Chapter 6).

The estimated total supply volume for Master Plan A under 2030 climate conditions is estimated to be 4.4 GL/yr. A value of 4.4 GL/yr was considered appropriate (rather than 3 GL/yr as per the goal of this project) because:

- some of the options may not be viable (e.g. detailed engineering investigations may indicate that aquifer storage may not be viable, as yet unidentified heritage issues may prevent pond construction, there may not be community support for the site, or ‘hidden’ costs such as rock excavation may be revealed upon detailed investigation)
- irrigation may be met by other non-potable supplies such as reclaimed water from the Lower Molonglo Treatment Plant
- users may not be willing to pay for connection to a stormwater harvesting scheme
- a relatively high demand was used for evaluating the options, and the higher the demand volume, the less supply–demand options required to meet 3 GL/yr.

Each of the options was modelled with a demand of 6.35 ML/ha/yr. This is greater than the currently allocated value (5 ML/ha/yr, ACT Government 2007) to account for climate change impacts (see Chapter 3.2). Improvements in irrigation practices could also reduce demand.

Master Plan A was developed on a least-cost basis using the following process:

1. The cheapest supply–demand option was selected.
2. The impact of the option selected in (1) on already selected options was tested (e.g. if the option was upstream of an already selected option, the impact on the already selected option was tested). If the cumulative additional cost (i.e. the cost of the selected option in (1) plus the cost of the impact on already selected options) was less than the next cheapest supply option, it was added to the list.
3. Steps 1–3 were repeated until no more options fitting the distance (4000 m) and volumetric reliability (95%) criteria were available.

The resultant portfolio or Master Plan A is shown in Table 11. A corresponding map is presented in Appendix Q. The total capital cost for supplying the 4.4 GL/yr is estimated to be $154M with a levelised cost of $3.02/kL.

Development of Master Plan A was completed in mid 2008. On development of Master Plan A, however, information not available at the commencement of the study regarding potential users of the harvested water (i.e. end users) became available. It was discovered that many end users considered in the analysis included those already met by non-potable water supplies such as Lake Burley Griffin, groundwater and the proposed North Canberra Effluent Reuse Scheme.

In light of the new information, a review of potential end users considered for the analysis was undertaken in mid 2008 by the technical working group. The outcome of the review was a revised list of potential end users of stormwater harvesting (see Appendix V). The most sensitive variables for identifying the cheapest-cost stormwater harvesting options include location of end users and the volume of water needed to meet each end use to a specified volumetric reliability. Therefore, any changes to end users in terms of their location and the demand water volume has a considerable impact on the levelised cost of individual options and the options selected to be included in a portfolio. Consequently, the revised list of end users and demand volumes meant the stormwater harvesting options included in Master Plan A might no longer represent the cheapest financial cost options at 95% volumetric reliability.

To incorporate the new information into the study, the process for the development-preferred portfolios was repeated for the revised list of end users and two new portfolios were developed (named as Portfolio B and Portfolio C or Master Plan B and Master Plan C). Master Plan B was similar to Master Plan A in terms of volumetric supply reliability (i.e. 95%), but included new information on potential users of stormwater. The second portfolio – Master Plan C – included least-cost stormwater harvesting options with a minimum of 85% volumetric supply reliability.

Since Master Plan B includes latest information on the potential users of stormwater, it supersedes Master Plan A. Hence Master Plans B and C should be treated as outcomes of this study. The Master Plan B and C are shown in Table 12 and Table 13 below. Corresponding maps are presented in Appendices W and X.

Total present value cost of Master Plan B is $177M, which comprises of $141M capital, $33M operation and maintenance and $3M replacement costs. The collective average annual supply of harvesting options included in this Master Plan is 3.3 GL/yr, which equates to a levelised cost of $3.67/kL.

Total present value cost of Master Plan C is $150M (i.e. 85% reliability portfolio), which comprises of $120M capital, $27M operation and maintenance and $3M replacement costs. The collective average annual supply of harvesting options included in this master plan is 3.5 GL/yr, which equates to a levelised cost of $2.94/kL. The 85% reliability master plan was cheaper because the required pond volume is much less compared to pond volumes of the 95% reliability master plan.

The financial cost figures include construction costs for new ponds and add-on costs for contingency, administration, procurement, insurance, site investigations and consultant design and supervision. In general, in each of the master plans, the new pond costs comprise roughly

50% of total costs. Inclusion of construction costs for new ponds as part of the total cost however is, debatable because construction of the pond can occur regardless of any harvesting scheme due to ponds (or some other form of water-sensitive urban design such as wetlands) may be necessary to reduce contaminant loads and decrease velocities in downstream waterways. In addition, some of the ponds are also already funded (e.g. WC0, aka North Weston Pond; NC18, aka Flemington Rd and Point Hut Pond), so further capital funding is not necessary. Hence we have estimated levelised cost of harvesting without pond construction costs (i.e. by including only harvesting infrastructure such as the pipes and the pumps) for Master Plans B and C: $1.70/kL and $1.61/kL respectively.

Including some sewer mining with these schemes may also reduce cost. The constant supply of reclaimed water from sewer mining means that the required pond size can be reduced, which can significantly reduce the cost of the scheme.

All master plans are dominated by supply options from existing lakes and ponds, especially the larger lakes with large catchments such as Tuggeranong and Ginninderra. As has been mentioned previously, lakes are a cheaper supply source simply because there is no pond construction cost. If a demand is located close to an existing pond or lake, the cheapest supply source will almost certainly be from that pond/lake.

Stormwater ponds in combination with ASTR are generally the next cheapest form of supply in levelised cost terms, which is due to the criteria of 95% volumetric reliability. If the criteria were for 85% volumetric reliability or less, direct supply from stormwater ponds would have been more prominent. However, significant uncertainty with ASTR feasibility exists in the ACT, which would impact these options.

Sewer mining has also not been considered in the development of the master plans. If it had, it would have been likely to feature given the high volumetric reliability required (but it may not have featured if the criteria were for a lower volumetric reliability).

Stormwater ponds feature in the master plans in locations where aquifer storage is not considered practical and where demands are located a long distance from existing lakes / ponds. It is also common that there is a high ratio between inflow and demand, as this is important in reducing the required pond size and hence keeping costs low.

7.2 Comparison of Master Plans A and B

The overall cost of Master Plan B has increased in levelised cost per unit volume terms compared to Master Plan A (i.e. Master Plan A has an overall levelised cost of $3.02 /kL, while Master Plan B has an overall levelised cost of $3.67 /kL). Costs have increased because there are less available demands in the revised list of potential end users of stormwater (see Appendix V), which means many of the cheaper supply options in Master Plan A have become no longer valid for Master Plan B.

The reduced number of available demands has also meant the total harvestable volume has decreased. Master Plan A predicted 4.4 GL/yr could be harvested, whilst Master Plan B now predicts only 3.3 GL/yr. Once again, this reduction is due to the demands which were removed from the revised analysis, not because of the availability of stormwater.

The individual supply–demand options that comprise Master Plan B have also changed. The supply options included in Master Plan B that were not included in Master Plan A are:

- Lower Stranger Pond (Tuggeranong, downstream of Upper Stranger, upstream of Central Murrumbidgee)
- NC14 (Dickson, North Canberra)
- WC20-1 (Stirling Playing Fields, Weston Creek)
- WC17 (Waramanga, Weston Creek)
- W26 (Mawson, Woden Valley).

Many of the supply options included in the both Master Plans A and B supply different demands. Some of the more notable changes in Master Plan B are:

- Yerrabi Pond: has dropped Gungahlin Lakes and Amaroo end uses – overall the demand has decreased
- Gungahlin Pond: has dropped Gungahlin Lakes end use and added Yerabbi and Amaroo and others changed volume
- Point Hut Pond: has dropped Calwell 1 end use
- W2: has added Deakin 4 and Hughes end uses – overall an increase in demand
- W0: dropped Yarralumla 5 and Government House which it was discovered are already supplied by Lake Burley Griffin – in the current plan it supplies National Zoo, Deakin 1, Deakin 2, Yarralumla 4 and Yarralumla 3. – overall a decrease in demand
- NC18: added Downer and Watson demand clusters, however the estimated demand for Mitchell and Lyneham 1 reduced significantly.

Nicholls Pond and Isabella Pond, which were included in Master Plan A, are not included in Master Plan B (as they already supply the end users suggested by Master Plan A).

7.3 Comparison of Master Plans A and C

Many differences also exist between Master Plan A (i.e. 95% reliability portfolio) and Master Plan C (i.e. 85% reliability portfolio). Some of these differences are due to the different objectives (i.e. 85% versus 95% volumetric reliabilities), while some are due to the different available demands. Some of the more notable differences in Master Plans A and C are:

- Master Plan C includes supply options of B1 (Kaleen, Belconnen), Lower Stranger (Tuggeranong, downstream of Upper Stranger), W26 (Mawson, Woden Valley), WC20-1 (Stirling Playing Fields, Weston Creek), WC17 (Waramanga, Weston Creek) and WC9 (Weston, Weston Creek), but these options are not in Master Plan A.

- Nicholls Pond and Isabella Pond are not included in Master Plan C, but are included in Master Plan A.

7.4 Next Steps

The next step of the methodology (see Chapter 1) is to assess TBL performance of the master plans. As mentioned earlier in this chapter, Master Plan A was developed first in early 2008 and key stakeholders of this study agreed to consider it as the preferred portfolio of stormwater harvesting. Accordingly, TBL performance assessment (i.e. ecological impact, social impact and multi-criteria assessment) was undertaken on Master Plan A during January to July 2008 (see Chapters 8, 9, 10 and 11 for a description of the processes followed and results of the TBL assessment on Master Plan A).

The emergence of new information on the potential user of stormwater harvesting on completion of the TBL analysis in mid 2008 had meant that revisions were required for both Master Plan A and its TBL assessment. The CSIRO project team agreed to revise Master Plan A and developed two new master plans, but due to limitations in availability of time and resources, further analysis of TBL performance assessment of new master plans could not be undertaken (i.e. Steps 6 and 7 of the methodology described in Chapter 1 were not repeated for Master Plans B and C). Chapters 8 to 11 can be used to gauge these impacts related to the new master plans, but caution should be used because drawdown levels, pond volumes and demands placed upon the ponds have changed and will influence these impacts (particularly ecological impacts).

Table 11: Supply–demand options included in Master Plan A

Supply name	Type	Potential for aquifer storage	Demand	Total life cycle cost ($)	Levelised cost ($/kL)	Levelised cost without pond ($/kL)	Capital cost ($)	Estimated pond area (m^2)	Irrigated area (ha)	Demand (ML)	Volumetric reliability (%)	Supply (ML/y)
Yerrabi Pond	Existing pond	N/A	Gungahlin Lakes[1]	486 000	0.24	–	335 000	–	22.5	142.9	98.1	140.2
			Amaroo	1 181 000	1.43	–	982 000	–	9.1	57.8	98.1	56.7
			Throsby	1 758 000	2.44	–	1 555 000	–	8.0	50.8	98.1	49.8
Gungahlin Pond	Existing pond	N/A	Gold Creek[1]	3 343 000	0.98	–	2 361 000	–	39.9	253.0	95.9	242.6
			Crace	591 000	1.39	–	493 000	–	5.0	31.8	95.9	30.4
			Nichols	839 000	1.49	–	696 000	–	6.6	41.9	95.9	40.2
			Gungahlin	455 000	2.17	–	401 000	–	2.5	15.6	95.9	14.9
			Palmerston	475 000	2.21	–	414 000	–	2.5	15.9	95.9	15.2
			Ngunnawal	654 000	3.46	–	580 000	–	2.2	14.0	95.9	13.4
			Gungahlin Lakes[1]	1 670 000	0.85	–	1 370 000	–	22.5	142.9	95.9	137.0
David St Wetland	Existing pond	N/A	O'Connor/ Turner[1]	78 000	0.48	–	60 000	–	1.9	12.2	95.0	11.6
Nichols Pond	Existing pond	N/A	Gold Creek[1]	290 000	0.68	–	224 000	–	5.2	32.8	95.0	31.1
Lake Ginninderra	Existing lake	N/A	Belconnen 2	163 000	0.51	–	124 000	–	3.5	22.2	97.9	21.7
			Belconnen 3	87 000	0.61	–	67 000	–	1.6	10.2	97.9	9.9
			Belconnen 1	181 000	0.71	–	145 000	–	2.8	17.8	97.9	17.4
			McKellar	223 000	0.85	–	172 000	–	3.0	19.0	97.9	18.6
			Melba 2	1 034 000	1.26	–	924 000	–	9.2	58.4	97.9	57.2
			Giralang	668 000	0.95	–	549 000	–	7.9	50.2	97.9	49.1
			Evatt 2	353 000	1.32	–	301 000	–	3.0	18.9	97.9	18.5
			Kaleen 2	1 647 000	1.49	–	1 349 000	–	12.4	78.7	97.9	77.1
			Macquarie/ Belconnen	1 233 000	1.53	–	1 039 000	–	8.9	56.8	97.9	55.6
			Uni of Canberra	636 000	1.60	–	529 000	–	4.5	28.6	97.9	27.9
			Melba 1	893 000	1.80	–	767 000	–	5.5	34.9	97.9	34.2
			Hawker	2 296 000	1.87	–	1 821 000	–	13.8	87.3	97.9	85.4
			Aranda	1 495 000	1.83	–	1 214 000	–	9.1	57.6	97.9	56.4
			Florey 2	361 000	2.00	–	321 000	–	2.0	12.8	97.9	12.6
			Bruce	1 065 000	2.14	–	884 000	–	5.6	35.6	97.9	34.8
			Evatt 1	716 000	2.21	–	621 000	–	3.6	22.9	97.9	22.4
			Scullin	1 087 000	2.38	–	958 000	–	5.1	32.4	97.9	31.7
			Kippax	3 349 000	2.14	–	2 964 000	–	17.4	110.5	97.9	108.1
			Page	476 000	2.78	–	424 000	–	1.9	12.1	97.9	11.8
			Weetangerra	1 192 000	2.95	–	993 000	–	4.5	28.6	97.9	28.0
			Macquarie & Cook	1 658 000	2.99	–	1 429 000	–	6.2	39.4	97.9	38.5
			Kaleen 1	1 070 000	3.16	–	951 000	–	3.8	24.1	97.9	23.6
			Kaleen 3	1 399 000	3.12	–	1 228 000	–	5.0	31.8	97.9	31.1
			Latham	1 204 000	3.36	–	1 106 000	–	4.0	25.4	97.9	24.9
			Flynn	1 183 000	6.01	–	1 096 000	–	2.2	14.0	97.9	13.7
			Spence	1 371 000	4.92	–	1 217 000	–	3.1	19.7	97.9	19.3
			AIS	2 115 000	4.24	–	1 889 000	–	5.6	35.2	97.9	34.5
			Higgins	1 574 000	7.33	–	1 445 000	–	2.4	15.2	97.9	14.9
Lake Tuggeranong	Existing lake	N/A	Greenway 1	517 000	0.68	–	417 000	–	8.5	53.8	98.1	52.8
			Kambah 4	1 448 000	1.15	–	1 185 000	–	14.0	88.9	98.1	87.2
			Murrumbidgee	4 927 000	1.22	–	3 552 000	–	45.0	285.8	98.1	280.2
			Waniassa 1	1 490 000	1.63	–	1 220 000	–	10.2	64.8	98.1	63.5
			Greenway 2	368 000	1.70	–	324 000	–	2.4	15.4	98.1	15.1
			Kambah 2	2 052 000	2.68	–	1 790 000	–	8.5	54.0	98.1	52.9
			Waniassa 3	1 686 000	2.75	–	1 462 000	–	6.8	43.4	98.1	42.6
			Kambah 3	2 078 000	2.85	–	1 788 000	–	8.1	51.4	98.1	50.4
			Waniassa 2	811 000	5.30	–	719 000	–	1.7	10.8	98.1	10.6
Point Hut Pond	Existing lake	N/A	Gordon	436 000	1.09	–	354 000	–	4.3	27.3	99.8	27.2
			Conder	1 363 000	1.60	–	1 098 000	–	9.2	58.3	99.8	58.1
			Banks	844 000	3.23	–	751 000	–	2.8	17.8	99.8	17.7
			Calwell 1	1 106 000	3.70	–	986 000	–	3.2	20.3	99.8	20.3
Upper Stranger Pond	Existing lake	N/A	Isabella Plains	637 000	1.19	–	537 000	–	5.8	36.6	99.7	36.5
			Bonython	295 000	1.22	–	247 000	–	2.6	16.5	99.7	16.5
Jarramlee (Dunlop Pond 1)	Existing pond	N/A	Charnwood 2[1]	627 000	1.43	–	514 000	–	5.3	33.4	95.0	31.7
Fassifern (Dunlop Pond 2)	Existing pond	N/A	Charnwood 2[1]	780 000	2.44	–	680 000	–	3.8	24.1	95.0	22.9
W2	Pond-ASTR	High	Curtin 1	2 658 000	3.16	1.91	1 957 000	3 446	6.6	41.7	100.0	41.7
			Curtin 2						2.5	15.6	100.0	15.6
W0	Pond-ASTR	High	Yarralumla 5	33 526 000	5.40	1.87	26 175 000	131 500	46.5	295.3	100.0	295.3
			Government House						20.0	127.0	100.0	127.0
Isabella Pond	Existing lake	N/A	Monash	419 000	2.41	–	372 000	–	1.9	11.7	100.0	11.7
			Waniassa 4	345 000	3.70	–	315 000	–	1.0	6.4	100.0	6.4
WC4	Stormwater pond	N/A	Weston	4 991 000	5.13	2.58	3 924 000	8 205	2.7	17.2	95.0	16.3
			Holder/Weston						2.0	12.7	95.0	12.1
			Holder						2.5	15.9	95.0	15.1
			Rivett						3.8	24.0	95.0	22.8
B14	Stormwater pond	N/A	Florey 1	579 000	3.36	1.84	404 000	864	1.9	12.3	95.0	11.7
NC9-11	Pond-ASTR	Moderate to High	Ainslie	7 273 000	4.31	1.88	5 540 000	16 980	6.5	41.3	100.0	41.3
			O'Connor/ Turner[1]						7.4	47.2	100.0	47.2
			Lyneham 4						4.1	26.0	100.0	26.0
WC0	Pond-ASTR	High	National Zoo	28 342 000	5.26	1.98	21 593 000	104 150	50.0	317.5	100.0	317.5
	Stormwater pond	N/A	[2]North Weston						5.4	34.3	95.0	32.6
	Stormwater pond		[2]Molongolo						2.3	14.6	95.0	13.9
West Belconnen Pond	Existing pond	N/A	Charnwood 2[1]	602 000	4.58	–	550 000	–	1.5	9.3	98.0	9.1
			Fraser	687 000	4.04	–	604 000	–	1.9	12.1	98.0	11.8
			Charnwood 1	1 091 000	4.31	–	983 000	–	2.8	17.9	98.0	17.5

Supply name	Type	Potential for aquifer storage	Demand	Total life cycle cost ($)	Levelised cost ($/kL)	Levelised cost without pond ($/kL)	Capital cost ($)	Estimated pond area (m^2)	Irrigated area (ha)	Demand (ML)	Volumetric reliability (%)	Supply (ML/y)
WC14-15	Stormwater pond	N/A	Duffy	1 789 000	5.43	2.68	1 347 000	3 012	3.7	23.5	95.0	22.3
W19	Stormwater pond	N/A	Phillip/Garran	8 770 000	4.89	1.40	6 715 000	30 840	11.4	72.3	95.0	68.7
			Phillip 2						8.8	55.9	95.0	53.1
W27	Stormwater pond	N/A	Pearce 1	7 528 000	5.60	1.67	5 706 000	24 620	10.6	67.3	95.0	63.9
			Mawson						4.5	28.9	95.0	27.4
T2	Stormwater pond	N/A	Gowrie	6 052 000	6.28	1.88	4 633 000	17 830	8.1	51.4	95.0	48.9
			Chisholm						2.7	17.5	95.0	16.6
T3	Stormwater pond	N/A	Calwell 3[1]	5 161 000	5.47	1.61	3 923 000	14 000	10.6	67.6	95.0	64.2
T4	Stormwater pond	N/A	Richardson	2 741 000	6.35	3.11	2 107 000	4 630	1.4	8.9	95.0	8.4
			Calwell 2						1.7	10.8	95.0	10.3
			Calwell 3[1]						1.8	11.1	95.0	10.6
NC18	Pond-ASTR	Moderate to High	Lyneham 1	12 150 000	4.52	2.04	9 303 000	33 500	6.4	40.6	100.0	40.6
			EPIC						6.1	38.5	100.0	38.5
			Gungahlin Cemetery						15.0	95.3	100.0	95.3
			Mitchell[1]						1.3	8.3	100.0	8.3
G23	Pond-ASTR	Moderate to High	[2]Harrison	3 210 000	4.89	2.47	2 431 000	5 270	7.0	44.5	100.0	44.5
B28	Stormwater pond	N/A	MacGregor	2 097 000	5.13	2.10	872 000	2 218	3.1	19.7	95.0	18.7
			Holt						1.5	9.5	95.0	9.0
WC19	Stormwater pond	N/A	Waramanga[1]	1 927 000	6.79	2.40	1 394 000	4 120	3.2	20.3	95.0	19.3
Sum				**196 000 000**	**3.02**		**154 000 000**		**709.6**	**4505.9**	**97.9**	**4409.2**

[1] Only meets a portion of the demand in the demand cluster

[2] This is an anticipated demand that does not yet exist

Notes

- Only supply–demand options that could meet 95% volumetric reliability or greater have been included.
- The following existing ponds and lakes were considered in the analysis: David St Wetland, Jarramlee Pond (i.e. Dunlop Pond 1), Fassifern Pond (i.e. Dunlop Pond 2), Lake Ginninderra, Gordon Pond, Gungahlin Pond, Isabella Pond, Lake Tuggeranong, Nichols Pond, Point Hut Pond, Upper Stranger Pond, Lower Stranger Pond, Yerrabi Pond, Tuggeranong Weir, West Belconnen Pond.
- Lake Burley Griffin has not been included in this analysis.
- Volumetric reliability from aquifer to demand has been modelled at 100%. The volumetric reliability from pond to aquifer is 95%. (There is no net loss of groundwater over the simulation period).
- All scenarios are modelled using 2030 climate series. This has been developed by modifying historical SILO data drill records. Rainfall and evaporation have been changed based on the worst 2030 climate scenario as per ACTEW’s *Future Water Options* report.
- Demand is based on a 2030 climate series and is measured at 6.35 ML/ha/yr (rather than current estimation of 5 ML/ha/yr

Table 12: Supply–demand options included in Master Plan B

Supply name	Type	Potential for aquifer storage	Demand	Total cost ($PV)	Levelised cost ($/kL)	Levelised cost w/o pond ost ($/kL)	Capital cost ($)	Operation & maintenance Cost ($PV)	Replacement cCost ($PV)	Total pipe & pump cost ($PV)	Total bore Cost ($PV)	Total pond cost ($PV)	Estimated pPond area (m2)	Irrigated area (ha)	Demand (ML/y)	Volumetric reliability (%)	Supply (ML/y)
Tuggeranong	Existing	N/A	Greenway 1	137 190	3.06	3.06	125 294	10 472	1 425	137 190	–	–	–	0.5	3.0	100.0	3.0
			Kambah 4	1 447 840	1.11	1.11	1 184 532	221 752	41 556	1 447 840	–	–	–	14.0	88.9	100.0	88.9
			Wanniassa 1	1 489 810	1.56	1.56	1 220 215	239 319	30 276	1 489 810	–	–	–	10.2	64.8	100.0	64.8
			Kambah 2	2 052 490	2.58	2.58	1 790 363	236 896	25 230	2 052 490	–	–	–	8.5	54.0	100.0	54.0
			Wanniassa 3	1 090 175	3.60	3.60	966 598	113 960	9 617	1 090 175	–	–	–	3.2	20.6	100.0	20.6
			Kambah 3	2 078 262	2.74	2.74	1 788 012	266 206	24 043	2 078 262	–	–	–	8.1	51.4	100.0	51.4
			Wanniassa 2	811 444	5.11	5.11	719 047	87 350	5 046	811 444	–	–	–	1.7	10.8	100.0	10.8
Ginninderra	Existing	N/A	Belconnen	124 913	0.98	0.98	104 917	15 840	4 156	124 913	–	–	–	1.4	8.9	97.4	8.7
			McKellar	223 414	0.82	0.82	172 315	42 203	8 896	223 414	–	–	–	3.0	19.0	97.4	18.5
			Melba 2	1 034 406	1.23	1.23	924 270	82 828	27 308	1 034 406	–	–	–	9.2	58.4	97.4	56.9
			Giralang	667 918	0.93	0.93	549 210	95 259	23 449	667 918	–	–	–	7.9	50.2	97.4	48.9
			Evatt 2	353 286	1.31	1.31	301 090	43 373	8 823	353 286	–	–	–	3.0	18.9	97.4	18.4
			Kaleen 2	1 647 179	1.46	1.46	1 349 171	261 201	36 807	1 647 179	–	–	–	12.4	78.7	97.4	76.7
			Macquarie/Belconnen	1 233 128	1.51	1.51	1 038 770	167 822	26 536	1 233 128	–	–	–	8.9	56.8	97.4	55.3
			Uni Canberra	636 200	1.55	1.55	529 212	93 639	13 348	636 200	–	–	–	4.5	28.6	97.4	27.8
			Melba 1	893 220	1.78	1.78	767 162	109 733	16 326	893 220	–	–	–	5.5	34.9	97.4	34.0
			Hawker	2 296 377	1.83	1.83	1 821 214	434 349	40 814	2 296 377	–	–	–	13.8	87.3	97.4	85.0
			Aranda	1 494 948	1.81	1.81	1 213 575	254 451	26 922	1 494 948	–	–	–	9.1	57.6	97.4	56.1
			Florey 2	360 787	1.96	1.96	321 277	33 514	5 996	360 787	–	–	–	2.0	12.8	97.4	12.5
			Bruce	1 018 245	2.00	2.00	874 523	131 774	11 948	1 018 245	–	–	–	5.6	35.6	97.4	34.6
			Evatt 1	716 050	1.95	1.95	620 631	84 733	10 686	716 050	–	–	–	4.0	25.6	97.4	24.9
			Scullin	1 087 440	2.34	2.34	958 190	114 111	15 138	1 087 440	–	–	–	5.1	32.4	97.4	31.5
			Kippax	3 349 216	2.11	2.11	2 964 263	333 305	51 648	3 349 216	–	–	–	17.4	110.5	97.4	107.6
			Page	475 683	2.75	2.75	423 708	46 336	5 640	475 683	–	–	–	1.9	12.1	97.4	11.8
			Weetangera	1 192 295	2.91	2.91	993 340	185 598	13 357	1 192 295	–	–	–	4.5	28.6	97.4	27.8
			Macquarie & Cook	1 657 779	2.94	2.94	1 428 764	210 611	18 403	1 657 779	–	–	–	6.2	39.4	97.4	38.3
			Kaleen 3	1 398 852	3.07	3.07	1 228 352	155 649	14 851	1 398 852	–	–	–	5.0	31.8	97.4	30.9
			Flynn	1 183 356	5.91	5.91	1 095 852	80 974	6 530	1 183 356	–	–	–	2.2	14.0	97.4	13.6
			Spence	1 371 176	4.86	4.86	1 217 168	144 806	9 202	1 371 176	–	–	–	3.1	19.7	97.4	19.2
			AIS	2 114 584	4.18	4.18	1 889 055	209 055	16 474	2 114 584	–	–	–	5.6	35.2	97.4	34.3
			Higgins	1 574 306	7.20	7.20	1 445 110	122 073	7 124	1 574 306	–	–	–	2.4	15.2	97.4	14.8
			Latham	1 204 112	3.31	3.31	1 106 430	85 809	11 873	1 204 112	–	–	–	4.0	25.4	97.4	24.7
			Kaleen 1	1 070 123	3.09	3.09	950 551	108 292	11 279	1 070 123	–	–	–	3.8	24.1	97.4	23.5
Point Hut Pond	Existing	N/A	Gordon[#]	302 999	0.95	0.95	239 143	53 764	10 092	302 999	–	–	–	4.3	27.3	99.6	27.2
			Conder	1 388 394	1.47	1.47	1 103 453	255 035	29 905	1 388 394	–	–	–	9.2	58.3	99.6	58.0
			Banks	843 814	3.24	3.24	751 295	84 208	8 311	843 814	–	–	–	2.8	17.8	99.6	17.7
Lower Stranger Pond	Existing	N/A	Greenway 2	257 663	1.14	1.14	220 522	29 943	7 198	257 663	–	–	–	2.4	15.4	100.0	15.4

Supply name	Type	Potential for aquifer storage	Demand	Total cost ($PV)	Levelised cost ($/kL)	Levelised cost w/o pond ost ($/kL)	Capital cost ($)	Operation & maintenance Cost ($PV)	Replacement cCost ($PV)	Total pipe & pump cost ($PV)	Total bore Cost ($PV)	Total pond cost ($PV)	Estimated pPond area (m2)	Irrigated area (ha)	Demand (ML/y)	Volumetric reliability (%)	Supply (ML/y)
Upper Stranger Pond	Existing	N/A	Isabella Plains	637 065	1.19	1.19	536 693	83 245	17 127	637 065	–	–	–	5.8	36.6	99.6	36.5
			Bonython	294 604	1.22	1.22	247 334	39 552	7 718	294 604	–	–	–	2.6	16.5	99.6	16.5
Gungahlin	Existing	N/A	Gold Creek	2 392 440	1.20	1.20	1 828 289	500 228	63 923	2 392 440	–	–	–	21.5	136.8	98.8	135.1
			Nicholls	838 748	1.38	1.38	696 274	122 883	19 591	838 748	–	–	–	6.6	41.9	98.8	41.4
			*Crace	591 040	1.28	1.28	493 492	82 706	14 841	591 040	–	–	–	5.0	31.8	98.8	31.4
			Palmerston	474 515	2.05	2.05	414 342	52 752	7 421	474 515	–	–	–	2.5	15.9	98.8	15.7
			Yerrabi	1 082 024	1.96	1.96	944 072	120 178	17 775	1 082 024	–	–	–	6.0	38.0	98.8	37.6
			Ngunnawal	653 559	3.21	3.21	580 174	66 855	6 530	653 559	–	–	–	2.2	14.0	98.8	13.8
			Gungahlin	455 095	2.01	2.01	401 156	46 667	7 272	455 095	–	–	–	2.5	15.6	98.8	15.4
			Amaroo	2 240 939	2.66	2.66	1 967 930	245 998	27 011	2 240 939	–	–	–	9.1	57.8	98.8	57.1
West Belconnen Pond	Existing	N/A	Charnwood 1	1 090 861	4.22	4.22	983 468	99 023	8 371	1 090 861	–	–	–	2.8	17.9	98.0	17.5
			Fraser	686 779	3.94	3.94	604 195	76 945	5 640	686 779	–	–	–	1.9	12.1	98.0	11.8
			Charnwood 2*	602 091	4.57	4.57	550 083	47 654	4 354	602 091			–	1.5	9.3	98.0	9.1
Yerrabi	Existing	N/A	Throsby**	1 729 858	2.97	2.97	1 546 914	163 470	19 475	1 729 858	–	–	–	6.6	41.7	95.0	39.6
B14	New Pond	N/A	Florey 1	578 853	3.36	1.02	403 662	169 437	5 754	175 013	–	403 840	864	1.9	12.3	95.0	11.7
B28	New Pond	N/A	Macgregor	2 096 921	5.13	1.01	1 583 646	499 621	13 654	412 640	–	1 684 281	4 110	3.1	19.7	95.0	18.7
			Holt											1.5	9.5	95.0	9.0
David St Wetland	Existing	N/A	Turner**	129 433	0.76	0.76	107 972	15 761	5 699	129 433	–	–	–	1.9	12.2	95.0	11.6
G23	New pond–ASTR	Moderate to high	*Harrison	3 209 924	4.90	1.65	2 430 840	676 162	102 922	536 595	543 069	2 130 260	5 270	7.0	44.5	100.0	44.5
NC18	New pond–ASTR	Moderate to high	Mitchell	14 071 468	5.22	1.75	11 003 665	2 607 107	460 697	2 284 154	2 443 811	9 343 502	30 880	2.2	13.7	100.0	13.7
			EPIC											6.1	38.5	100.0	38.5
			Gungahlin Cemetery											13.0	82.3	100.0	82.3
			Watson											1.8	11.4	100.0	11.4
			Lyneham 1											2.5	15.7	100.0	15.7
			Downer											3.4	21.6	100.0	21.6
NC14	New pond–ASTR	Moderate to high	Watson/Dickson	8 746 434	6.31	1.02	6 704 040	1 835 794	206 600	325 502	1 086 138	7 334 793	27 240	10.1	63.9	100.0	63.9
			Dickson/Ainslie											4.8	30.2	100.0	30.2
NC9–11	New pond–ASTR	Moderate to high	Lyneham 2	5 065 939	5.89	1.70	3 894 169	1 018 589	153 181	644 836	814 604	3 606 499	9 150	4.1	26.0	100.0	26.0
			Dickson											2.1	13.6	100.0	13.6
			O'Connor 1											1.1	6.7	100.0	6.7
			Ainslie											1.9	12.1	100.0	12.1
T3	New pond	N/A	Calwell 3**	5 161 396	5.46	0.46	3 922 811	1 206 984	31 600	433 871	–	4 727 525	14 000	10.6	67.6	95.0	64.2
T4	New pond	N/A	Richardson	2 741 010	6.36	1.99	2 106 617	619 982	14 410	856 424	–	1 884 585	4 630	1.4	8.9	95.0	8.4
			Calwell 2											1.7	10.8	95.0	10.3
			Calwell 3**											1.8	11.1	95.0	10.6
T2	New pond	N/A	Gowrie	6 052 083	6.28	0.59	4 632 879	1 386 996	32 207	565 545	–	5 486 537	17 830	8.1	51.4	95.0	48.9
			Chisholm											2.7	17.5	95.0	16.6
WC4	New pond	N/A	Rivett	4 298 955	5.06	1.91	3 381 239	889 352	28 365	1 618 606	–	2680349	6 710	3.3	21.0	95.00	19.9
			Holder/Weston											2.0	12.7	95.00	12.1

Supply name	Type	Potential for aquifer storage	Demand	Total cost ($PV)	Levelised cost ($/kL)	Levelised cost w/o pond ost ($/kL)	Capital cost ($)	Operation & maintenance Cost ($PV)	Replacement cCost ($PV)	Total pipe & pump cost ($PV)	Total bore Cost ($PV)	Total pond cost ($PV)	Estimated pPond area (m2)	Irrigated area (ha)	Demand (ML/y)	Volumetric reliability (%)	Supply (ML/y)
			Weston											1.8	11.1	95.00	10.6
			Holder											2.5	15.9	95.00	15.1
WC0	New pond	N/A	*North Weston	4 258 738	6.23	1.18	3 279 698	956 181	22 858	803 667	–	3 455 071	8 750	5.4	34.3	95.00	32.6
			*Molonglo											2.3	14.6	95.00	13.9
WC20–1	New pond	N/A	Stirling**	4 612 459	10.08	0.62	3 531 370	1 065 802	15 287	283 669	–	4 328 790	12 000	5.2	32.7	95.00	31.1
WC19	New pond	N/A	Waramanga**	4 963 855	9.64	0.27	3 789 271	1 157 368	17 216	136 932	–	4 826 923	14 500	5.8	36.8	95.00	35.0
WC17	New pond	N/A	Waramanga**	2 664 468	5.94	1.42	2 042 396	607 073	14 998	637 747	–	2 026 720	5 000	3.5	22.2	95.00	21.1
			Stirling**											1.6	9.9	95.00	9.4
WC14–15	New pond	N/A	Duffy	1 788 955	5.44	1.61	1 346 823	431 149	10 983	530 323	–	1 258 632	3 012	3.7	23.5	95.00	22.3
W27	New pond	N/A	Mawson**	9 655 260	8.19	0.56	7 429 120	2 186 751	39 389	655 350	–	8 999 910	35 782	2.7	17.0	95.00	16.1
			Pearce 1											10.6	67.3	95.00	63.9
W19	New pond	N/A	Phillip/Garran	10 875 352	5.36	0.52	8 453 789	2 353 738	67 825	1 056 209	–	9 819 143	40 000	7.3	46.4	95.00	44.1
			Phillip 2											8.5	53.9	95.00	51.2
			Phillip 1**											7.1	44.8	95.00	42.6
W26	New pond	N/A	Torrens/Mawson**	10 059 002	10.02	0.33	7 786 303	2 239 158	33 542	329 122	–	9 729 880	39 540	11.3	71.8	95.00	68.2
W2	New pond–ASTR	High	Curtin 1	5 835 376	4.10	2.02	4 473 866	1 154 465	207 046	2 058 873	814 604	2 961 900	7 450	6.6	41.7	100.00	41.7
	New pond–ASTR	High	Curtin 2											2.5	15.6	100.00	15.6
	New pond	N/A	Deakin 4											2.3	14.6	95.00	13.9
	New pond	N/A	Hughes											4.2	26.7	95.00	25.3
W0	New pond–ASTR	High	National Zoo	12 442 231	4.29	1.53	9 829 843	2 291 204	321 184	2 802 640	1 629 208	8 010 384	30 700	23.6	150.0	100.00	150.0
	New pond–ASTR	High	Deakin 1											2.5	15.9	100.00	15.9
	New pond–ASTR	High	Deakin 2											0.6	4.1	100.00	4.1
	New pond	N/A	Yarralumla 4											1.5	9.5	95.00	9.0
	New pond–ASTR	High	Yarralumla 3											2.8	18.0	100.00	18.0
Dunlop Pond 1	Existing	N/A	Charnwood 2*	626 687	1.41	1.41	514 329	96 759	15 598	626 687	–	–	–	5.3	33.4	95.0	31.7
Dunlop Pond 2	Existing	N/A	Charnwood 2*	779 626	2.44	2.44	679 761	88 615	11 250	779 626	–	–	–	3.8	24.1	95.0	22.9
TOTAL				**176 763 112**	**3.67**	**1.70**	**141 519 116**	**32 548 448**	**2 695 549**	**74 732 155**	**7 331 434**	**94 699 523**		**527.6**	**3350.1**	**97.7**	**3274.3**

*Anticipated future demand (demand does not currently exist)

**The supply only meets a portion of the demand

– Pipes and pumps from Point Hut Pond to Gordon already exist. The costs shown in here include an estimation of pipe and pump costs and are therefore an overestimate of actual cost.

Notes regarding Table 12:

- Only supply–demand options that could meet 95% volumetric reliability or greater have been included.
- The following existing ponds and lakes were considered in the analysis: David St Wetland, Jarramlee Pond (i.e. Dunlop Pond 1), Fassifern Pond (i.e. Dunlop Pond 2), Lake Ginninderra, Gordon Pond, Gungahlin Pond, Isabella Pond, Lake Tuggeranong, Nichols Pond, Point Hut Pond, Upper Stranger Pond, Lower Stranger Pond, Yerrabi Pond, Tuggeranong Weir, West Belconnen Pond.
- Lake Burley Griffin has not been included in this analysis.
- Volumetric reliability from aquifer to demand has been modelled at 100%. The volumetric reliability from pond to aquifer is 95%. (There is no net loss of groundwater over the simulation period).
- All scenarios are modelled using 2030 climate series. This has been developed by modifying historical SILO data drill records. Rainfall and evaporation have been changed based on the worst 2030 climate scenario as per ACTEW's *Future Water Options* report.
- Demand is based on a 2030 climate series and is measured at 6.35 ML/ha/yr (rather than current estimation of 5 ML/ha/y)

Table 13 Supply–demand options included in Master Plan C

Supply name	Type	Potential for aquifer storage	Demand	Total cost ($PV)	Levelised cost ($/kL)	Levelised cost w/o pond cost ($/kL)	Capital cost ($)	Operation & maintenance Cost ($PV)	Replacement cost ($PV)	Total pipe & pump cost ($PV)	Total bore cost ($PV)	Total pond cost ($PV)	Estimated pond area (m2)	Irrigated area (ha)	Demand (ML/y)	Volumetric reliability (%)	Supply (ML/y)
David St Wetland	Existing	N/A	O'Connor 1	49 086	0.58	0.58	38 460	7 479	3 147	49 086	–	–	–	1.1	6.7	84.9	5.7
			Turner	173 757	0.81	0.81	144 786	20 957	8 014	173 757	–	–	–	2.7	17.1	84.9	14.6
Tuggeranong	Existing	N/A	Greenway 1	137 190	3.06	3.06	125 294	10 472	1 425	137 190	–	–	–	0.5	3.0	100.0	3.0
			Kambah 4	1 447 840	1.11	1.11	1 184 532	221 752	41 556	1 447 840	–	–	–	14.0	88.9	100.0	88.9
			Wanniassa 1	1 489 810	1.56	1.56	1 220 215	239 319	30 276	1 489 810	–	–	–	10.2	64.8	100.0	64.8
			Kambah 2	2 052 490	2.58	2.58	1 790 363	236 896	25 230	2 052 490	–	–	–	8.5	54.0	100.0	54.0
			Wanniassa 3	1 090 175	3.60	3.60	966 598	113 960	9 617	1 090 175	–	–	–	3.2	20.6	100.0	20.6
			Kambah 3	2 078 262	2.74	2.74	1 788 012	266 206	24 043	2 078 262	–	–	–	8.1	51.4	100.0	51.4
			Wanniassa 2	811 444	5.11	5.11	719 047	87 350	5 046	811 444	–	–	–	1.7	10.8	100.0	10.8
Ginninderra	Existing	N/A	Belconnen	124 913	0.97	0.97	104 917	15 840	4 156	124 913	–	–	–	1.4	8.9	98.1	8.7
			McKellar	223 414	0.81	0.81	172 315	42 203	8 896	223 414	–	–	–	3.0	19.0	98.1	18.7
			Melba 2	1 034 406	1.23	1.23	924 270	82 828	27 308	1 034 406	–	–	–	9.2	58.4	98.1	57.3
			Giralang	667 918	0.92	0.92	549 210	95 259	23 449	667 918	–	–	–	7.9	50.2	98.1	49.2
			Evatt 2	353 286	1.30	1.30	301 090	43 373	8 823	353 286	–	–	–	3.0	18.9	98.1	18.5
			Kaleen 2	1 647 179	1.45	1.45	1 349 171	261 201	36 807	1 647 179	–	–	–	12.4	78.7	98.1	77.2
			Macquarie/Belconnen	1 233 128	1.50	1.50	1 038 770	167 822	26 536	1 233 128	–	–	–	8.9	56.8	98.1	55.7
			Uni Canberra	636 200	1.54	1.54	529 212	93 639	13 348	636 200	–	–	–	4.5	28.6	98.1	28.0
			Melba 1	893 220	1.77	1.77	767 162	109 733	16 326	893 220	–	–	–	5.5	34.9	98.1	34.3
			Hawker	2 296 377	1.82	1.82	1 821 214	434 349	40 814	2 296 377	–	–	–	13.8	87.3	98.1	85.6
			Aranda	1 494 948	1.80	1.80	1 213 575	254 451	26 922	1 494 948	–	–	–	9.1	57.6	98.1	56.5
			Florey 2	360 787	1.95	1.95	321 277	33 514	5 996	360 787	–	–	–	2.0	12.8	98.1	12.6
			Bruce	1 018 245	1.98	1.98	874 523	131 774	11 948	1 018 245	–	–	–	5.6	35.6	98.1	34.9
			Evatt 1	716 050	1.94	1.94	620 631	84 733	10 686	716 050	–	–	–	4.0	25.6	98.1	25.1
			Scullin	1 087 440	2.32	2.32	958 190	114 111	15 138	1 087 440	–	–	–	5.1	32.4	98.1	31.8
			Kippax	3 349 216	2.10	2.10	2 964 263	333 305	51 648	3 349 216	–	–	–	17.4	110.5	98.1	108.4
			Page	475 683	2.73	2.73	423 708	46 336	5 640	475 683	–	–	–	1.9	12.1	98.1	11.8
			Weetangera	1 192 295	2.89	2.89	993 340	185 598	13 357	1 192 295	–	–	–	4.5	28.6	98.1	28.0
			Macquarie & Cook	1 657 779	2.92	2.92	1 428 764	210 611	18 403	1 657 779	–	–	–	6.2	39.4	98.1	38.6
			Kaleen 3	1 398 852	3.05	3.05	1 228 352	155 649	14 851	1 398 852	–	–	–	5.0	31.8	98.1	31.1
			Flynn	1 183 356	5.87	5.87	1 095 852	80 974	6 530	1 183 356	–	–	–	2.2	14.0	98.1	13.7
			Spence	1 371 176	4.82	4.82	1 217 168	144 806	9 202	1 371 176	–	–	–	3.1	19.7	98.1	19.3
			AIS	2 114 584	4.15	4.15	1 889 055	209 055	16 474	2 114 584	–	–	–	5.6	35.2	98.1	34.6
			Higgins	1 574 306	7.15	7.15	1 445 110	122 073	7 124	1 574 306	–	–	–	2.4	15.2	98.1	14.9
B14	New pond	N/A	Florey 1	1 166 532	2.47	1.21	878 365	270 540	17 627	573 019	–	593 514	1 329	1.9	12.3	85.0	10.5

Supply name	Type	Potential for aquifer storage	Demand	Total cost ($PV)	Levelised cost ($/kL)	Levelised cost w/o pond cost ($/kL)	Capital cost ($)	Operation & maintenance Cost ($PV)	Replacement cost ($PV)	Total pipe & pump cost ($PV)	Total bore cost ($PV)	Total pond cost ($PV)	Estimated pond area (m2)	Irrigated area (ha)	Demand (ML/y)	Volumetric reliability (%)	Supply (ML/y)
			Latham											4.0	25.4	85.0	21.6
B1	New pond	N/A	Kaleen 1	807 495	2.67	0.73	577 126	219 089	11 279	220 439	–	587 056	1 313	3.8	24.1	85.0	20.5
Point Hut Pond	Existing	N/A	Gordon[#]	302 999	0.95	0.95	239 143	53 764	10 092	302 999	–	–	–	3.4	21.6	99.6	21.5
			Conder	1 388 394	1.47	1.47	1 103 453	255 035	29 905	1 388 394	–	–	–	10.1	64.0	99.6	63.7
			Banks	843 814	3.24	3.24	751 295	84 208	8 311	843 814	–	–	–	2.8	17.8	99.6	17.7
Lower Stranger Pond	Existing	N/A	Greenway 2	257 663	1.14	1.14	220 522	29 943	7 198	257 663	–	–	–	2.4	15.4	100.0	15.4
Upper Stranger Pond	Existing	N/A	Isabella Plains	637 065	1.19	1.19	536 693	83 245	17 127	637 065	–	–	–	5.8	36.6	99.6	36.5
			Bonython	294 604	1.22	1.22	247 334	39 552	7 718	294 604	–	–	–	2.6	16.5	99.6	16.5
Gungahlin	Existing	N/A	Gold Creek	2 392 440	1.19	1.19	1 828 289	500 228	63 923	2 392 440	–	–	–	21.5	136.8	99.8	136.5
			Nicholls	838 748	1.36	1.36	696 274	122 883	19 591	838 748	–	–	–	6.6	41.9	99.8	41.8
			*Crace	591 040	1.27	1.27	493 492	82 706	14 841	591 040	–	–	–	5.0	31.8	99.8	31.7
			Palmerston	474 515	2.03	2.03	414 342	52 752	7 421	474 515	–	–	–	2.5	15.9	99.8	15.9
Yerrabi	Existing	N/A	Amaroo	1 180 505	1.55	1.55	981 696	171 797	27 011	1 180 505	–	–	–	9.1	57.8	89.2	51.6
			Yerrabi	165 497	0.33	0.33	99 649	48 073	17 775	165 497	–	–	–	6.0	38.0	89.2	33.9
			Ngunnawal	567 043	3.09	3.09	502 822	57 690	6 530	567 043	–	–	–	2.2	14.0	89.2	12.5
			*Throsby	1 758 415	2.63	2.63	1 555 370	179 299	23 746	1 758 415	–	–	–	8.0	50.8	89.2	45.3
			Gungahlin	383 305	1.88	1.88	336 696	39 336	7 272	383 305	–	–	–	2.5	15.6	89.2	13.9
Dunlop Pond 1	Existing	N/A	Charnwood 2**	686 470	1.10	1.10	529 790	133 273	23 408	686 470	–	–	–	7.9	50.1	85.0	42.6
Dunlop Pond 2	Existing	N/A	Charnwood 2**	754 353	3.08	3.08	672 921	73 637	7 795	754 353	–	–	–	2.6	16.7	99.6	16.6
West Belconnen Pond	Existing	N/A	Charnwood 1	1 090 861	4.17	4.17	983 468	99 023	8 371	1 090 861	–	–	–	2.8	17.9	99.3	17.8
			Fraser	686 779	3.89	3.89	604 195	76 945	5 640	686 779	–	–	–	1.9	12.1	99.3	12.0
W2	New pond	N/A	Deakin 3	6 598 993	3.19	1.42	5 254 813	1 266 956	77 224	2 935 743	–	3 663 250	9 300	14.0	88.9	85.0	75.6
			Curtin 1											6.6	41.7	85.0	35.5
			Deakin 4											2.3	14.6	85.0	12.4
			Deakin 1											2.5	15.9	85.0	13.5
			Deakin 2											0.6	4.1	85.0	3.5
WC4	New pond	N/A	Weston	1 525 267	3.07	1.26	1 136 898	369 799	18 569	719 344	–	805 923	843	2.7	17.2	85.0	14.6
			Holder/Weston											2.0	12.7	85.0	10.8
			Holder											2.5	15.9	85.0	13.5
W0	New pond–ASTR	High	National Zoo	8 318 228	3.26	1.50	6 481 388	1 512 765	324 075	2 203 495	1 629 208	4 485 526	12 785	23.6	150.0	100.0	150.0
	New pond		Yarralumla 3											2.8	18.0	85.0	15.3
	New pond		Yarralumla 4											1.5	9.5	85.0	8.1
WC0	New pond	N/A	*North Weston	2 318 649	3.79	1.31	1 747 308	548 483	22 858	803 667	–	1 514 983	2 435	5.4	34.3	85.0	29.1
			*Molonglo											2.3	14.6	85.0	12.4
W26	New pond	N/A	Torrens/Mawson	10 466 222	7.25	0.78	8 116 597	2 295 722	53 904	1 122 720	–	9 343 502	37 550	14.4	91.4	85.0	77.7
			Farrer											3.8	23.9	85.0	20.3
W27	New pond	N/A	Mawson	5 417 012	4.39	0.70	4 061 520	1 309 418	46 074	863 498	–	4 553 514	13 126	4.5	28.9	85.0	24.6
			Pearce 1											10.6	67.3	85.0	57.2
			Pearce 2											0.4	2.4	85.0	2.0

Supply name	Type	Potential for aquifer storage	Demand	Total cost ($PV)	Levelised cost ($/kL)	Levelised cost w/o pond cost ($/kL)	Capital cost ($)	Operation & maintenance Cost ($PV)	Replacement cost ($PV)	Total pipe & pump cost ($PV)	Total bore cost ($PV)	Total pond cost ($PV)	Estimated pond area (m2)	Irrigated area (ha)	Demand (ML/y)	Volumetric reliability (%)	Supply (ML/y)
W19	New pond	N/A	Phillip/Garran	10 909 402	3.92	1.17	8 675 638	2 129 952	103 813	3 244 411	–	7 664 991	29 550	7.3	46.4	85.0	39.4
			Hughes											4.2	26.7	85.0	22.7
			Garran											1.5	9.4	85.0	8.0
			Phillip 1											7.5	47.9	85.0	40.7
			Lyons											3.5	22.2	85.0	18.9
			Phillip 2											8.5	53.9	85.0	45.8
			Curtin 2											2.5	15.6	85.0	13.3
WC19	New pond	N/A	Waramanga	4 671 651	6.33	0.29	3 541 677	1 102 394	27 580	213 058	–	4 458 593	12 650	9.3	59.0	85.0	50.2
WC20–21	New pond	N/A	Chapman	1 742 278	4.70	1.53	1 294 992	433 454	13 832	566 375	–	1 175 903	2 800	4.7	29.6	85.0	25.2
WC17	New pond	N/A	Stirling	3 249 710	3.98	1.12	2 484 331	734 846	30 533	912 778	–	2 336 932	5 810	10.3	65.3	85.0	55.5
WC9	New pond	N/A	Rivett	1 295 020	4.94	2.96	1 015 447	269 778	9 795	776 027	–	518 993	1 145	3.3	21.0	85.0	17.8
WC15	New pond	N/A	Duffy	1 013 860	3.45	1.80	757 164	245 714	10 983	530 323	–	483 537	1 058	3.7	23.5	85.0	20.0
NC14	New pond — ASTR	Moderate to high	Hackett	5 950 689	4.04	1.14	4 531 238	1 209 628	209 823	591 747	1 086 138	4 272 804	11 720	2.3	14.6	100.0	14.6
			Downer											3.4	21.6	100.0	21.6
			Watson/Dickson											10.1	63.9	100.0	63.9
G23	New pond — ASTR	Moderate to high	*Harrison	2 238 370	3.42	1.65	1 672 189	463 258	102 922	536 595	543 069	1 158 705	2 756	7.0	44.5	100.0	44.5
NC18	New pond — ASTR	Moderate to high	Mitchell	8 606 998	3.62	1.64	6 630 718	1 566 952	409 328	1 734 052	2 172 277	4 700 669	13 865	2.2	13.7	100.0	13.7
			EPIC											6.1	38.5	100.0	38.5
			Gungahlin Cemetery											13.0	82.3	100.0	82.3
			Watson											1.8	11.4	100.0	11.4
			Lyneham 1											2.5	15.7	100.0	15.7
NC9-11	New pond – ASTR	Moderate to high	Lyneham 2	4 899 841	4.07	1.62	3 746 431	948 592	204 818	868 906	1 086 138	2 944 797	7 405	4.1	26.0	100.0	26.0
			Dickson											2.1	13.6	100.0	13.6
			Ainslie											1.9	12.1	100.0	12.1
			Dickson/Ainslie											4.8	30.2	100.0	30.2
T3	New pond	N/A	Calwell 3	4 648 885	3.82	0.82	3 548 910	1 054 557	45 417	1 000 767	–	3 648 118	9 260	12.4	78.7	85.0	66.9
			Theodore											2.9	18.4	85.0	15.7
T2	New pond	N/A	Gowrie	9 630 924	5.25	1.11	7 462 476	2 099 878	68 571	2 032 329	–	7 598 595	28 590	8.1	51.4	85.0	43.7
			Fadden/Chisholm											8.1	51.4	85.0	43.7
			Chisholm											2.7	17.5	85.0	14.8
			Fadden											2.3	14.6	85.0	12.4
			Gilmore											1.9	11.7	85.0	10.0
T4	New pond	N/A	Richardson	1 054 516	4.28	1.61	753 215	292 097	9 204	396 635	–	657 881	1 489	1.4	8.9	85.0	7.6
			Calwell 2											1.7	10.8	85.0	9.2
B28	New pond	N/A	Macgregor	1 039 991	2.84	1.13	769 772	256 566	13 654	412 640	–	627 352	1 413	3.1	19.7	85.0	16.7
			Holt											1.5	9.5	85.0	8.1
TOTAL				**150 299 853**	**2.94**	**1.61**	**120 144 102**	**27 441 455**	**2 714 297**	**75 987 885**	**6 516 830**	**67 795 138**		**585.0**	**3714.8**	**93.5**	**3474.5**

*Anticipated future demand (demand does not currently exist)

**The supply only meets a portion of the demand

– Pipes and pumps from Point Hut Pond to Gordon already exist. The costs shown in here include an estimation of pipe and pump costs and are therefore an overestimate of actual cost.

Notes regarding Table 13

- Only supply–demand options that could meet 85% volumetric reliability or greater have been included.
- The following existing ponds and lakes were considered in the analysis: David St Wetland, Jarramlee Pond (i.e. Dunlop Pond 1), Fassifern Pond (i.e. Dunlop Pond 2), Lake Ginninderra, Gordon Pond, Gungahlin Pond, Isabella Pond, Lake Tuggeranong, Nichols Pond, Point Hut Pond, Upper Stranger Pond, Lower Stranger Pond, Yerrabi Pond, Tuggeranong Weir, West Belconnen Pond.
- Lake Burley Griffin has not been included in this analysis.
- Volumetric reliability from aquifer to demand has been modelled at 100%. The volumetric reliability from pond to aquifer is 85%. (There is no net loss of groundwater over the simulation period).
- All scenarios are modelled using 2030 climate series. This has been developed by modifying historical SILO data drill records. Rainfall and evaporation have been changed based on the worst 2030 climate scenario as per ACTEW's *Future Water Options* report.
- Demand is based on a 2030 climate series and is measured at 6.35 ML/ha/yr (rather than current estimation of 5 ML/ha/y)

8 ECOLOGICAL ASSESSMENT OF STORMWATER HARVESTING

In this chapter, an attempt is made to assess environmental and ecological effects on the urban streams, ponds and lakes from which water is to be harvested, and also on the downstream receiving systems that will undergo a resultant reduction in supply.

The master plan has identified 28 potential supply sites for urban stormwater harvesting. These include 10 existing stormwater ponds, 16 proposed new urban ponds of various sizes, and Lakes Ginninderra and Tuggeranong. Most of the ponds are clustered around three of Canberra's major urban waterways: Ginninderra Creek, the Molonglo River including its Sullivans Creek tributary, and Tuggeranong Creek, all of which flow into the Murrumbidgee River (see Figure 13).

Of the eight ponds situated along Ginninderra Creek, six are pre-existing with three ponds upstream and three downstream of Lake Ginninderra, and two new ponds proposed between Lake Ginninderra and Dunlop 1 (i.e. Jarramlee) (Figure 14).

Four new ponds are proposed for the Sullivans Creek catchment (in addition to David Street Wetland), and eight new ponds are proposed on tributaries and stormwater drains of the Molonglo River downstream of Lake Burley Griffin. The Lake itself, although in the flow sequence, has not been considered as a potential harvesting source. This is in line with key assumptions of the study (see Chapter 2).

The five harvestable sites on Tuggeranong Creek include three new ponds which will be upstream of the pre-existing Isabella Pond and Lake Tuggeranong. In the current plan it is not intended to harvest water from Tuggeranong Weir which forms a pondage within the upper reaches of Lake Tuggeranong itself (see Figure 14).

Of the remaining two ponds, Point Hut is connected directly to the Murrumbidgee River, while the Upper Stranger Pond flows first into Stranger Pond which is not used for harvesting, and then to the Murrumbidgee River (see Figure 14).

The time series of inflows and outflows derived from the hydrological modelling of ponds and lakes in the master plan, including ASR and ASTR where this is used, provide information on pond dynamics and estimated hydrographs for stream and river reaches between ponds. This hydrological data underpins the analyses of the ecological and environmental impacts of the water harvesting proposal. The assumptions and estimates used in the hydrological analyses, especially the application of general scaling arguments to estimate flows in uncalibrated catchments, and the simple geometric models of pond morphology that do not necessarily meet the principles of water-sensitive urban design (ACT 2008), mean that conclusions regarding environmental responses should only be considered as indicative. The set of environmental indicators selected to be relevant to the condition in ponds and streams are demonstrated using the modelled data, but re-analyses will be required to provide specific, detailed descriptions for particular sites once detailed pond designs are established.

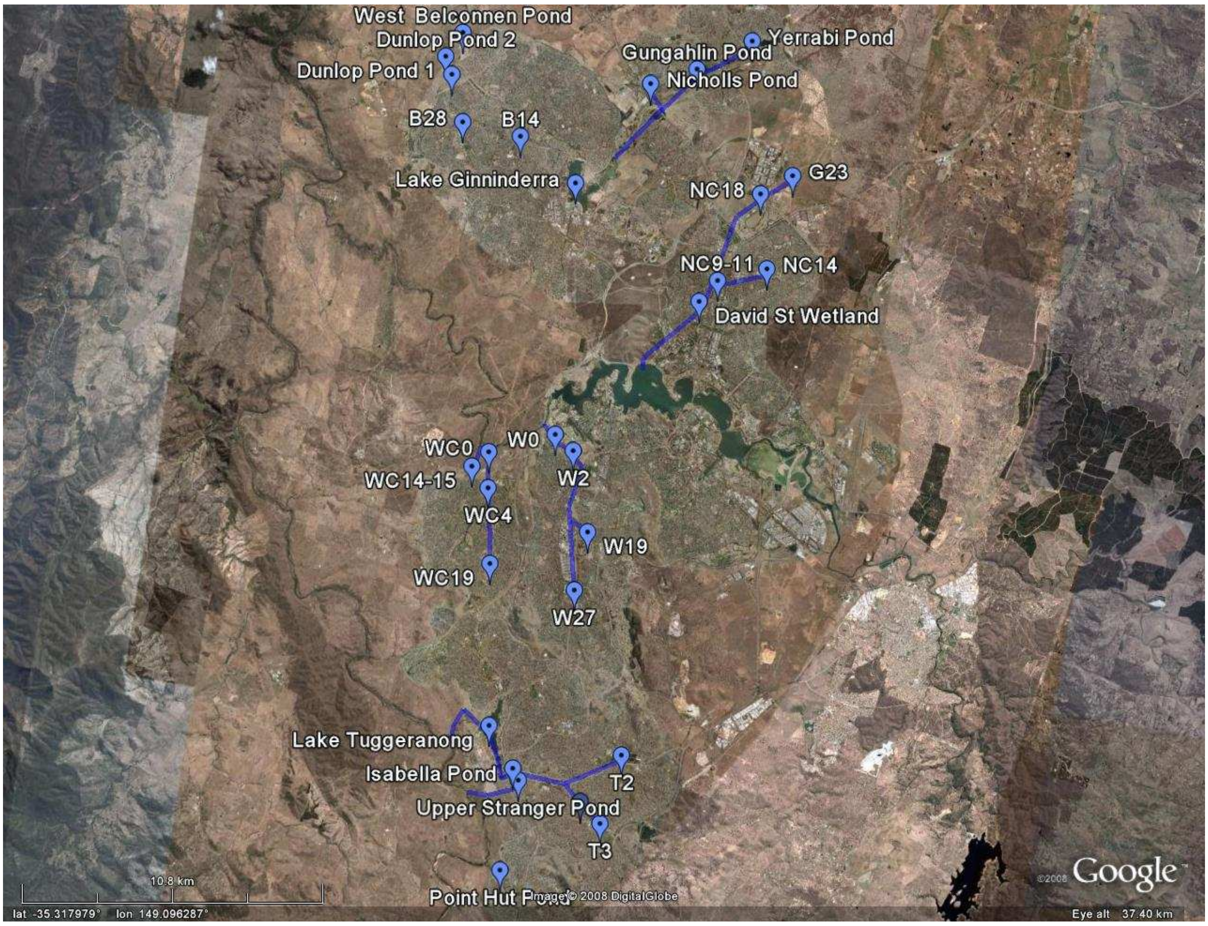


Figure 13: Map of pond locations and connections

8.1 Aims of Ecological Assessment

The proposed harvesting options will have impacts on existing lakes, existing parklands where new ponds are to be established, and the flow patterns in urban streams and receiving waterways. Ecological assessment of these options is needed to:

- flag potential ecological risks associated with stormwater harvesting and inform ways of mitigating identified risks
- demonstrate any ecological benefits provided by stormwater harvesting
- provide a comparative assessment of ponds so that relative contributions of each pond to ecological impacts are easily understood and communicated
- inform design improvements for ponds performing poorly under model assumptions and
- contribute to a deliberative multi-criterion evaluation for making the triple bottom line assessment of stormwater harvesting options.

It is important to realise that although the environmental analysis will inform on individual ponds and river segments, the findings relate to conditions determined by the interacting parts of the harvesting system. If the analysis indicates that a harvesting site is providing poor environmental returns it cannot simply be removed from the scheme as this could impact on downstream conditions and alter the responses of sequential harvesting sites. Consequently the environmental analysis described in this chapter is applicable for the master plan described in the previous chapter.

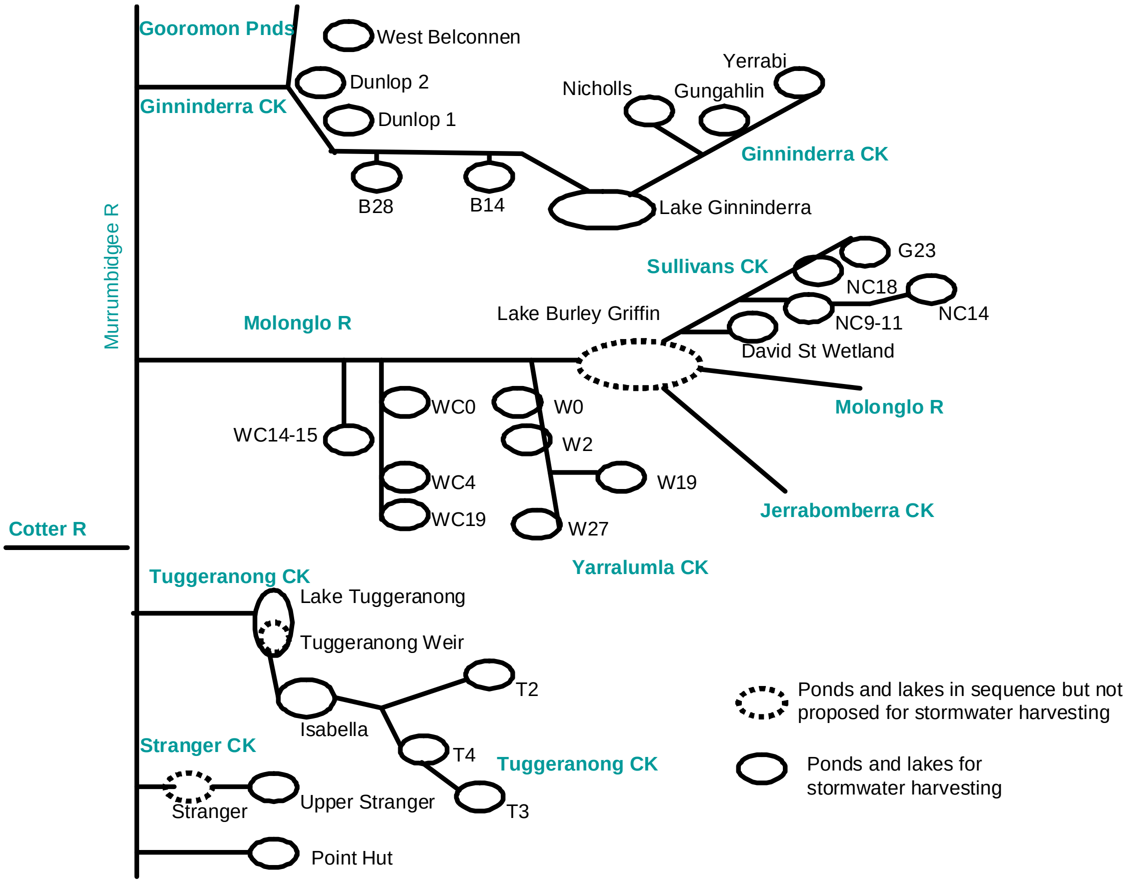


Figure 14: Diagrammatic representation of ponds, lakes, rivers and streams influenced by the stormwater harvesting proposal (note: new ponds have alpha-numeric codes).

8.2 Ecological Requirements of Canberra Ponds and Streams

8.2.1 Background

Urban streams and ponds are usually a mixture of natural and created systems that have been modified or built to meet the drainage requirements of increased stormwater run-off from urban development. They are constructed to remove water quickly in order to avoid property flooding. This means that urban streams are generally channelised with flow capacities that minimise flood connections with riparian areas. In most cases they are highly degraded in comparison with un-impacted aquatic ecosystems. The degradation is attributed to a number of characteristics of urban drainage waterways. Two key features are the changes in hydrology and water quality that result from direct piping of run-off from large impervious areas to receiving waters (Ladson 2004; Walsh et al. 2005a; Walsh et al. 2005b). This generally results in delivery of increased total water volumes with higher frequency of flood peaks and larger peak flow volumes. Typically these hydrological changes are associated with altered channel morphology and stability, an increased delivery of contaminants from the catchment, and in some cases increases in sediment loads. Other changes may include enhanced nutrient and salt loads, and increased water temperatures in ponds where extended retention can lead to reduced oxygen concentrations. Many of these responses are influenced by specific characteristics of the catchment and waterways and so vary between systems (Walsh et al. 2005a).

Hydrological changes in rivers and streams are known to influence the occurrence and distribution of aquatic biota including river, riparian and floodplain species. Early investigations focused on the physical effects of flow within river channels but now a broader view of water regime considers the role of hydrological variability in maintaining all the interconnected components of aquatic ecosystems (Poff et al. 1997; Richter et al. 1997; Stewardson and Gippel 2003). This has led to the notion that the natural flow regime provides a template against which flows in modified waterways can be compared in order to target environmental flows. Richter et al. (1997) used the natural flow paradigm to set targets for water regimes because the hydrological variation and associated characteristics of timing, duration, frequency and rate of change, are critical in sustaining the full native biodiversity and integrity of aquatic ecosystems. Numerous hydrological variables, based on flow statistics, have been proposed for characterising water regimes. Richter et al. (1997; 1998) used over 30 hydrological statistics in their 'range of variability approach' to characterise annual statistics for unregulated flows. These were then used to derive environmental flow rules for regulated flows that would create hydrographs with statistical attributes close to the natural ranges (Stewardson and Gippel 2003). However a major difficulty with purely hydrological analyses is linking the changes in water regime to biotic responses. The flow events method (Stewardson and Gippel 2003) addresses these difficulties by formulating measurements of habitat and environmental conditions as functions of hydrological variables, thereby providing time series of environmental responses for frequency analyses. However, this approach still requires identification of the quantitative links between hydrological change and ecological responses and these connections are generally poorly known.

Hydrological analyses can be applied to urban streams, but their interpretation is often difficult because a 'natural' flow template cannot be described. This is because unregulated flows either did not naturally occur, as in the case of constructed waterways, or historical flows are unknown because small streams were rarely gauged. Even less is known of the ecological characteristics of such streams prior to urbanisation, so linking flows to environmental outcomes, based on information collected from pre-regulated periods, is usually impossible. In these cases emphasis is placed on using generalised relationships between flows and ecological responses, even though these are often poorly quantified.

Stormwater run-off combines impacts of both hydrology and water quality (Ladson 2004; Walsh et al. 2005b) and so it is difficult to improve the ecological condition of urban streams simply by improving stream habitat, such as through the introduction of rock substrates. However, the introduction of properly designed and operated wetland water quality control ponds, as proposed in the stormwater harvesting plan, has the potential to provide ecological benefits to urban streams by improving their water quality and hydrology (Wong et al. 1998; Victorian Stormwater Committee 2006). Often these ponds are associated with additional engineering facilities such as retardation basins to capture large flows, and gross pollutant traps designed specifically to manage the trash from urban areas. In combination these facilities can help reduce hydrological and water quality impacts on urban streams although these potential benefits are not always achieved (Ladson 2004; Walsh et al. 2005b). Success depends on their design and capacity (Wong et al. 1998; Victorian Stormwater Committee 2006) as well as the characteristics of the inflows. In addition, wetland water quality control ponds can enhance visual and environmental attributes in urban landscapes. If these positive attributes are attainable, then the implementation of the stormwater harvesting plan could provide environmental benefits in addition to the projected water savings. However, the potential benefits to urban streams need to be balanced against the reduced flows reaching receiving waterways such as the Murrumbidgee and Lower Molonglo Rivers, and the influence of the altered hydrology on their ecology.

8.2.2 Canberra water system

Management of ACT waterways is described in the legislative framework of the *Territory Plan 2008* (ACT Government 2008a). The ACT catchments and their water resources have been divided into three water use categories: conservation, water supply, and drainage, and open space. Their locations are shown in Figure 15 along with Canberra's urban areas. Within each of these categories water uses such as maintenance of ecosystems, recreation and water supply are designated for the streams, lakes and rivers. The permitted water uses and the environmental values relevant to the various sub-catchments have been described most recently in the *Water Use and Catchment General Code* of the *Territory Plan 2008* (ACT Government 2008b). Policies relating to the drainage and open space catchments affect urban lakes and water bodies, and are described in Part C of the *Water Use and Catchment General Code*. This area includes most of the proposed stormwater harvesting scheme but excludes the Murrumbidgee and Molonglo Rivers which may be impacted if the harvesting scheme results in significantly reduced inflows. Because of their iconic and community significance, the Murrumbidgee River and extensive sections of the Molonglo River are categorised as a subset of the conservation catchments for which the general policies are described in Part A of the *Water Use and Catchment General Code*.

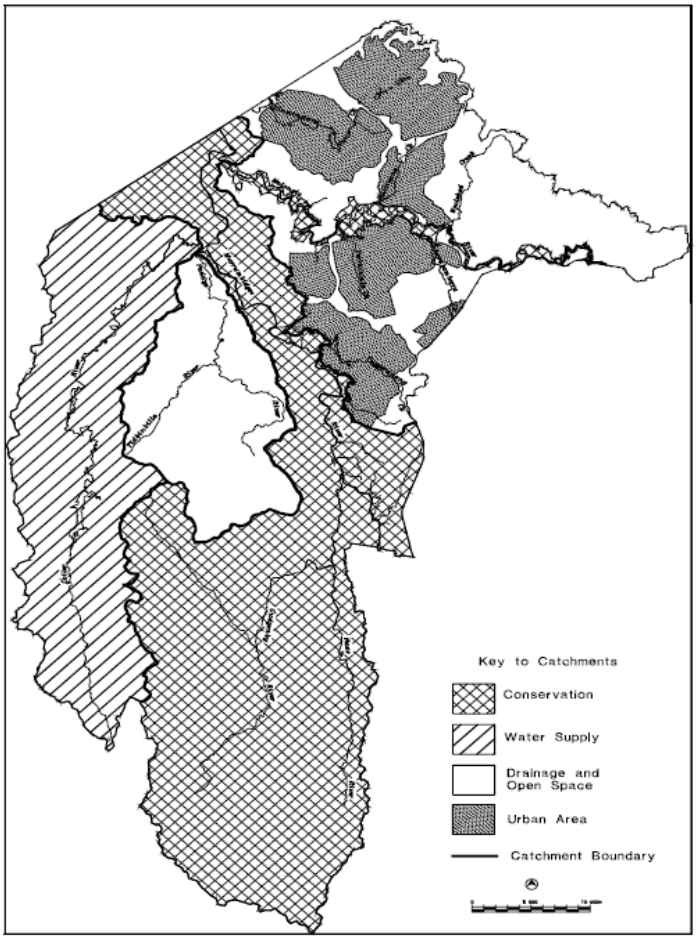


Figure 15: Water use catchments (source: Element 11.8, ACT Government 2008b)

8.2.3 Environmental flows

The *Environmental Flow Guidelines 2006* (ACT Government 2006) are a disallowable instrument under the *Water Resources Act 2007* (ACT Government 2008c). The guidelines set out the environmental flow requirements needed to maintain aquatic ecosystems in all rivers and streams in the ACT including created urban waterways. They are used in conjunction with the water resource management plan, *Think water act water* (ACT Government 2004a), to manage ACT water resources. The *Water Resources Act 2007* requires preparation of environmental flow guidelines to determine the flow of water needed to maintain aquatic ecosystems by:

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

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

- land use and management practice needs to be cognisant of stream flow and water quality impacts downstream
- stream-flow diversions need to be restricted to authorised diversions
- lake and reservoir releases need to be consistent with the protection of downstream ecology and water uses and
- groundwater abstraction need to be consistent with authorised abstraction.

The environmental flow guidelines divide ACT aquatic ecosystems into four management categories that are set within the three water use catchments described in the *Territory Plan* (Table 14). The modified ecosystems are a special subset of the conservation catchments and arise from considerations of catchment condition, environmental flows and iconic status; and include the Murrumbidgee and Molonglo Rivers. As a result, the proposed stormwater harvesting master plan contains components in both modified ecosystems and created ecosystems (these latter ecosystems occurring in the drainage and open space catchments). Different environmental flow guidelines have been established for each of these ecosystem types and need to be considered in analysing the impact of the proposed stormwater harvesting on ecological conditions.

Table 14: Types of aquatic ecosystems, their location, and link to the *Territory Plan* catchment categories (ACT Government 2006)

Category of aquatic ecosystem	**Description**	**Management goal**	**Water bodies in this category**
Natural ecosystems (conservation catchments)	Ecosystems that have persisted in a relatively pristine condition.	Primary goal: maintain aquatic ecosystems in their pristine state, Secondary goals: range of functions including recreation.	Water bodies in Namadgi National Park, excepting the Cotter River catchment. Water bodies in Tidbinbilla Nature Reserve.
Water supply ecosystems (water supply catchments)	Ecosystems in catchments designated to provide the ACT water supply.	Primary goal: provide water supply, Secondary goals: range of functions including conservation and recreation.	Water bodies in the Cotter River catchment. The Googong Foreshore Area and the Queanbeyan River downstream of Googong Dam.
Modified ecosystems (conservation catchments)	Ecosystems modified by catchment activities (land-use change, discharges) or by changes to the flow regime.	Range of functions including recreation, conservation and irrigation.	All water bodies not included in the other three categories. Includes the Murrumbidgee and Molonglo Rivers, and Lake Burley Griffin.
Created ecosystems (drainage and open space catchments)	Ecosystems in urban lakes, ponds and streams that have developed as a result of urbanisation	Range of functions including recreation, conservation and irrigation.	Water bodies within the urban area excluding the Molonglo River.

Environmental flows are provided either by releases from dams or by restricting abstractions from catchments. In the ACT, the volume of water available for abstraction is limited to that remaining after environmental flows have been provided. The *Environmental Flow Guidelines* seek to maintain modified ecosystems in as natural a state as possible, while flows in created ecosystems, including urban streams, are to be restored to natural flow regimes as far as practicable. It is recognised that restoring urban streams to pre-development conditions is unlikely and the ecological objective is more to maintain a range of healthy aquatic ecosystems.

The *Environmental Flow Guidelines* for the ACT were first devised in 1999 and were based on the 'holistic' approach which was considered to:

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

These attributes align with those of the natural flow paradigm described earlier. The *Environmental Flows Guidelines* 2006 state that this approach works by … *identifying the essential features of the* *flow regime, including the natural variability, seasonal variation, floods, and intermittent dry periods*. The influence of these flow characteristics on ecosystem components is then identified in order to set environmental flow requirements.

Six particular flow components have been recognised in the guidelines:

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

The flow guidelines relevant to areas encompassing the proposed stormwater harvesting scheme have been extracted from the full list and are given in Table 15. Base flows, channel maintenance flows and impoundment drawdown levels are the flow characteristics applied to modified and created ecosystems and so have bearing on the water harvesting proposal.

The base flow is estimated for each month, for each stretch of stream or river, using daily flow data and specified as a monthly flow (ACT Government 2004b). This takes account of seasonal variations while still providing a workable regulation, although selection of the base flow threshold has been contentious. The guidelines specify the 80th percentile as base flow, and this has gained some support, especially in the Cotter River water supply catchment where studies by the Cooperative Research Centre for Freshwater Ecology (CRC FE) indicate that these flows have sustained ecological objectives (Ogden et al. 2004). It is generally considered that the base flow should be the 80th percentile of the modelled natural flow, but in many cases this pre-development hydrographical information is not available. Instead, the mean monthly flows are estimated from monthly flow records calculated over the period from when gauging commenced to the current year (ACT Government 2004b). This has some inherent problems – for example, flow statistics for the Murrumbidgee River are calculated from gauged data taken after the construction of Tantangara Dam. In addition, if base flows are re-calculated as new hydrological years are added to the data set, then the base flow will alter as run-off changes in response to catchment influences such as extractions, urbanisation or climate change. Decisions on the appropriate method for estimating base flows are still to be made but will be especially difficult for created and modified catchments where the paucity of data does not allow for the ecological effects of the 80th percentile flows to be assessed.

Table 15: Environmental flow guidelines for modified and created ecosystems (ACT Government 2006)

Flow			
Base flows	Modified ecosystems	Murrumbidgee River	Maintain 80th percentile monthly flow November – May, and 90th percentile monthly flow June – October inclusive. Abstractions may not exceed flow rate.
		Other reaches in the ACT in modified ecosystems	Maintain 80th percentile monthly flow in all months. Abstractions may not exceed flow rate.
	Created ecosystems	All reaches in created ecosystems	Maintain 80th percentile monthly flow in all months. Abstractions may not exceed flow rate.
Channel maintenance flows	Modified ecosystems	All reaches in the ACT including the Murrumbidgee	Protect 90% of the volume in events above the 80th percentile from abstraction
	Created ecosystems	All reaches in created ecosystems	Protect 90% of the volume in events above the 80th percentile from abstraction
Groundwater abstraction limits	Modified ecosystems	All reaches in the ACT including the Murrumbidgee	Groundwater abstraction is limited to 10% of the long term recharge
	Created ecosystems	All reaches in created ecosystems	Groundwater abstraction is limited to 10% of the long term recharge
Impoundment drawdown levels	Modified ecosystems	All impoundments	Drawdown is limited to 0.20m below the spillway
	Created ecosystems	All impoundments	Drawdown is limited to 0.20m below the spillway

To sustain flooding flows, the current management strategy is to limit the water available for abstraction to 10% of the volume above base flow. It is thought that this will preserve the 1.5 to 2.5 year annual recurrence flows that determine the meander frequency, width and depth of river channels. A lack of pre-development hydrographs makes it difficult to speculate what the 'natural' high flows were in the now highly modified urban systems.

The earlier flow guidelines were reviewed by the CRC FE in 2004 as part of the development of the 2006 guidelines (Ogden et al. 2004). The effectiveness of the environmental flow guidelines was assessed by referring to monitoring data and research on ACT rivers, and through consultation with local scientific experts. The review highlighted the paucity of data available to make assessments and concluded that there were insufficient data to comment on flow guidelines for any systems other than the regulated parts of the Cotter River and in the Queanbeyan River downstream of Googong Dam. This situation has not changed significantly in the intervening period, making it difficult to determine the influence that stormwater harvesting might have on the ecology of created and modified ecosystems. A workshop organised by the CRC FE during the review of environmental flows attempted to set some ecological objectives for the different ecosystem categories. This information is included in the Environmental Flow Guidelines (2006) and as these are currently the most authoritative set of environmental flow analyses for the ACT waterways, the objectives for modified and created ecosystems are noted here (Table 16). The ecological objectives are the same for both these ecosystem categories, but the flow characteristics required to meet the objectives are not defined.

Table 16: Objectives for modified and created ecosystems

Modified ecosystems and created ecosystems		
All reaches	To maintain healthy aquatic ecosystems in terms of biota	Macroinvertebrate assemblages are maintained at AUSRIVAS band A level. Assessed using protocols as per the ACT AUSRIVAS sampling and processing manual <http://ausrivas.canberra.edu/au/ausrivas> Non-dominance (<20% cover) of filamentous algae in riffles for 95% of the time. Assessed using standardised collection and processing methods as per Norris et al. 2004.
	To prevent degradation of riverine habitat through sediment deposition	Sediment deposition is limited to <20% of total depth of pools measured at base flow using techniques per Ecowise Environmental (2005) methods.
	To prevent degradation of macrophytes in urban lakes and ponds	Extent of emergent macrophyte beds are maintained at current levels or enhanced.

8.2.4 Lakes and ponds

Urban lakes and ponds form an integral part of the Canberra urban water system and the ACT Government is committed to continuing and expanding their use because of the community and environmental benefits they provide.

The management strategy for urban lakes and ponds that are situated on public lands and provide community use and environmental values is described in Canberra's *Urban Lakes and Ponds Plan of Management 2001* (ACT Government 2001a). This plan applies to all of the existing ponds included in the stormwater harvesting proposal except for Nicholls Pond and David Street Wetland. It is likely that all of the proposed new ponds will fall under this management plan.

The *Environmental Flow Guidelines 2006* (ACT Government 2006) stipulate that water levels in urban ponds should be maintained in order to sustain stands of submerged and emergent macrophytes. The plants create a significant aquatic habitat and introduce structural and functional complexity that enhances biodiversity and biological activity. They are an integral component of the water treatment processes and in general add to the aesthetic and recreational values of the ponds. The guidelines express concerns that excessive drawdown of ponds or regular large oscillations in depth could preclude establishment and growth of macrophytes. Significant drawdown could also result in increased detention of flows and this might impact on downstream ecological function through alteration of urban stream hydrology (this is contrary to the usual concern that flows in urban water ways are excessive and ponds provide important water retention capacity). For these reasons the drawdown limit is set at 0.2 m, although the guidelines recognise the need to monitor the effect of the drawdown limit and if necessary to modify it in order to balance maintenance of macrophytes and improved stream flows. In the hydrological analysis of the stormwater harvesting plan, drawdown limits for harvested ponds was increased to 1 m and this may have ecological implications.

8.2.5 Connectivity of urban streams and ponds

Within the complex urban water management framework of the ACT, the link between urban ponds and urban streams is nebulous despite their intrinsic connectivity. Less emphasis has been placed on the management of urban streams, but this is changing with the introduction of environmental flow guidelines (ACT Government 2006) and the activities of community groups associated with organisations such as Water Watch (e.g. Ginninderra Waterwatch 2007). A possible ecological benefit of the stormwater harvesting proposal could be the enhancement of the aquatic health of urban streams across Canberra through improvements in hydrology and water quality. Often these streams are discounted as 'concrete drains', but some 66% of the total length of Canberra's urban waterways have been retained in a natural or slightly modified form (Table 17; I. Lawrence pers.comm.). Further restoration of natural channels is currently being considered within Sullivans Ck, Weston Ck and Tuggeranong Ck. Improved flow and water quality conditions could assist these and other restoration activities.

Table 17: Extent of 'natural or slightly modified channel' retained along Canberra's urban drains/waterways.

Urban waterway	**Total channel length (km)**	**Natural channel (%)**	**Urbanisation (%)**
Gooromon Ponds & Halls Ck	21	90	10
Ginninderra Ck	38	90	65
Sullivans Ck	22	40	60
Woolshed Ck	10	90	20
Jerrabomberra Ck	24	90	20
Yarralumla Ck	12	20	90
Weston Ck	6	25	90
McQuoid Ck	4.5	90	20
Tuggeranong Ck	24	30	80
Lower Stranger Ck	5	40	80
Point Hut Ck	10	70	60
Totals	177	66	

The ACT environmental flow guidelines do not require environmental releases from urban lakes and ponds (ACT Government 2006). This is in part because ponds can only release water by overtopping or via discharge through a valve at the base of the weir, and so controlled discharges are not considered practicable. In addition, the release of bottom water is not favoured as the water quality in these layers is generally poor and could have detrimental effects on downstream aquatic ecosystems. A further reason for not requiring environmental releases from urban ponds is that reductions in flow below the ponds tends to be compensated for by increased run-off from urban areas (ACT Government 2006). Actually these interactions do not often influence flows as the urban dams are maintained near to full most of the time so that moderate flows and floods overwhelm the small retardation volume and pass downstream. In these cases it is more likely that environmental flow considerations would require a reduction in discharge from the ponds and lakes in order to retard the rapid flood peaks arising from urban stormwater run-off. As the proposed harvesting of stormwater from the ponds has the potential to influence their water depths, water level oscillations, flow retardation volumes and downstream flow patterns, these issues are addressed in the following analyses.

8.2.6 Biotic and landscape attributes

The most recent review of the status of riverine and riparian species and their requirements in the ACT is the *Aquatic Species and Riparian Zone Conservation Strategy, Action Plan 29, 2007*, a part of *Ribbons of Life ACT* (ACT Government 2007). This strategy addresses issues relating to aquatic and riparian zone flora and fauna, and the provision of habitat for several threatened or uncommon terrestrial or amphibious species that are strongly associated with riparian zones. The primary focus of the strategy is the rivers and larger tributary creeks and it contains information on the

Murrumbidgee and Molonglo Rivers, but in general excludes the highly urbanised Tuggeranong, Weston, Yarralumla, Sullivans, Woolshed, Jerrabomberra and Ginninderra Creeks. However it does make some important general points regarding the protection and support of aquatic habitat with examples relevant to urban waterways. In particular it emphasises the importance of riparian zones as *… ecological or linking corridors, and as a distinctive part of a wider habitat mosaic with special features such as access to water and often structurally complex vegetation*. The river corridors are particularly important for allowing dispersal and gene flow between localised populations. The report suggests that a major threat to riparian fauna in the ACT is modification and fragmentation of riparian habitat by land uses, and it highlights the downstream connectivity provided by movement of water, sediments, organic materials and living organisms, which means that areas of conservation value cannot be separated from upstream activities. A particularly relevant example is given for the Molonglo River, where the lower gorge (near the Murrumbidgee River confluence), which has significant nature conservation values, is impacted by upstream influences of Lake Burley Griffin, major urban stormwater inflows and lengths of degraded river.

The strategy considers species threatened under the *Nature Conservation Act 1980* (ACT), which includes four threatened fish species, the Murray River Crayfish (*Euastacus armatus*) and the Tuggeranong Lignum (*Muehlenbeckia tuggeranong*). In addition the strategy considers two species strongly associated with the riparian zones in the ACT, the threatened painted honeyeater (*Grantiella picta*), and the pink-tailed worm lizard (*Aprasia parapulchella*) which has special protection status and is largely restricted to the Murrumbidgee and Molonglo River valleys and nearby hill slopes.

As well as threatened species, the strategy addresses the conservation of aquatic fauna generally including platypus (*Ornithorhynchus anatinus)* and the eastern water rat (*Hydromys chrysogaster*). Platypus are still regularly recorded from the Cotter, Murrumbidgee and Molonglo Rivers. The eastern water rat is considered common and widespread in the ACT and region and commonly found in the urban lakes such as Lake Burley Griffin and Lake Ginninderra. They have been recorded from the Molonglo and Murrumbidgee Rivers, and Sullivans and Ginninderra Creeks.

The strategy suggests key considerations for maintaining and improving the natural integrity of the rivers and riparian zones including some that are particularly relevant to the stormwater harvesting proposal:

- protection of the river corridors from the effects of existing and proposed urban development, possible expansion of recreational infrastructure, and other threats such as inappropriate grazing regimes
- maintenance and improvement of linear and upslope connectivity
- restoration of riparian habitat
- maintenance and improvement of in-stream habitat (including streamflow) and where feasible, rehabilitation of native fish populations
- maintenance of wildlife corridors
- maintenance and protection of aquatic ecosystem processes and water quality.

Several of these objectives are reliant on connectivity between system components resulting from hydrographical fluctuations. These could be influenced by the impacts of stormwater harvesting on the hydrology of both urban streams and receiving rivers and waterways.

In addition to the *Aquatic Species and Riparian Zone Conservation Strategy,* information on key management problems associated with rivers and riparian zones is encapsulated in specific catchment management plans and regional reports. Such reports include: The ACT *Natural Resource Management Plan 2004-2014* (ACT Government 2004c); *The Ginninderra Catchment Group Strategy 2000* (Ginninderra Catchment Group 2000); *The Molonglo Catchment Strategy 2000-2024* (Molonglo Catchment Group 2005); *The Molonglo River Corridor Boundary Study* (Red-Gum Environmental Consulting 2007); *The Murrumbidgee Catchment Blueprint* (Murrumbidgee Catchment Management Board 2003); and ACT water reports and Water Watch reports.

The ACT *Natural Resource Management Plan* (ACT Government 2004c), sets broad natural resource management targets for rivers and creeks in the ACT, and these have been largely endorsed by specific catchment management groups. The most pertinent targets with respect to the stormwater harvesting proposal deal with biodiversity and water quality.

Biodiversity catchment targets manage for biodiversity conservation, to protect and improve the biodiversity value of threatened and endangered native species and ecological communities, to enhance and protect the natural integrity of aquatic ecosystems, and to manageecologically significant invasive species and minimise threats to biodiversity.

Water quality and allocation in ACT controlled waters always meet or exceed the relevant standards in the regulations of the *Environment Protection Act 1997*, the provisions of the *Water Resources Management Plan* (1999) and *Environmental Flow Guidelines* (1999) and their subsequent revisions.

One particular target for urban waters (WMT3) was included in the NRM plan to introduce measures, *… to reduce the intensity of and the volume of urban stormwater flows so that the run-off event that occurs on average once every three months is no more than predevelopment size'.*

The *Ginninderra Catchment Group Strategy* (Ginninderra Catchment Group 2000) reports that for most of its length the Ginninderra Creek is an open stormwater channel, draining urban and semi-rural suburbs. According to Table 17 about 90% of the channel length is still in a natural form. The hydrology of the creek has changed through human activities affecting quality, quantity, and speed of flows. Water quality within the creek and its tributaries is characterised by high turbidity, low dissolved oxygen, high nutrient levels, litter, and stream and tributary bank erosion. Major goals set for the catchment include:

- reducing the volume and velocity of urban stormwater run-off entering the creek
- decreasing the amount of visual and dissolved pollutants entering the creek
- increasing biodiversity of the catchment through revegetation
- conserving existing areas of remnant vegetation and enhancing populations of endangered species.

The *Molonglo Catchment Strategy* (Molonglo Catchment Group 2005) reports that the biological condition during 2002/03 was *extremely impaired* based on sampling by the ACT Government at two sites below Lake Burley Griffin (Coppins Crossing and Sturt Island) before it enters the Murrumbidgee River. In most cases dissolved oxygen readings were very low, there was an increasing trend in chlorophyll-a concentrations and a number of phosphorus exceedences recorded. Flow peaks have been reduced by Lake Burley Griffin and Scrivener Dam and, this combined with extensive clearing of native riparian vegetation, has resulted in stream bank erosion and sedimentation in waterways producing siltation and nutrient enrichment. The riparian ecosystems are highly modified with only fragments of native vegetation remaining (ACT Government 2007). Macroinvertebrate sampling on the Molonglo River (Site 242) indicated that these river sections are severely impaired to impoverished in their macroinvertebrate assemblages (ACT Government 2004d). Densely urbanised sub-catchments generate high levels of nutrients and toxins from stormwater systems. This state of affairs has led to the catchment strategy including a goal addressing the following aspects:

- water in rivers, creeks, lakes and wetlands is above the national standards for healthy ecosystems and
- within the Molonglo Catchment, only the highly urbanised Sullivans Creek tributary and the Molonglo River below Lake Burley Griffin are included in the stormwater harvesting proposal.

Near its confluence with the Murrumbidgee River, the Molonglo River becomes more deeply incised and the vegetation of the section protected within the gorge displays high floristic diversity. The topography and vegetation of the valley and riparian zone provides important wildlife habitat and connectivity (ACT Government 2007). The ecological significance of this area is further reinforced by the Molonglo River Corridor Boundary Study prepared for the National Capital Authority (Red-Gum Environmental Consulting 2007). This reiterates the importance of the area as known habitat of the pink-tailed worm lizard and notes in addition its frequent use as nesting and hunting grounds for various raptors. The river corridor is also home to at least five species of reptile that are geographically uncommon in the region (stone gecko, marbled gecko, eastern copper-tailed striped skink, Boulenger’s skink and the nobbi dragon). Species such as the eastern long-necked tortoise and the black-headed snake have been recorded at Coppins Crossing (ACT Government 2001b) and the area supports a large population of the regionally uncommon eastern wallaroo. Also present are species such as the bush rat and platypus which occur in some of the larger pools (ACT Government 2001b). The Molonglo River Corridor Boundary Study suggests that these species and the areas of the corridor they frequent are natural qualities that are important to conserve in a functioning river corridor.

The *Murrumbidgee River Corridor Management Plan* (ACT Government 1998) sets out the management objectives for sections of the river including those near to and downstream of the urban centre that might be influenced by reduced flows due to stormwater harvesting. A number of reserves and special purpose reserves are dispersed along the river between Point Hut Crossing and Uriarra Crossing. The characteristics of these areas are described in the management plan and revisited in the *Aquatic Species and Riparian Zone Conservation Strategy* (ACT Government 2007). Maintaining and improving the condition of this iconic river is a clear objective of the management strategies and this will rely on maintaining appropriate hydrological conditions. A detailed discussion of the environmental characteristics is not provided here as later analysis of stormwater harvesting indicates that it does not have a major effect on modelled 2030 flow conditions in the Murrumbidgee River.

This brief overview highlights the lack of data and information from which to formulate links between flow conditions and environmental responses. However, it does demonstrate that areas potentially influenced by stormwater harvesting have environmental attributes that must be considered when assessing the water saving benefits of the harvesting proposal.

8.3 Approach

The objective in analysing the influence of stormwater harvesting on environmental attributes was not to describe the current ecological conditions of the affected rivers and streams, or even to predict their possible condition under the 2030 flow scenario for which the stormwater harvesting was modelled, but to assess the impact that harvesting compared to not harvesting might have on ecological conditions using a 2030 flow scenario. Given the paucity of ecological data on these systems there was a need to return to general conceptual models of flow influences on the aquatic environment and infer as much as possible from the hydrological modelling associated with the stormwater harvesting analysis.

Our approach drew on fundamentals common to any pond or stream derived from ecological theory informed by observations and study in other systems. For each component of the ecological assessment we derived a conceptual model from which to infer ecological relevance based on modelled hydrology. In working from these conceptual models the analysis typically fell into two parts described in detail in the following pages:

- **Preliminary hydrological analysis:** Detect and characterise mathematically the relevant patterns in a range of model time series. These analyses typically involved standard hydrological calculations, such as the estimation of exceedance curves and spell analyses. These procedures are well established and the results stand alone as a useful summary of the expected hydrological characteristics of the ponds and streams, conditional on the assumptions embedded in the hydrological modelling. The results of these analyses for all ponds are in 0. Frequently the time series were separated into summer and winter periods where summer was considered as the period November to April inclusive and winter as May to October.

- **Inferring ecological impact:** The conceptual models provided the theoretical underpinning for linking hydrology to ecology. In order to provide a quantitative assessment based on this understanding, we codified a transparent and replicable set of equations or rules to provide ecological indicators that draw on key elements of the hydrological analysis. The results of these analyses for all ponds are in 0.

In describing the methodology we provide illustrative examples from specific streams and ponds (e.g. David St Wetland), however these results are not necessarily typical of all ponds, and the interpretation and conclusions are drawn from considering the complete set of tables and figures provided in Appendices R and S. In some cases it is useful to distinguish between new and existing ponds. The naming conventions differ for new and existing ponds; new ponds have names that are simply one or two letters followed by a number (e.g. WC15). Existing ponds were modelled with and without harvesting using the non-harvesting conditions as a base case, while new ponds were modelled only for harvesting conditions and compared with estimated flows in the absence of ponds as a base case. This means that new ponds sometimes appear far more effective than old ponds (e.g. in the nutrient retention analysis) because with a new pond there is not only the removal of water by harvesting, but also the action of a newly constructed pond as well.

Base conditions are defined as:

- existing ponds: pond modelled without harvesting

- new ponds: modelled streamflow only at that location.

8.3.1 Hydrological analyses

Pond Analysis

The hydrological modelling provided daily time series for pond depth, volume and surface area for the 65-year modelled period. Variations in these attributes are due to changes in rainfall run-off, stormwater harvesting and evaporation. Examples of base and harvesting modelled time series of the David St Wetland volume are shown in Figure 16. There is a clear seasonal signal that shows pond volumes are lowest in summer and that differences between base and harvesting cases are largest during summer. Characteristics of the time series considered relevant to ecological responses of the ponds were identified and quantified and included pond drawdown and pond turnover rate.

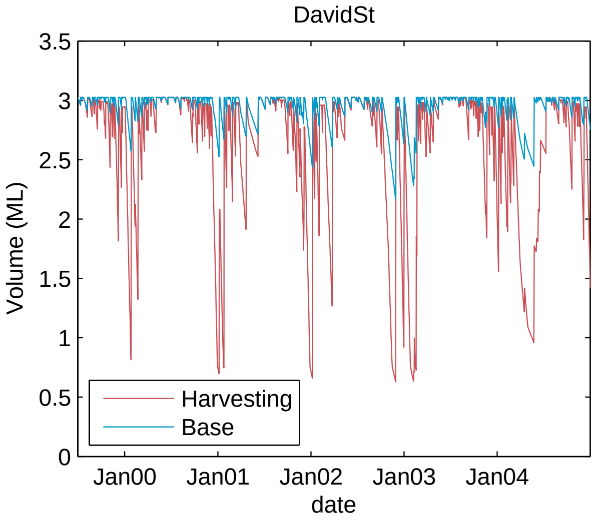


Figure 16: Example of model volume time series

Drawdown and surface area reduction exceedance curves

Pond drawdown is the reduction in water level from full and is calculated as the difference between the modelled depth time series and pond depth when full. Pond drawdown is useful for inferring the time-varying characteristics of pond and lake shore exposure.

The calculation of exceedance curves was the most common procedure used to characterise and communicate patterns in the time series. Exceedance curves quantify the seasonal patterns and differences between base and harvesting cases in a way that allows ready comparison between ponds. For example, within any drawdown time series, there is a considerable variation in drawdown – periods of no drawdown when the lake is full, interspersed with periods when drawdown can reach over 1 m – and this variability needs to be captured and communicated in a way that allows easy comparisons between different lakes and ponds, and between base and harvesting cases. An exceedance curve shows the proportion of the time series for which the drawdown is a particular level or greater. An example of exceedance curves for pond drawdown is given in Figure 17.

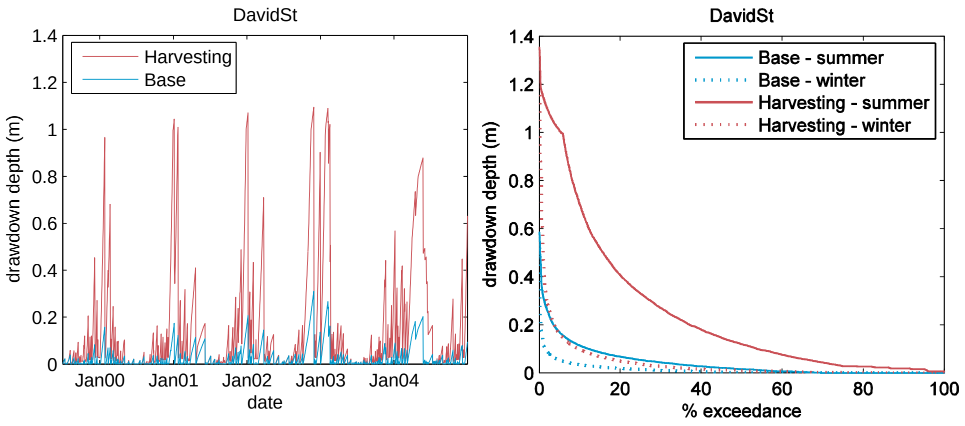


Figure 17: Example of a model time series for pond drawdown, and the equivalent exceedance curve for that time series

The solid blue curve in Figure 17 shows the curve for the base case in summer and the solid pink line shows the harvesting case in summer. The blue and pink dotted lines show the base and harvesting curves in winter. As previously noted, summer was defined as a six-month period from November to April inclusive and winter encompassed the six months from May to October. This two-part division of the year captured the differences between the wet and dry extremes in Canberra.

The exceedance curve in Figure 17 is read as follows. Under the base case a 20 cm drawdown is exceeded approximately 5% of the time in summer, whereas in the harvesting case a 20 cm drawdown is exceeded approximately 40% of the time in summer (i.e. 40% of the 'summer'). Figure 17 also indicates that drawdown can exceed 1 m in the harvesting case despite the fact that harvesting is switched off once lake drawdown reaches 1 m. This is due to modelled evaporation losses which are as high as 7.5 mm per day in summer, with a mean of 6 mm per day.

The exceedance curves were calculated from the daily data. To calculate the winter base case exceedance curve, for example, all the drawdown values for winter were sorted from highest to lowest. The sorting produces a rank order of points, so a point with rank $r = 5$ is the fifth highest point in the data series. If N is the total number of points in the series, then the percentage exceedance for a point of rank r is $100r/N$. In this way we calculated exceedance curves for both drawdown and surface area for each pond.

Shore dry spell duration

The time percentages in the exceedance curves are calculated from the full 65-year modelled time series of lake drawdown, so the curves do not capture the between-year variations (for example, a 5% exceedance which is a relatively rare, large drawdown, can result from a handful of extremely dry years or from a 5% period of every summer). The timing and duration of periods of high drawdown are significant in the ecological assessment, as it determines the conditions for the emergent vegetation growing in shallow waters.

The duration of shore exposure was calculated at two different drawdown levels, 20 cm and 50 cm. If a lake has a 1:10 slope at its shore, a 20 cm drawdown corresponds to 2 m of exposed shore, and 50 cm drawdown corresponds to 5 m of exposed shore. We calculated the number of consecutive days for which these two drawdown levels were exceeded and the shoreline exposed, and estimated average recurrence intervals for different durations of drawdown (see Figure 18 for examples).

Again, the results are separated into base and harvesting cases, and summer and winter conditions are shown separately. As an example of how to read these plots, the left-hand plot in Figure 18 shows that for David St Wetland, a 20-day period of summer shore exposure can be seen at the 20 cm drawdown level approximately once every 10 years in the base case, and approximately once every year in the harvesting case. The right-hand figure shows that in the base case the 50 cm drawdown is rarely seen (only once in the 65-year record), however shore exposure durations of various lengths are seen at the 50 cm level in the harvesting case.

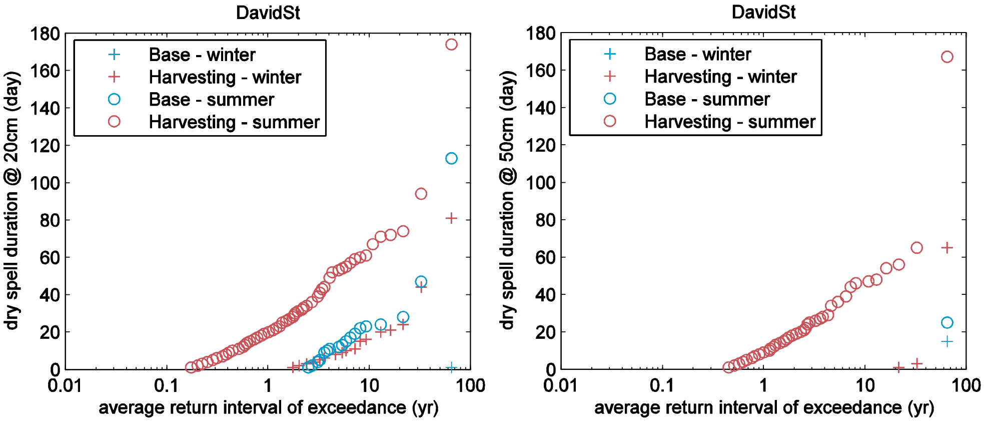


Figure 18: Sample shore dry spell duration plots

To make these calculations for a particular drawdown level (e.g. 20 cm) all points in the model time series where drawdown reached this level or greater were identified and then the number of consecutive days calculated for which this drawdown level was exceeded. This reduced the daily time series of drawdown depths to a much shorter time series containing the duration of the dry periods and the dates at which these dry periods commenced. Events of given duration were then counted, for example, in the time series spanning 65 years there might be one event that is 100 days long, two events that are 80 days long and so on. The average return intervals is estimated from these counts: if there is one 100-day event in 65 years its average return interval is estimated to be 65, if we see two 80-day events in 65 years its average return interval is estimated as 65/2 = 32.5 and so on. Where there are no events of a particular duration they are not marked on the graphs, hence each marker shown in Figure 18 represents the fact that a certain number of events of that duration were seen in the model time series.

Pond turnover rate

The turnover rate is a measure of pond flushing, and is calculated by dividing the flow of water into the pond by the volume of the pond. Dividing the inflow (ML/day) by the pond volume (ML) gives a rate as a proportion per day. For example a turnover rate of 0.1 /day means that one tenth of the pond volume is flushed per day. Both pond volume and the flow of water out of the pond vary on a daily basis, so turnover rates too vary on a daily basis. As in the analysis of drawdown in the previous section, it is helpful to consider both the exceedance curves for pond turnover (showing the distribution of turnover rates in the modelled pond for the 65 year period) and an analysis of the return interval for the duration of selected turnover rates considered to be environmentally relevant. An example is given in Figure 19. Note that when the pond is not spilling the turnover rate reflects the rate of dilution due to incoming water.

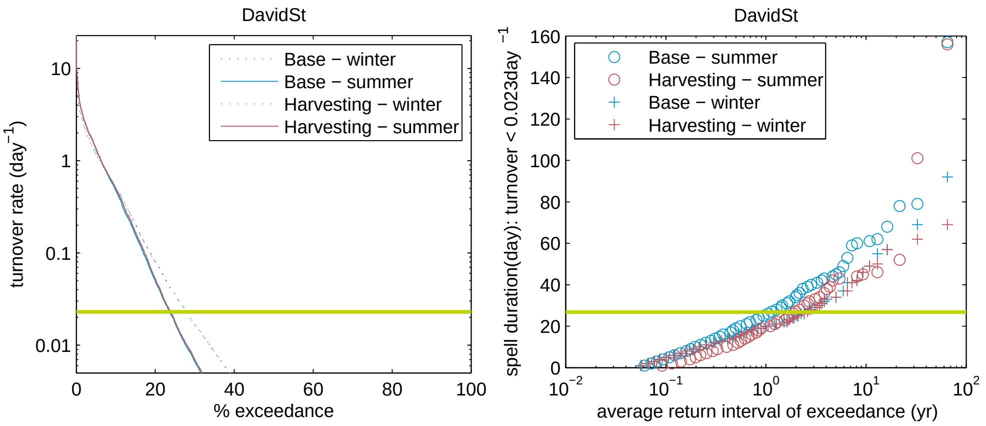


Figure 19: Example of pond turnover rate graphs showing exceedance curves and durations of periods for which turnover rate remains below a critical value for phytoplankton bloom development

Streamflow analysis

The construction of new stormwater ponds and the extraction of water from existing lakes and ponds will change the flow patterns of urban stream reaches fed by pond overflow. Again the aim was to characterise these differences in a way that can inform possible impacts on the ecology of these stream reaches. The available modelled hydrological data included the spill from individual ponds, but not the time series for flow in stream reaches. In this analysis the spill volume was considered equivalent to the discharge in the stream reach just below the pond. Flows immediately upstream of ponds can also be estimated from pond inflow time series and are comprised of the spill from the upstream pond and catchment run-off in the intervening stream section. The hydrological modelling for the stormwater harvesting proposal did not include all reaches downstream of ponds (e.g. the lower reaches of the Molonglo River or Ginninderra Creek) and so flow analyses were not possible for these sections using the base data set.

As flows in the Murrumbidgee and Molonglo River are important to assess because of the ecological and iconic status of these rivers modelled flow data was obtained from the recent CSIRO Murray Darling Sustainable Yield Project (CSIRO 2008). Modelled historic flows, and predicted flows under climate change scenarios were obtained for the Murrumbidgee River and the Lower Molonglo River (Rachael Gilmore pers. comm.) for the period analysed in the stormwater recovery proposal.

Individual pond inflow and spill

Again, an effective way to characterise and communicate the nature of a pond spill or inflow time series is through an exceedance curve. The procedure was the same as described for pond drawdown: daily spill values were sorted from highest to lowest and the percentage exceeded calculated from the rank of each value (percentage exceedance = $100r/N$, where r is the rank and N is the number of points in the time series). The left hand side of Figure 20 shows an example of an exceedance curve (also called a flow duration curve) for pond spill. The exceedance curve shows the proportion of time for which a particular flow rate or higher is observed in the time series.

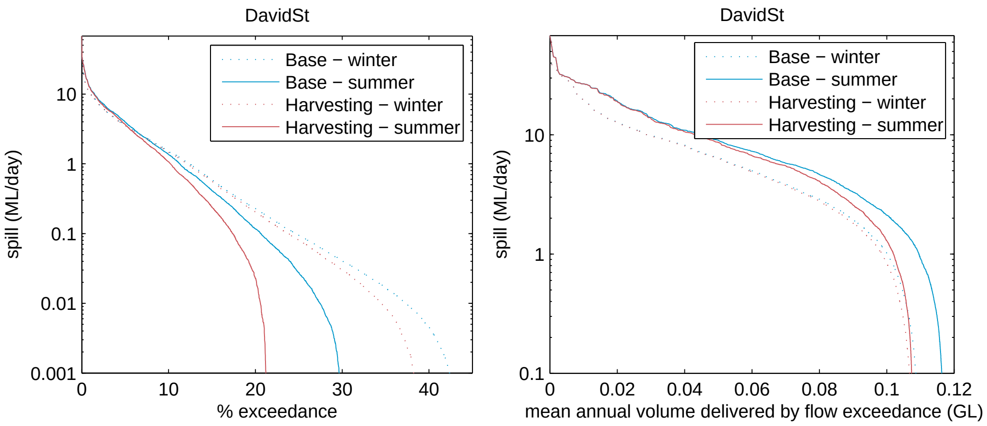


Figure 20: Example exceedance curve for pond overflow (left) and the same data plotted by volume instead of percentage of time (right)

The sum of all daily flows over the 65-year model period is the total flow out of the pond for that time. Dividing this total spill by 65 gives a mean annual outflow. The distribution of daily flows contributing to the mean annual outflow volume is shown on the right hand side of Figure 20. It is derived in a similar manner to the exceedance curve: the same sorted flow points are plotted, but rather than showing the percentage of time for which they are exceeded it shows the cumulative volume that a flow rate or higher contributes to the total flow from the pond. Thus from this plot we can see the total reduction in spill that results from stormwater harvesting as the difference in the intercept with the x-axis. The sum of the differences for all ponds will be greater than the volume delivered to demand clusters under the master plan due to extra losses from evaporation.

When a pond is drawn down for harvesting it requires more water to fill to the spilling level than is the case without harvesting. The extent to which the zero-spill behavior of the ponds is changed by harvesting was quantified using a dry spell analysis of a similar kind to that used to assess shore dry spell duration. All points in the model time series where the spill was zero were identified and the number of consecutive days in any continuous period counted, so yielding a shorter time series containing only the dates at which zero-spill periods commenced and their duration. The numbers of events different duration were then used to estimate the average return intervals. Figure 21 shows an example of a graph produced by the zero-spill spell analysis.

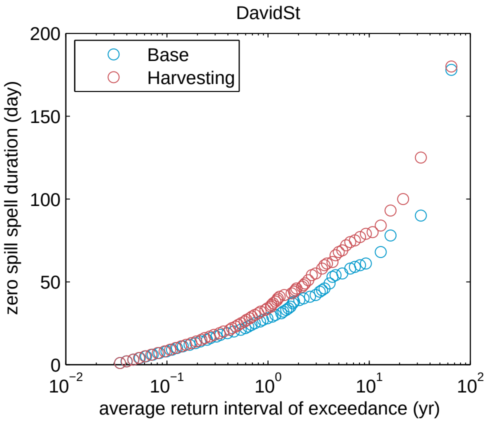


Figure 21: Example of zero spill spell duration graph

Another characteristic of interest in the spill time series is the nature of the peak events – the points at which flow rates are a maximum. For each model flow time series we located all the peaks defined as when the daily flow increased from the previous day and decreased again the following day. There are more sophisticated peak detection methods that seek to ensure independence between peak events, but for our purposes this basic peak detection method is sufficient for ascertaining the differences between base and harvesting flows. Once the peaks magnitudes were identified, they were sorted from highest to lowest and the average return intervals were derived from this sorting: over a 65-year period if an event had rank *r* (i.e. is the *r*th highest point in the record) then the average return interval for a peak of that magnitude or higher is estimated as 65/r years (see examples in Figure 22). We were specifically interested in events of a reasonably high frequency, i.e. ARIs or annual reccurence intervals of one to three months). Hence the ARI is presented in units of months rather than years.

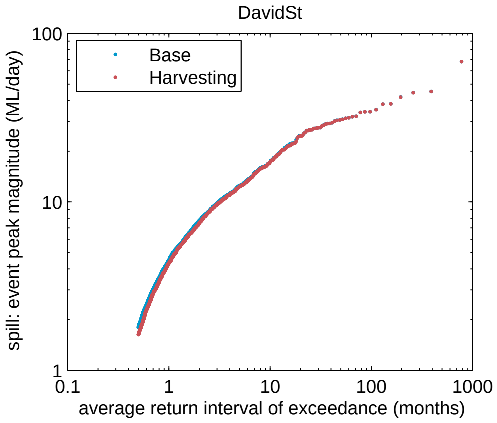


Figure 22: Example of flood frequency analysis.

Naturally seasonal differences occur in flow patterns in the urban streams. They are likely to be exaggerated under stormwater harvesting as abstraction rates from the ponds are highest during summer months when streamflows are already naturally low. These differences are highlighted in the exceedance curves and dry spell analyses by showing separate plots for summer and winter (where summer and winter are six-month periods as defined previously). For a more detailed view of the impact on stream flow the distribution of non-zero flow rates for each month was plotted over the model record (see Figure 23 for an example). Each panel in the figure represents a particular month, and shows the probability density function for all the non-zero flows in that month over the 65-year period. The area under the curve is set so that it is proportional to the amount of time for which the flow is non-zero. Where the area is smaller for harvesting than base, the impact of harvesting has been to increase the number of zero-flow days. Our interest in this plot is not the zero-flow component (as these have been analysed separately (e.g. Figure 21), but rather to ascertain which part of the flow distribution is most affected by stormwater harvesting. The probability distributions were derived using a mixture density fit (Gershenfeld 1998) to the daily flows in each month over the 65-year record.

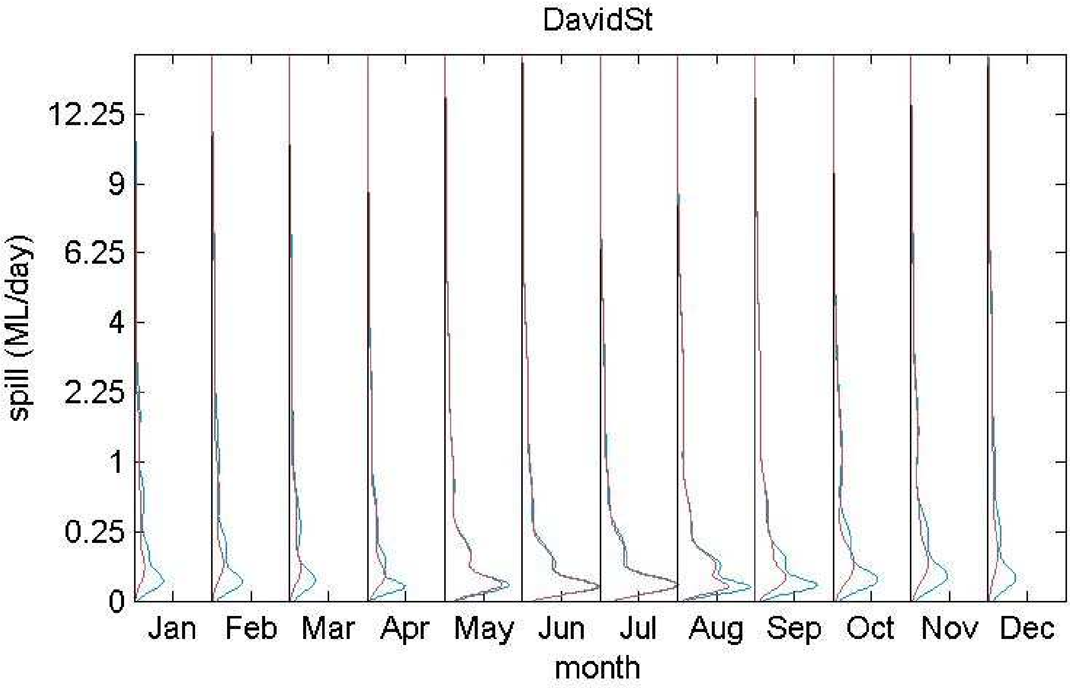


Figure 23: Distribution of non-zero flows, as estimated by the mixture density fit to the pond spill for each month over the 65-year record (blue: base; pink: harvesting)

Total monthly flows from the ponds were also plotted by month to highlight expected changes to flow patterns under stormwater harvesting (Figure 24). Each panel in Figure 24 shows a total monthly spill for each year of the record in that month. These are sorted from highest to lowest, so that points in each panel form an exceedance curve similar to those shown previously. Again, these graphs were used in subsequent ecological analysis to provide insight to the hydrological changes expected under harvesting. Note that monthly eightieth percentile flow levels are shown on each panel of Figure 24.

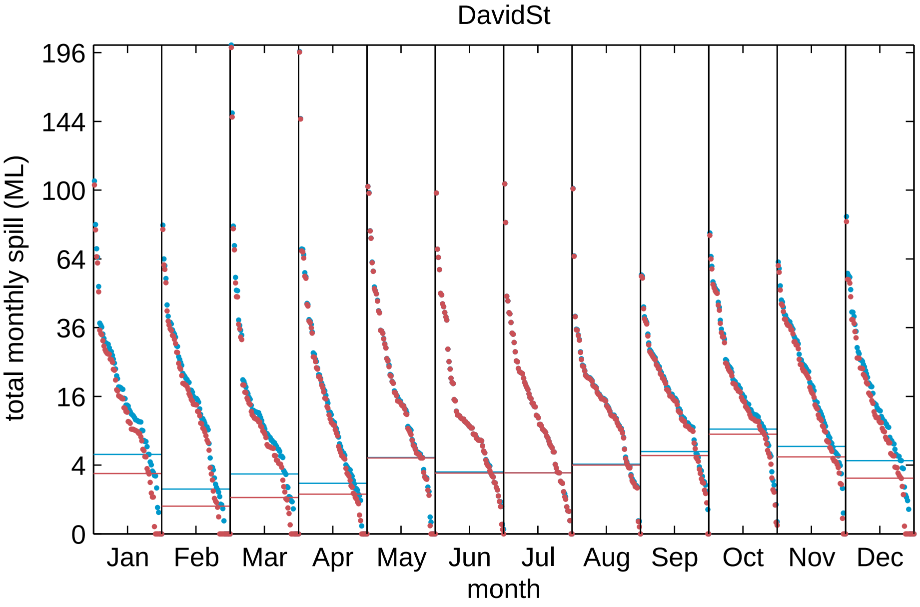


Figure 24: The total spill for each month. Each point in the graph represents the total spill in one month in one year of the 65-year period. Blue: base; Pink: harvesting. The horizontal bars marked in each panel show the 80th percentile of the monthly flows (i.e. the flow rate which 80% of the monthly spills exceed).

Cumulative downstream impacts

The hydrological analysis so far has been pond-specific, and individual graphs and quantities were derived for each pond or lake. The ponds are interconnected according to the plan in Figure 14 and so have cumulative impacts on the streamflow of the Murrumbidgee River and its tributaries (Ginninderra Creek, Molonglo River, Tuggeranong Creek), and a cumulative impact on Sullivans Creek before it enters Lake Burley Griffin. The hydrological modelling that informed our analysis did not model the flows in the lower reaches of these streams, and nor did it model the flows in the Murrumbidgee River. From the modelling time series available we could consider only the cumulative pond contribution to these stream reaches, but not assess how those contributions impact the overall stream flow characteristics which are comprised not only of pond spills.

The cumulative contribution of ponds to a particular stream was calculated by summing the spills of those ponds directly connected to that stream. For example, the contribution to Sullivan’s Creek is the sum of the flow from David St wetland, NC9-11 and NC18. Even though G23 is on the Sullivan’s creek stream line, its flow is linked to NC18, and so the spill from NC18 captures the combined effect of G23 and NC18. For each stream (Sullivans Creek, Ginninderra Creek, Molonglo River, Tuggeranong Creek and the Murrumbidgee River) the contributing pond spills were summed and these time series of cumulative flow used to calculate flow exceedance curves and summed monthly spills as previously described.

These calculations do not provide an indication of how the total flows in these streams are influenced by harvesting, but rather a time series of the differences between base and harvesting cases, which may be subtracted from the total flow in a stream reach to provide an estimate of the impact on the total flow. The hydrological modelling for the stormwater proposal did not include flows in these lower reaches and measured time series from gauges could not be used to address this question as the stormwater analysis uses a 2030 climate scenario.

The CSIRO Murray Darling Sustainable Yields (MDSY) project included the catchment of the Murrumbidgee River in its analysis (CSIRO 2008) and modelled flows under 2030 climate change scenarios. The results from this work were made available (Rachel Gilmore pers. comm.) and provided data on the lower stretch of the Molonglo River downstream of Lake Burley Griffin, and for the Murrumbidgee River. It should be noted that there are differences between the 2030 climate-change assumptions used in the two different projects, so again it is important to view results with care. As with all our analyses, they are conditional on model assumptions and there are many characteristics in the real world systems that are not captured in these models. The value of the modelling in this project is not to predict the exact time course of hydrology in the system, but to offer insights into how a system would change under stormwater harvesting – it is this relative question of assessing *the changes* under harvesting that is important.

Analyses of the effects of water harvesting on stream flows of receiving waters has focused on the Murrumbidgee and Molonglo Rivers. Four time series were available from two locations in the MDSY modelling, the Murrumbidgee and the lower Molonglo Rivers. Site 4107381 is on the Murrumbidgee River above the Molonglo River junction, while site 4107561 is on the lower Molonglo River. To estimate the flow in the Murrumbidgee below the Molonglo junction the daily flows from the two sites were added. The four time series available from each location were:

- predevelopment flows with historic climate – (natural)
- current development flows with historic climate – (present)
- future climate (2030) flows for the 10 percentile of global climate models (GCM) – (Change 10)
- future climate (2030) flows for the 90 percentile of GCMs – (Change 90)

The difference time series calculated from the cumulative pond spills were subtracted from these four MDSY time series to show the impact of the harvesting on total river flows. Exceedance curves were calculated (Figure 25) along with the summed monthly flow (Figure 26) and spell analyses carried out for dry spells (Figure 27) and flow peaks (Figure 28).

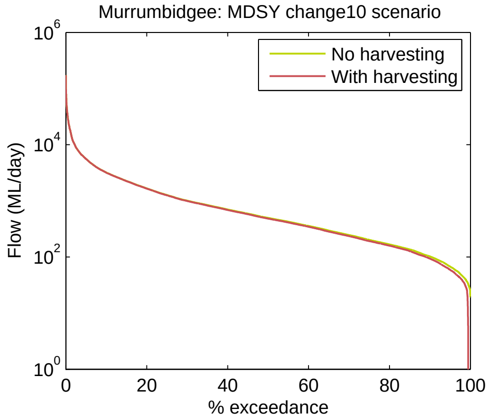


Figure 25: Exceedance curve for MDSY modelled flow both with and without harvesting (Murrumbidgee River)

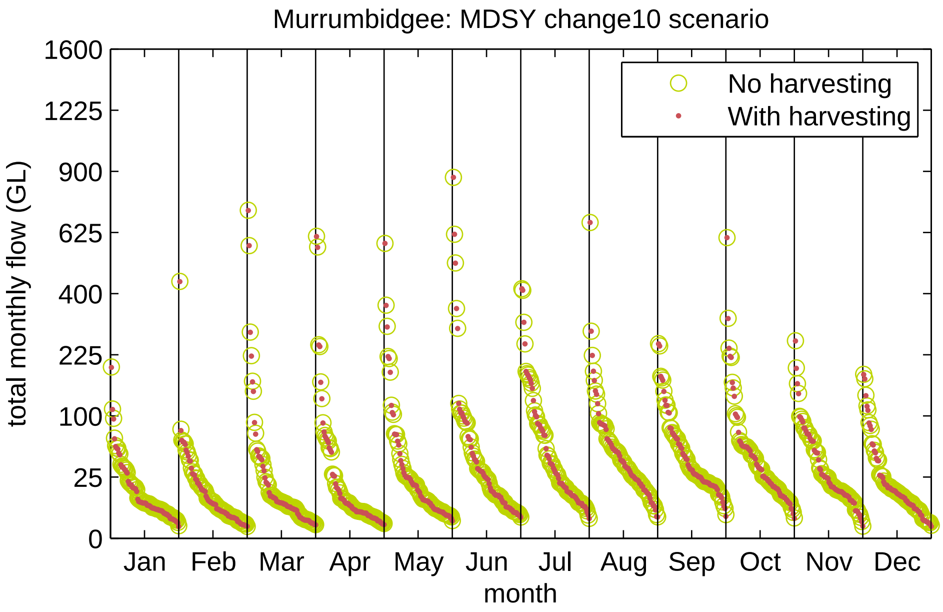


Figure 26: Monthly flow in the MDSY modelled time series for the 65-year record, both with and without harvesting (Murrumbidgee River)

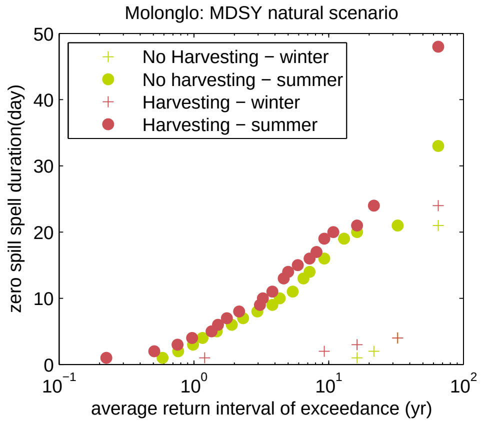


Figure 27: Example of zero spill spell analysis for MDSY natural scenarios (Lower Molonglo River)

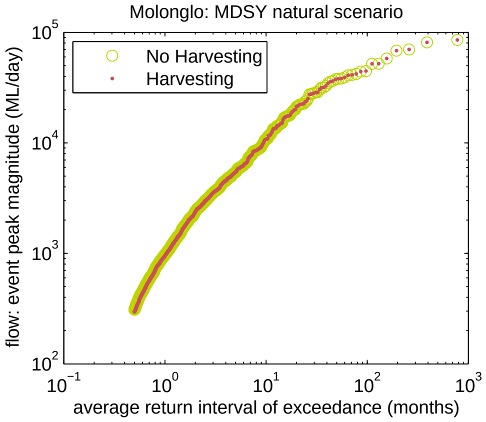


Figure 28: Example of flow peaks analysis for MDSY scenarios (Lower Molonglo River)

Uncertainties in hydrological analyses

It is important to note that these analyses and the model results used in these calculations are based on several assumptions. In particular, to infer the effects of water extraction on lake drawdown and lake surface area, relationships between lake volume and depth were prescribed in the hydrological modelling. These relationships were estimated from basic hypsometric assumptions that do not capture many of the complex characteristics of lake geometry. In particular, if the modelled shore slopes are steeper than reality, the modelling results in this report would indicate an under-estimation of the drawdown and the surface area reductions associated with water harvesting. Furthermore, the same end-user demand for the harvested stormwater was assumed for each year, and yet it is expected that demand will vary from year to year. Uncertainty due to this year-to-year variation is highest in summer. For these reasons, the actual drawdown and surface area reduction estimates carry uncertainties that have not been quantified.

8.3.2 Ecological responses

Aquatic vegetation in ponds

The functionality of urban ponds for sediment and nutrient removal is enhanced by the presence of both submerged and emergent aquatic vegetation and maintenance of this vegetation is a critical aspect of pond management (Wong et al. 1998; Lawrence 2001a; Victorian Stormwater Committee 2006; ACT Government 2001a; Hoban et al. 2006). The presence of vegetation also creates a range of habitats that support aquatic organisms and contribute to sustaining aquatic diversity (Blackham et al. 2006). The diversity of aquatic organisms is enhanced by increasing the range of aquatic vegetation types to provide a variety of habitats and food resources. Because of their different life forms and reproductive cycles, aquatic macrophytes generally occur in zones defined by water depths and inundation frequencies (Wong et al. 1998; Lawrence 2001a; Victorian Stormwater Committee 2006; Hoban et al. 2006), the conditions within these zones determining the variety and health of the plants that occur. A general zoning pattern adapted from several sources is depicted in Figure 29 along with a notional estimate of the inundation frequency required to sustain plants commonly occurring in the various zones (Wong et al. 1998; Victorian Stormwater Committee 2006; Melbourne Water 2005; Hoban et al. 2006). The location of zones in a pond with a shore slope of 1 in 10 is also shown to provide perspective. Water depths depicted on the vegetation line nominally separate the four major overlapping plant zones of ephemeral, emergent, submergent, and the deep open water zone where phytoplankton generally dominate. The emergent zone can be further subdivided into shallow marsh, marsh, deep marsh and deep emergent areas which, along with the ephemeral swamp, are most likely to be affected by fluctuations in water depth.

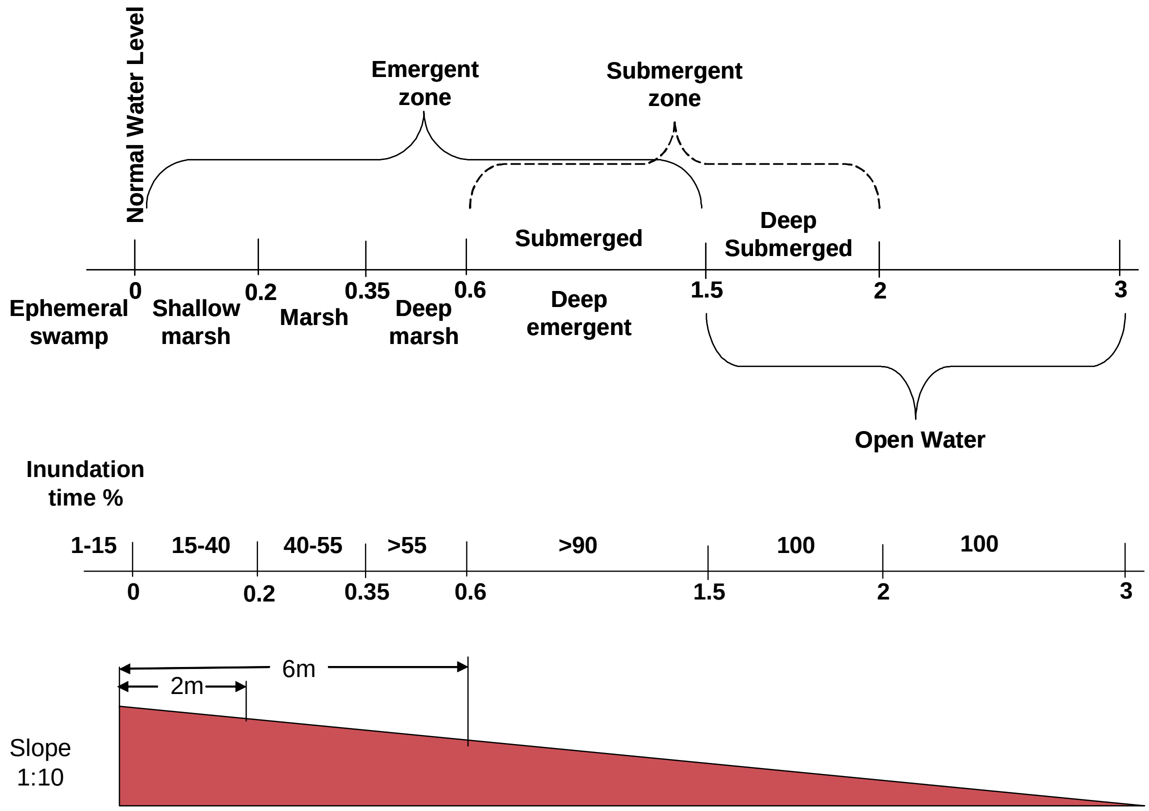


Figure 29: Wetland plant zones, inundation requirements and locations on a 1:10 slope

The inundation frequency line indicates that various wetting and drying cycles are required by plants in the different zones and that a static water level will not continually support all of these zonal groups. However, identifying and delivering the inundation requirements for specific plant species is a difficult management task and frequently the detailed information on which to make such decisions is not available (Hoban et al. 2006). To try and circumvent this problem, but still provide an indication of the capacity of each stormwater harvesting pond to support a diverse macrophyte community, the following analysis assesses the responses of major functional plant types occurring across the inundation zones. Four functional plant groupings were identified consisting of, ephemerals, annuals, perennials and submerged species. The ephemeral and submerged species are included in Figure 29 which indicates their respective requirement for either damp, rarely inundated conditions or continually inundated with rare dry periods.

The likely responses of plants from the major functional groups to various inundation frequencies over a 10 year period were estimated from literature sources (Wong et al. 1998; Melbourne Water 2005; Victorian Stormwater Committee 2006) and expert opinion. In Table 18 the left hand column shows the average return intervals (ARI) in years ranging from 1–10 that were considered in the analysis. The body of the table is in two parts, the left hand section for dry periods of >75 days duration and the right hand section for dry periods of 50–75 days duration. These time periods were selected because many aquatic macrophtes can withstand drying for periods of a month or two through different reproductive or physiological mechanisms, re-emerging or re-colonising once water returns. Re-establishment generally requires several weeks or months depending on the functional type, so if dry periods last less than a month then successful germination and establishment of plants in the intermittently re-defined zones is less likely to occur because re-inundation will reduce their probability of survival. Conversely, longer periods without water, especially during the growing season, will impact more severely across a range of plant types causing significant changes in community composition and plant biomass. In this analysis it is considered that dry periods of less than about one and a half months will not greatly influence the diversity of plants supported within a pond. Dry periods having the greatest effect on plants are considered as those that comprise a third or more of the growing season, which is defined here as the period November to April and is 180 days long.

Table 18: Aquatic macrophyte responses to 50–75 day and >75 day dry periods with 1–10 year return periods (ARI)

Considered across the depth range of 0-0.8m using 0.2m and 0.5m depths as indicators

		>75 day Dry					50-75 day Dry			
ARI Years	Ephemerals	Annuals	Perrenials	Submerged	**Relative Ranking**	Ephemerals	Annuals	Perrenials	Submerged	**Relative Ranking**
1	**-**	**-**	**+**	**-**	**1**	**-**	**+**	**+**	**+**	**2**
2	**+**	**+**	**++**	**+**	**3**	**+**	**+**	**+++**	**++**	**4**
3	**+++**	**+++**	**++**	**++**	**5**	**+++**	**+++**	**+++**	**+++**	**6**
4	**+++**	**+++**	**+++**	**+++**	**6**	**++**	**++**	**+++**	**+++**	**6**
5	**+++**	**++**	**+++**	**+++**	**6**	**++**	**++**	**++**	**+++**	**5**
6	**++**	**++**	**++**	**+++**	**5**	**++**	**++**	**++**	**+++**	**5**
7	**+**	**+**	**++**	**+++**	**3**	**+**	**+**	**++**	**+++**	**3**
8	**+**	**+**	**++**	**+++**	**3**	**+**	**+**	**++**	**+++**	**3**
9	**-**	**-**	**+**	**+++**	**1**	**-**	**-**	**+**	**+++**	**1**
10	**-**	**-**	**+**	**+++**	**1**	**-**	**-**	**+**	**+++**	**1**
			Score							
	No dry period		**1**							

Each section of Table 18 is further divided into the major functional aquatic plant groups, ephemerals, annuals, perennials and submerged. Under each of these headings an indication of the extent of diversity likely to be supported by the water regime is depicted by plus signs. In developing this response matrix, each functional group was considered individually and the likely response to the dry period for each of the return intervals was assessed.

Within each functional plant group the scores indicate whether conditions are better or worse for supporting diversity of that group. These scores are not quantitative and three pluses are not three times better than a single plus, but they provide an indication of diversity extent over a scale ranging from zero to three. The lack of a plus sign does not necessarily indicate a total absence of the group, but a strong suppression of their presence and a low probability of extensive diversity. Because each functional group was considered independently the scores cannot be quantitatively compared across groups, but the patterns can, and it is the patterns of diversity that the analysis seeks to describe.

An improved probability of enhanced diversity may be associated with increased plant biomass, but this is difficult to quantify, especially as the analyses are based only on hydrological conditions while the influence of other environmental attributes such as nutrients and light are not included. However, it is reasonable to expect that conditions more supportive of enhanced diversity for a functional group might be accompanied by an increased biomass of that group.

After scoring each of the functional groups, for each return time, and for each dry period, a relative ranking index between 1 and 6 was given across all cases within a dry period category. This combines the scores of the likelihood for increased diversity across the functional plant groups and indicates the order of conditions expected to support an increased probability of improved diversity for that dry period type.

The diversity responses of the functional plant groups to the different drying regimes were then assessed over a depth range of 0–1.0 m. The 1 m limit was set because the maximum drawdown modelled for the harvested ponds was 1 m, and with an assumed shore slope of 1 in 10 (Figure 29) rooted vegetation will be impacted to this depth. At any point within the 0–1 m depth range it is possible for 50–75 day dry periods and >75 days dry periods to occur. To deal with such cases a combined scoring matrix was devised which gives precedence at a point to one or other of the drying periods depending on the ARI. The relative ranking of the priority drying period (Table 18) was used in the matrix (Table 19) to create the interaction scores. In general the relative ranking for the >75 day dry period was given precedence unless the 50–75 day dry period occurred more frequently, in which case its relative ranking was used. Note that ARI's giving equivalent relative rankings within the different dry spells have been combined in Table 19. A description of two of the columns in Table 19 demonstrates this approach. If the >75 day dry period occurs with an ARI of one year then it is more likely to determine the plant diversity than a 50–75 day dry period at equivalent or longer ARI's, consequently all values in the first column in Table 19 are set to 1. In contrast, if the >75 day dry period occurs every 9–10 years, then the plant diversity over shorter time periods will be determined by the ARI of the 50–75 day dry spell. Consequently the final column of Table 19 re-iterates the relative rankings for the 50–75 day dry spell given in Table 18.

Table 19: Combined scores for 50–75 day and >75 day dry periods of various ARI

		>75 day Dry ARI						
		1	**2**	**3**	**4-5y**	**6**	**7-8y**	**9-10y**
50-75 day Dry ARI	**1**	1	2	2	2	2	2	2
	2	1	3	4	4	4	4	4
	3-4y	1	3	6	6	6	6	6
	5-6y	1	3	5	6	5	3	5
	7-8y	1	3	5	6	5	3	3
	9-10y	1	3	5	6	5	3	1

Two indicator depths, 0.2 m and 0.5 m, were chosen to assess the impact of dry conditions at the water edge. Each was scored using the combined matrix and the average of the two used to estimate the overall capacity of the system to support increased aquatic plant diversity. The dry spells at these two depths were analysed as described in Figure 18 providing a basis for scoring each pond according to its drawdown characteristics. Data is provided for each pond as a final combined score with harvesting in place and also as the difference in scores between the base and harvesting scenarios to indicate the direction of change brought about by stormwater harvesting.

Phytoplankton risk in ponds

There is considerable concern that phytoplankton blooms, especially of toxic cyanobacteria, may occur in urban ponds and lakes, restricting their recreational use and reducing their ecological value (Burge and Breen 2006). Phytoplankton growth rates are affected by a wide range of environmental conditions including availability of light and nutrients, and temperature effects on thermal stratification and growth rates. Population increases are also curtailed by losses such as grazing and washout. In urban ponds and lakes where water residence time can be short, washout of phytoplankton cells is a major restriction to bloom formation curtailing the occurrence of blooms despite other conditions being suitable for their development. Numerous analyses describing the influence of detention time on phytoplankton population growth have been published (Reynolds 2003; Sherman et al. 1998; Burge and Breen 2006) and these provide the basis of the following analysis. In particular, Burge and Breen (2006) describe these interactions in the context of urban ponds.

The exponential growth of phytoplankton populations is described by the specific growth rate μ, ($\mu=\ln(N_t/N_0)/t$, where t is the number of days, N_t the final cell concentration and N_0 the initial cell concentration) which quantifies the potential increase in cell numbers over time. The reduction in cell numbers due to washout is described by an exponential dilution function D, quantifying the rate at which a passive tracer is removed from the pond due to the inflow of water without the tracer ($D=\ln(C_t/C_0)/t$ where t is the number of days, C_t the final concentration of the constituent and C_0 the initial concentration). This is also termed the turnover rate of the water in the pond and is usually calculated as the ratio of the inflow volume to the pond volume. When the turnover rate and the specific growth rate are equal then phytoplankton cannot increase in numbers as cell loss by washout matches the cell increase due to growth. When the growth rate exceeds the turnover rate of the water then population increases can occur, with the net rate of increase depending on the extent by which growth rate exceeds the turnover rate. If growth rates are less than the turnover rate then phytoplankton cell numbers will show a net rate of decrease determined by the difference between the growth rate and pond turnover rate.

A typical phytoplankton growth rate in natural waters is a doubling of the population every three days, which is equivalent to a specific growth rate of 0.23 /day (Westwood and Ganf 2004; Burge and Breen 2006). Faster growth rates can occur, especially if reduced mixing due to thermal stratification becomes advantageous for buoyant cyanobacteria (Westwood and Ganf 2004). However, urban water bodies incorporating best practise design are shallow with a large surface area per volume and are subject to wind forcing and diurnal convective mixing which help prevent persistent stratification (Burge and Breen 2006). Light limitation is also less likely in these shallow ponds and under these conditions the nominated specific growth rate of 0.23 /day is considered representative of partially mixed and well mixed systems (Westwood and Ganf 2004).

Phytoplankton blooms of cyanobacteria become a problem when cell numbers exceed 30 000 /ml, with the time taken to reach this level depending on the net growth rate and the size of the starting population (Burge and Breen 2006). Assuming a starting population of 100 cells /ml, the time to taken to reach problem concentrations at the nominated specific growth rate is ca. 25 days. However, the actual rate of increase in a pond is given by the net growth rate which is the difference between the nominal specific growth rate and the turnover rate of the pond. If the turnover rate of the pond is equivalent to 10% of the specific growth rate then the phytoplankton increase will occur at 90% of its maximum rate and the time taken to reach a problem concentration will be 28 days. If the pond turnover rate is 20% of the specific growth rate then the time increases to 31 days. So as the pond turnover rate increases, the period required for bloom formation also increases. In the analysis used here, periods of time are identified when the pond turnover rate is 0.1 or less of the nominal specific growth rate (i.e. the pond turnover rate is 0.023 /day or less and the phytoplankton growth rate is 90% or more of the nominal specific growth rate).

An exceedance plot for the daily turnover rate was derived for each of the ponds with and without harvesting as described in the hydrological methods (Figure 19). Although exceedance curves do not indicate the length of sequential periods of a response, it is clear that very low turnover rates are common in some ponds. In Yerrabi Pond for example turnovers >0.01 per day occur for only 15% of the time so that the mitigation effects on phytoplankton growth rates are expected to be minimal (Figure 30).

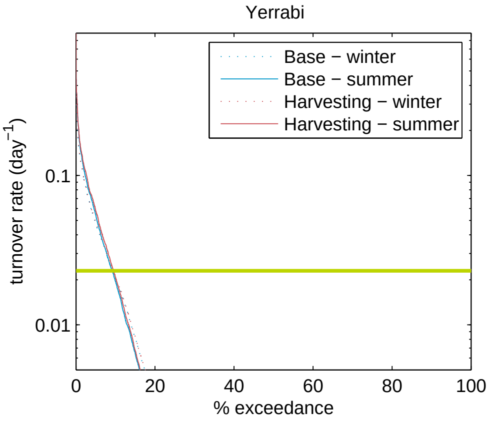


Figure 30: Turnover rate exceedance curve for Yerrabi pond. For other ponds see 0

To account for the time required for bloom development, the frequency distribution of sequential days with turnover rates of 0.023 /day or less was derived for each pond and used to calculate average return intervals for the different durations of consecutive days. Based on the nominal specific growth rate a period of 28 consecutive days was considered sufficiently long to result in the development of a phytoplankton bloom and this value is shown on the graphs of average return interval as a horizontal green line. For example in David St. Pond (Figure 19) there is little difference with or without harvesting and the typical return interval for the occurrence of periods supporting phytoplankton blooms is about once a year. The average recurrence time of bloom supporting conditions is used as an indicator of the phytoplankton bloom risk and provides a basis for assessing the impact of stormwater harvesting. Note that this analysis does not indicate whether blooms will actually occur or not, but determines whether flow conditions are consistent with those required for blooms. The analysis is appropriate for making comparisons between ponds of their hydrological potential to support blooms. The same analysis can be carried out with a range of growth rates if more or less conservative indicators are required.

Impact on water quality

Wetland water pollution control ponds are generally used to improve water quality in urban streams although their ability to do this varies widely and depends on characteristics such as the hydraulic loading (Wong et al. 1998; Melbourne Water 2005; Victorian Stormwater Committee 2006). Detailed models are available for estimating the ability of wetland pollution control ponds to retain contaminants such as nutrients and sediment but they usually require detailed information on pond characteristics including morphology which are not well defined for the proposed harvesting ponds analysed here (Lawrence 2001b). Instead, a simpler approach has been chosen based on empirical relationships between hydraulic loading and nutrient retention (Wong et al. 1998; Victorian Stormwater Committee 2006). Where ponds retain nutrients this has two advantages for downstream environments. Firstly, the reduction in nutrient concentration decreases the extent of biological uptake by organisms reliant on nutrients in solution. This can help reduce the growth of organisms such as algae, phytoplankton and submerged macrophytes which in high concentrations can become a nuisance or even a health risk. Secondly, a reduced concentration in outflows means a reduction in the total load of nutrient being carried downstream that may end up accumulating in receiving systems such as a ponds, lakes, or slow flowing rivers. The total load reduction achieved by a particular pond is a function of its capacity for nutrient concentration reduction, but also the volume of pond discharge.

Phosphorus is considered a particularly important nutrient in the eutrophication of inland waters. To reflect this status, the retention of total phosphorus (TP) is used here as an indicator of a ponds capacity to reduce downstream nutrient loads. As the removal of TP by urban ponds appears to be similar to that of total nitrogen, the analysis should provide a general index of flow effects on water nutrient quality (Wong et al. 1998; Victorian Stormwater Committee 2006). The relationship between TP retention and hydraulic loading as presented by Wong et al. (1998) is shown in Figure 31. Hydraulic loading is defined as pond inflow divided by pond surface area.

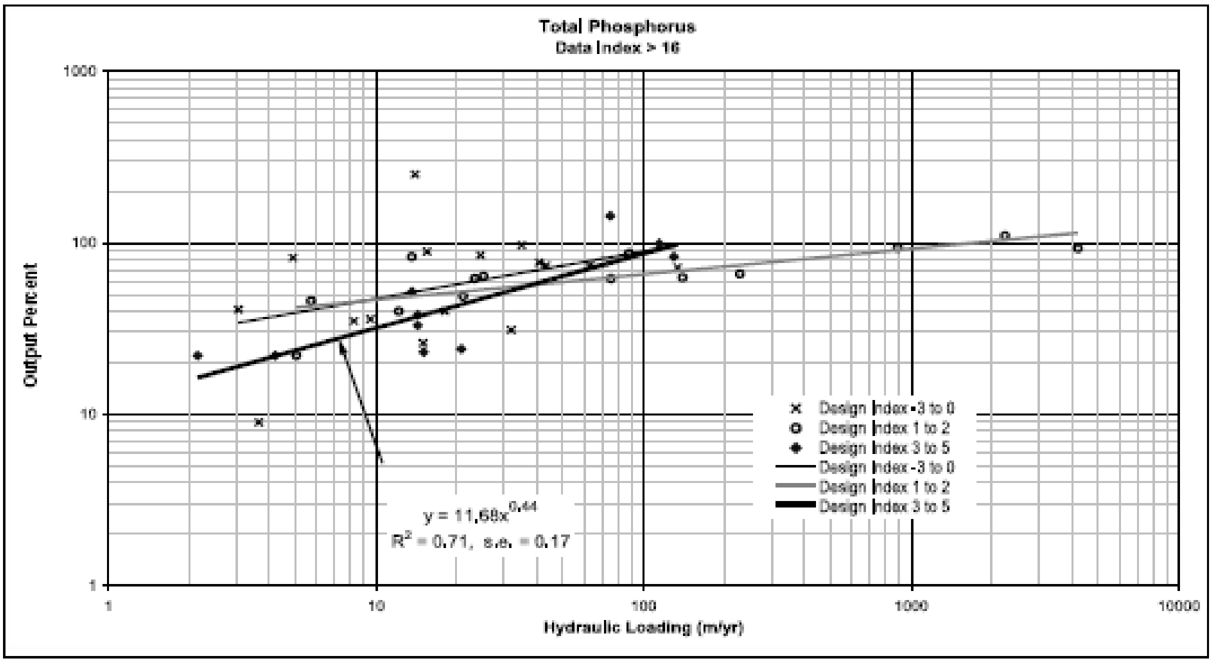


Figure 31: Changes in outflow TP concentrations as a percentage of inflow concentration with hydraulic loading (from Wong et al. 1998).

The hydraulic loading of each pond was calculated and the percent reduction in TP concentration in the outflow estimated from the equation in Figure 31. This value was subtracted from 100 to give the percentage nutrient retention in the pond and used as one measure of the effectiveness of a pond in moderating nutrient conditions. The hydraulic loading can be calculated using either base or harvesting inflow rates for existing ponds, however the results are substantially the same and only the base case inflow was used in calculating hydraulic loading. In the absence of regular and reliable nutrient monitoring data the inflowing TP concentrations are unknown and so were assumed to be equivalent across ponds. If there are large differences in TP concentrations between pond inflows then this index will not reflect those differences.

Similarly, the following calculations of the nutrient loads passing downstream do not account for different inflowing TP concentrations and the load reductions are weighted only by the volume of water passing from a pond. On the other hand, assuming equivalent inflowing concentrations of TP to all ponds does standardise the indices so that the capability of ponds to reduce nutrients can be compared. The following steps were taken to calculate a nutrient load reduction indicator:

1. For existing ponds we assume no change in nutrient retention efficiency, however there is still a load reduction in downstream flows due to direct removal of water through harvesting from the pond. Here the load reduction indicator is calculated as:

   [output fraction*(base mean daily spill – harvesting mean daily spill)],

   where the output fraction is the proportion of incoming nutrient passing through the pond and was calculated from the equation in Figure 31.

2. For new ponds the load reduction is due to two effects: increased nutrient retention due to creation of a pond and the direct reduction in load due to removal of water from the system. Here the load reduction indicator is calculated as:

   [base mean inflow – (output fraction)*harvesting mean daily spill].

   This assumes that there was no significant nutrient retention in the stream prior to pond construction giving a notional output fraction of 1.

Stream flow changes

As described in Chapter 8.2.3, many characteristics of stream flow can influence ecological responses depending on the organisms present and their location within the channel or riparian zone. The data available for analysis from the stormwater harvesting proposal are the estimated pond inflows and outflows with and without water harvesting based on modelled 2030 run-off estimates. In most cases pre-development flows are unknown so the original flow characteristics cannot be used to provide a template for comparison of the predicted flow regimes. This makes it difficult to interpret the influence of changing flows on urban stream ecology. Particular flow characteristics identified in the ACT *Environmental Flows Guidelines* (ACT Government 2006) as being important within created and urban systems were base flows and abstraction limits (Table 15) while the *ACT Natural Resource Management Plan* (ACT Government 2004c) also identified the need to reduce peak flows in urban streams (see Chapter 8.2.6).

The outflow from ponds occurring along a water course describes the stream flow just below the pond. As the distance from the pond increases the reliability of this estimate decreases due to enhancement of stream flows by surface run-off, tributary inflows and urban inputs. Similarly, pond inflows provide an estimate of flow patterns just upstream. In the following analyses, patterns for both inflows and outflows are presented but more detailed calculations are provided for pond spills in order to demonstrate the influence of harvesting on downstream flows.

Two sections of the hydrological analysis providing information on creek flow regimes are described in 0 under the headings, Spill and Inflow, and Monthly Flow Patterns. The following description of the inflows and outflows of ponds on Yarralumla Creek illustrates the interpretation of these measurements (Figure 32).

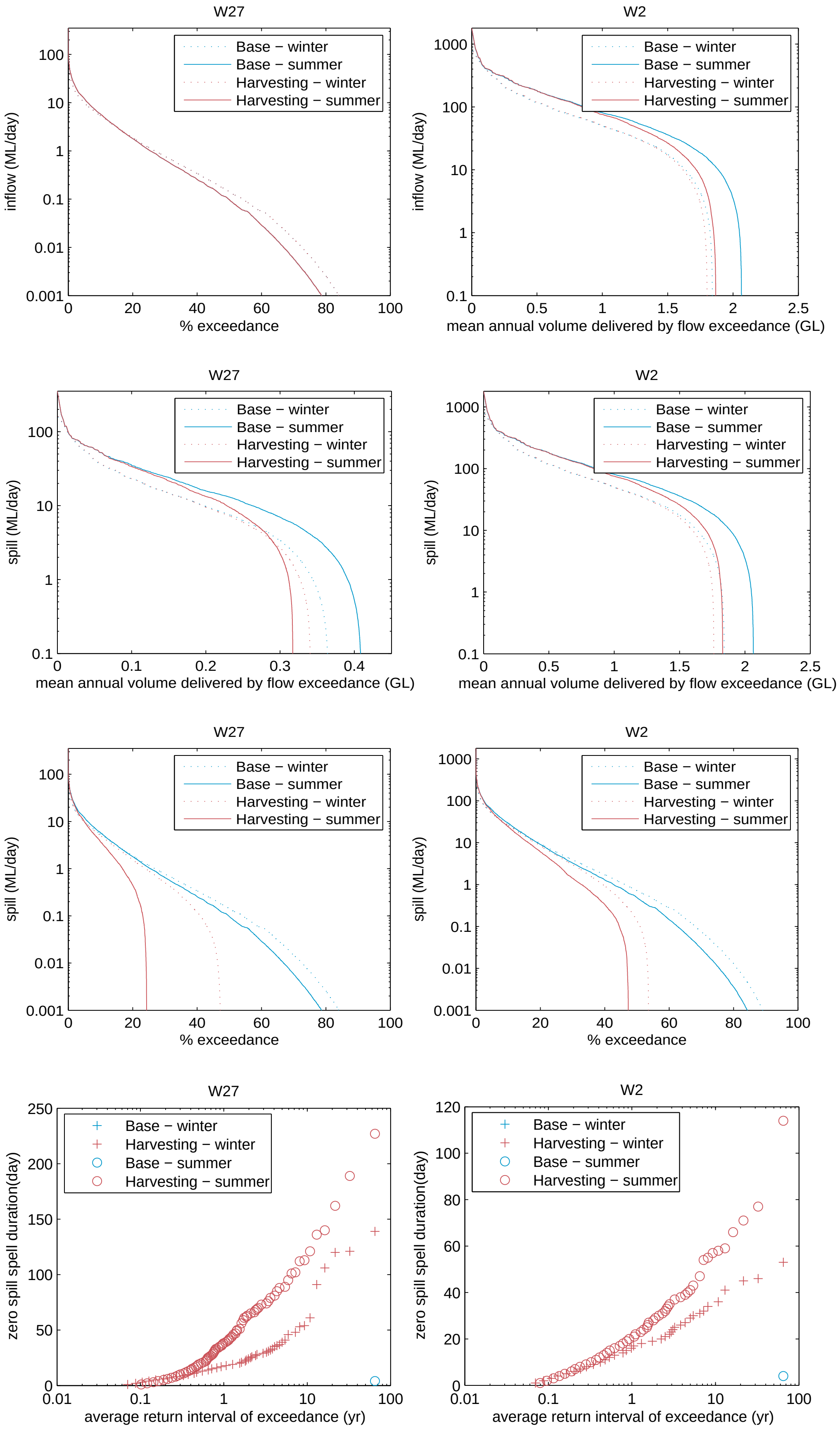


Figure 32: Spill exceedance curves and zero-spill spell analysis for ponds W27 and W2. For other ponds see 0

Ponds W27 and W19 are at the top of the tributaries considered within the Yarralumla Creek system. The inflows to these ponds are those expected under the 2030 climate change scenario assuming current levels of urban development. As there are no harvesting points above these ponds the exceedance curves for mean annual volume inflows with and without harvesting overlie each other. In contrast, the mean annual volume delivered downstream by outflows (pond spills), is altered by harvesting as water is removed from the system (Figure 32). In the case of pond W27 the total annual volume released is reduced from 0.41 GL to ca. 0.32 GL. The mean annual volume delivered by high flows remains virtually unchanged and differences are largely due to changes in the lower flows between ca. 1 and 50 ML/day. As a consequence, the percent exceedance curves for spill rates show that flows of 0.1 ML/day which occur 50% of the time without harvesting will occur 22% of the time with harvesting. In addition periods of zero flow which rarely occur without harvesting will increase with harvesting and on average a dry period of 40 days will occur once each summer.

The figures of monthly flow patterns for spills (Figure 33) display flow exceedance curves for each month based on the 65 years of data analysed. The 80th percentile of monthly flows is marked on the individual monthly graphs to help evaluate changes in flow distributions. For pond W27 the exceedance plots show that flow reductions occur in summer and that lower flow rates are most influenced. As a result, the 80th percentile monthly flow in pond W27 is frequently reduced to zero. Pond W19 shows similar patterns to W27 although the actual values differ.

Pond W2 is downstream of ponds W19 and W27 and so influenced by their harvesting, and as a result the mean annual inflow reduces from 2.1 to 1.85 GL (Figure 32). Its spill volumes are also reduced by harvesting with the annual volumetric outflow decreasing by ca. 0.3 GL. Reductions in spills from this pond largely influence downstream flow rates below 50 ML/day. As with the upstream ponds this results in an increase in dry spells. Without harvesting, dry spells are rarely encountered; but with harvesting they increase in occurrence so, on average, a dry period of 25 days should occur once each summer.

It is difficult to interpret the ecological implications of these flow changes without information on pre-development flow regimes, but in the absence of such information, analyses must necessarily be based on general responses observed in urban waterways. Recent studies have suggested that although stormwater flows to urban streams can impact both water quality and flow characteristics, it is the flow impacts that have an immediate influence on the aquatic biota, particularly macroinvetebraes. As a result of the increased imperviousness of urban surfaces, and the direct connection of run-off to receiving waters by pipes and culverts, even relatively small rainfall events can generate large inflows compared to the run-off expected under natural conditions (Walsh and Fletcher et al. 2005; Walsh and Roy et al. 2005). It has been argued that because the timing of storm events is unchanged, and high rainfalls generally occur in the wettest part of the year, the larger run-off events will have less of an impact on the stream biota as the disturbance occurs with a frequency and timing similar to that of the natural catchment to which they were adapted (Walsh and Roy et al. 2005). In contrast, the disturbance from frequent, smaller storms, where run-off enhancement moves stream discharge from low to high impact levels, may have more of an effect. In the study reported by Walsh and Roy et al. (2005) these were storms with an average return interval of approximately 1 in 3 to 1 in 4 months. Similar ARI flows were also identified in the NRM plans (Chapter 8.2.6) as problematic and were to be combated by reducing flows with this ARI to pre-development size (ACT Government 2004c). Based on these observations an analysis was developed to assess the influence of harvesting on stream flows by estimating the reduction in peak flows with ARI’s of 1 in 1 month and 1 in 3 months.

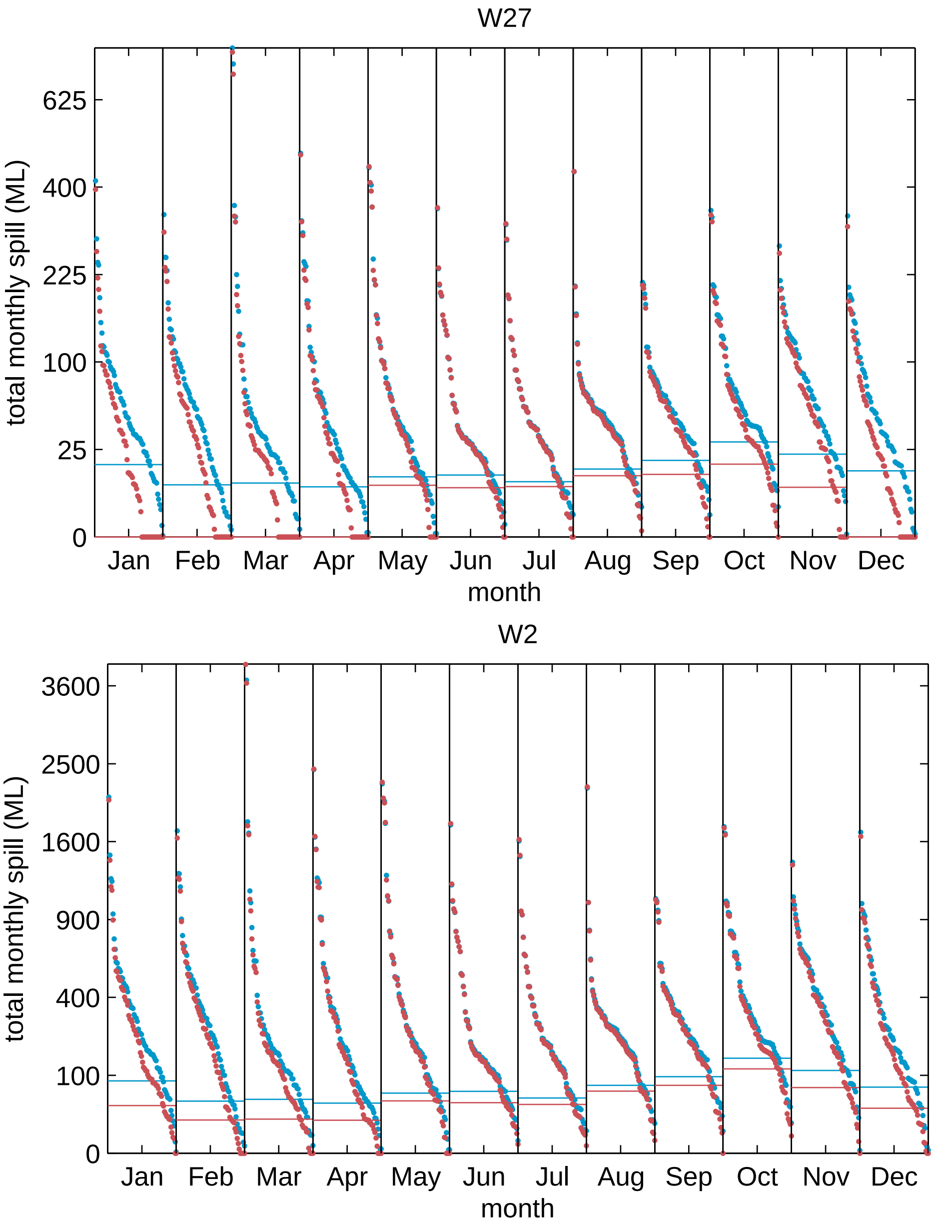


Figure 33: Monthly flow patterns for ponds W27 and W2. For other ponds see 0

Dry spells are a major disturbance to aquatic organisms but the extent of impact is dependent on the ability of different organisms to respond. In some cases, resting stages such as spores can withstand desiccation for prolonged periods; while in other cases, organisms can aestivate in moist sediments or other refuges either in adult form or some other lifecycle stage. Those that can withstand desiccation often re-appear rapidly once flows are resumed whereas those surviving in refuges depend on re-connection of the waterways to ensure redistribution. Attempting to identify the ecological benefits or dis-benefits of particular durations of zero flow is difficult and more easily addressed by comparison with pre-development conditions, especially if the aim of management interventions is to move urban waterways towards a more natural regime. Knowledge of pre-development flow patterns then sets a direction and target against which achievable outcomes can be compared. As pre-development data was not available, interpretations of changes were again reliant on general ecological information.

The urban streams considered here are punctuated with ponds and lakes impounded behind structures that completely separate lower and upper stream reaches. This lack of connectivity means that fish are unlikely to be well dispersed through the system and not greatly affected by zero flows. Even fish that have dispersed upstream from artificially stocked ponds should be able to retreat back as streams dry up. In comparison, the macroinvertebrates have a more restricted ability to move within the stream and rely on an ability to recolonise from refuges (resilience) or to produce dessication-resistant resting stages (resistance) in order to survive drying (Fritz and Dodds 2004; Boulton 1989). Macroinvertebrates are widely used as indicators of ecological condition and although there is not a great deal of information on their quantitative responses to drying, a coarse index is devised to assess the influence of harvesting on zero flow periods and their impact on invertebrate diversity and density.

It is believed that small streams in the Canberra region flowed intermittently under natural conditions, drying up at times in summer. A study of the macroinvertebrates of intermittent streams in Kansas, USA by Fritz and Dodds (2004) made the following general observations. A nine-month dry period resulted in an 86% reduction in taxa richness and 97% reduction in density of macroinvertebrates in the four-day period after re-wetting compared to the pre-drying assemblages. In comparison a two-month drying period reduced richness by 50% and density by 96% on re-wetting. In both cases the invertebrates at intermittent flow sites recovered to pre-flood conditions in 30 days, but recovery was dominated by colonisation from refuges rather than tolerance to dessication, so resilience was considered more important than resistance in the re-establishment of macroinvertebrate populations.

Fritz and Dodds (2004) expected the reduction in macroinvertebrate populations to scale as a function of the ratio of the dry period duration to the average duration of dry periods in the flow record and to be further modified by the proximity of refugia. In the ACT, the urban ponds and lakes, which in general do not dry out over summer, provide the streams with nearby refuge sites for macroinvertebrate populations. Assuming that this connectivity fulfils the requirements for re-colonisation, the drying effect on the macroinvertebrate populations will be a function of the length of the drying period. Information was not available on the average dry periods that might have occurred in a natural flow record so the ratio approach of Fritz and Dodds (2004) could not be used.

Macroinvertebrates are an important food source for birds and fish and play a role in transforming materials entering from the catchment. Their role in supporting trophic links will depend on the length of time that productive macroinvertebrate communities persist during summer (defined as the six-month period from November to April). Zero flows reduce the presence of macroinvertebrates and so reduce the capacity of the system to support populations dependent on the macroinvertebrates as a food source. The period of reduced macroinvertebrate occurrence due to zero flows was calculated as the number of dry days occurring with an average return period of either one or two years, expressed as months, and added to the one-month recovery period. This was subtracted from the six-month summer to produce an estimate of the remaining growing season uninfluenced by a dry spell. This index can be compared between locations and with and without harvesting. It is assumed that longer periods unaffected by zero flows are more satisfactory, but as these streams were naturally intermittent an intermediate value is likely to indicate a more natural situation. However, without pre-development data this cannot be identified, but a notional scale might be that reductions in suitable conditions below three months duration (i.e. less than half the growing season, are likely to significantly disturb macroinvertebrate communities).

The cumulative effect of pond harvesting on major downstream waterways was assessed through an analysis of the flow changes in the Murrumbidgee River and the lower Molonglo River near to where it enters the Murrumbidgee. In both these cases modelled flow data was available describing pre-development and current flows, and flow under two climate change scenarios (CSIRO 2008). This enabled the direct comparison of natural and predicted flows and calculation of the stream flow indices described above to assess the effects of harvesting on components of stream ecology.

8.4 Results

8.4.1 Hydrological analyses

A significant difference between the existing and the new ponds exists. Most of the existing lakes and ponds are larger and have lower hydraulic loading (ratio of inflow to surface area) and mean turnover rate (ratio of mean annual inflow to volume). The new ponds can be considered as small waterbodies that are filled more easily and flushed more rapidly than existing ponds. A notable exception is David St Wetland, which is an existing pond with a similar design to the proposed new ponds.

The bulk hydraulic quantities identified in Table 20 represent a broad overview of the pond characteristics, and will be used in a later section to explain differences that emerge between ponds in the ecological analysis.

The more detailed hydrological analyses resulted in a series of graphs characterising different aspects of the hydrology of the ponds and streams (see Chapter 8.3.1). The graphs for each pond and stream are provided in 0 and tables of quantities derived from these graphs are found in 0. The purpose of the hydrological analysis was to underpin the ecological analysis, but it stands alone as a useful summary of expected impacts of stormwater harvesting on the ponds.

A key assumption in the hydrological modelling was a pond drawdown limit of 1 m. In all ponds drawdown levels vary from year to year, but are always at their highest in summer and are significantly larger with harvesting than without. With harvesting, the drawdown in all ponds routinely reaches the 1 m drawdown limit (typically between 5% and 10% of the time), whereas this drawdown level is never reached without harvesting. The modelling suggests that in the base case summer pond drawdown for existing ponds exceeds 0.5 m between 0.2% and 7% of the time whereas with harvesting drawdown exceeds 0.5 m between 13% and 25% of the time. A more detailed breakdown is provided in Table 97 in 0 while figures showing drawdown time series and exceedance curves are provided in 0, but the general finding is that previously rare drawdown events will be experienced far more frequently. Patterns in surface area changes directly mimic the drawdown changes but note that surface area changes are likely to be an underestimate due to the hypsometric assumptions underlying the modelling.

The duration of time for which drawdown levels are exceeded is important for inferring impacts on aquatic vegetation. A more complete analysis of the impact on vegetation is provided later and here we simply point to some results of the dry spell analysis which add to our understanding of harvesting impacts on drawdown. Indicative impacts are shown in Table 21. Under the hydrological modelling assumptions, existing ponds rarely experience prolonged periods (>50 days or >75 days) of shore exposure at the 50 cm drawdown level. They either never exist or are experienced only once every approximately 40–50 years (with the exception of West Belconnen pond). When harvesting is enabled the average return interval (ARI) for such events reduces dramatically, and so under harvesting we would expect more frequent occurrences of prolonged periods of shore exposure (return intervals as low as three years in some ponds).

Table 20: Table of bulk hydraulic characteristics

Pond name	**Volume (ML)**	**Surface area (ha)**	**Mean annual inflow (ML)**	**Hydraulic loading (m/yr)**	**Mean turnover rate inflow/vol (y-1)**	**Mean turnover time vol/inflow (yr)**
David St	3.025	0.3	229.7	76	76	0.01
Dunlop Pond 1 (Jarramlee)	13.97	0.7	108.5	16	8	0.13
Dunlop Pond 2 (Fassifern)	13.91	0.7	52.4	8	4	0.27
Ginninderra	3555.2	105.6	9527.4	9	3	0.37
Gungahlin	554.17	23.8	4409.4	19	8	0.13
Isabella Pond	72.001	5.8	3445.4	60	48	0.02
Lake Tuggeranong	2551.5	56.7	6128.5	11	2	0.42
Lower Stranger Pond	61.56	4.1	851.3	21	14	0.07
Nichols Pond	48.001	4.0	134.2	3	3	0.36
Point Hut Pond	336	16.8	1207.7	7	4	0.28
Tuggeranong Weir	144	9.6	3558.4	37	25	0.04
Upper Stranger Pond	45.1	4.5	717.5	16	16	0.06
West Belconnen	100	10.0	230.1	2	2	0.43
Yerrabi	444.17	26.7	1346.9	5	3	0.33
B14	1.728	0.1	1235.7	1430	715	0.001
B28	8.22	0.4	480.6	117	58	0.017
T2	35.66	1.8	550.1	31	15	0.065
T3	28	1.4	971.2	69	35	0.029
T4	9.26	0.5	1350.4	292	146	0.007
W19	61.68	3.1	1095.2	36	18	0.056
W27	49.24	2.5	775.2	31	16	0.064
WC15	6.024	0.3	448.0	149	74	0.013
WC19	8.24	0.4	209.0	51	25	0.039
WC4	16.41	0.8	1741.5	212	106	0.009
G23	10.54	0.5	946.1	180	90	0.011
NC14	37.9	1.9	447.8	24	12	0.085
NC18	67	3.4	1681.3	50	25	0.040
NC911	13.58	0.7	746.7	110	55	0.018
W0	240	12.0	3595.7	30	15	0.067
W2	6.892	0.3	3672.0	1066	533	0.002
WC0	65.7	3.3	2351.3	72	36	0.028
Average current	567.3	19.2	2282.0	20.6	15.3	0.21
Average new	39.2	2.0	1311.6	232.2	116.1	0.03
Median current	86.0	7.7	1029.5	13.2	5.8	0.20
Median new	16.4	0.8	971.2	71.6	35.8	0.03

* Note that the David St inflow rate is likely to be an overestimate as not all of the flow from the David St catchment enters David St pond (it is an offline pond).

Table 21: Shore exposure at 50 cm drawdown. Average return interval (ARI) for shore exposure duration >50 days. Taken from more detailed breakdown in Table 91 to Table 94.

Pond name	Base ARI (d>50 day)	Harvesting ARI (d>50 day)	Base ARI (d >75 day)	Harvesting ARI (d >75 day)
David St		14		22
Jarramlee (Dunlop Pond 1)		3		3
Fassifern (Dunlop Pond 2)		5		5
Ginninderra	39	3	45	3
Gungahlin		3		4
Isabella Pond				40
Lake Tuggeranong		4		4
Lower Stranger Pond	43	39	49	8
Nichols Pond	39	3	45	2
Point Hut Pond	39	7	44	5
Tuggeranong Weir	47	43	55	31
Upper Stranger Pond		18		10
West Belconnen	6	3	13	2
Yerrabi	40	4	46	3
B14				
B28		7		15
T2		3		5
T3		7		13
T4		7		14
W19		3		5
W27		3		5
WC15		9		19
WC19		5		7
WC4		8		35
G23		14		22
NC14		3		4
NC18		4		5
NC911		4		6
W0		3		4
W2		49		39
WC0		4		6

Pond turnover rate is the pond inflow rate divided by the pond volume and is a measure of how well the pond flushes; a shorter turnover time is associated with a higher flushing rate. Flushing rates are important for inferring risk of algal blooms. Given that harvesting can reduce pond inflows (if they are downstream of a harvested pond) and spills, there is the possibility that harvesting can reduce pond flushing times. Alternatively, given that pond volumes are lower under harvesting, it is possible that harvesting can increase pond flushing time. Exceedance curves and spell analyses for pond flushing rates given in 0, show that changes in turnover rate are minimal due to harvesting so we expect harvesting to have a minimal impact on pond flushing characteristics.

Pond inflows and spills were regarded as a proxy for streamflows immediately upstream and downstream of ponds. In general the impacts on pond inflows are minimal, with the exception of ponds that lie at the end of a chain of harvested ponds. Changes to pond spills are more pronounced, although not as obvious as might have been expected. The analysis of peak flow events shows that the highest flow events are barely affected by stormwater harvesting, and any differences in peak flows are limited to small changes at low flows. The main difference between base and harvesting spills is in the number of zero-spill days: a higher proportion of the flow time series is zero, and in particular the duration of zero-spill periods is lengthened under harvesting scenarios. The differences are particularly pronounced in summer. These differences reflect the fact that during high flows ponds are more likely to be full and spill volumes will be barely affected by stormwater harvesting. Under low flows pond levels are drawndown more by harvesting, lengthening the period of time required to fill a pond to the point of spilling. Hence the main differences in pond spills are seen at the zero and low-level flows. The ecological implications are discussed in the next section.

The analysis of the cumulative harvesting from Ginninderra, Tuggeranong and Sullivans Creeks on the Molonglo and Murrumbidgee Rivers show that just under 5 GL less water flows to the Murrumbidgee River as a result of harvesting. This volume is comprised of approximately 2 GL less for each of Ginninderra Creek and the Molonglo River and just under 1 GL less for Tuggeranong Creek. The changes in volume are mostly attributable to changes in low flows rather than the peak discharges.

While differences in the contribution of the urban stormwater system to the Molonglo and Murrumbidgee Rivers are significant, the impact on the flow characteristics appears to be minimal. For all the MDSY scenarios the flow exceedance curves, flow peaks analysis and zero-spill spell analysis show little difference between base and harvesting cases. Again, as for the spills from individual ponds, the most pronounced differences are observed at the low flows. There is a small increase in the duration and frequency of zero-spill periods in the Molonglo River in particular.

Consistent across the hydrological analysis is that most of the impacts of harvesting will be felt in summer during periods of low flow.

8.4.2 Ecological responses

Quantities derived from the hydrological analyses and used to make ecological assessments are described in Chapter 8.3.2. Tables listing the output from these analyses are provided in 0 and are discussed in the following sections. The results of the hydrological and ecological analyses are summarised in Table 26. In this table the eight indices on the right hand side of the table that inform on changes in ecological condition are shown for current and new ponds. At the bottom of the table the mean and median are shown for the current and new ponds to indicate where there are major differences in the way that they behave to hydrological changes.

Emergent aquatic vegetation in ponds

The results of analyses assessing the extent of shoreline dry periods are presented in Table 22. Larger scores indicate an increased probability of macrophyte diversity being generated by the near shore water regime. The average shoreline dry spell for pre-existing ponds is calculated for both the base case without harvesting which is the current situation, and with the level of harvesting proposed in the stormwater feasibility study. For the new ponds the shoreline dry spell analysis is only provided for the harvesting case as the construction of these ponds is predicated by their role in stormwater harvesting. Base cases for existent ponds generally show low indices reflecting the current practices of maintaining constant water levels varying less than 0.2 m (ACT Government 2006). Constant water levels are expected to support reduced macrophyte diversity with dominance by large emergent perennials and submerged macrophytes. Introducing harvesting to the current ponds generally improves the likelihood that they will support a diverse array of macrophytes as shown by the change in index in the second column in Table 22. The changes are quite variable with some ponds showing little improvement and others significant increases in the index. The final column in Table 22 shows the index for all ponds with stormwater harvesting occurring.

Table 22: Shoreline dry spell index of influence on macrophyte diversity

Pond name	**Base case average score (20 cm and 50 cm)**	**Base case change**	**Harvesting case average score (20 cm and 50 cm)**
David St	1	2	3
Jarramlee (Dunlop Pond 1)	1	5	6
Fassifern (Dunlop Pond 2)	1	2.5	3.5
Ginninderra	3	3	6
Gungahlin	1	4.5	5.5
Isabella Pond	1	0	1
Lake Tuggeranong	1	4.5	5.5
Lower Stranger Pond	1	1	2
Nichols Pond	2	2.5	4.5
Point Hut Pond	3	0.5	3.5
Tuggeranong Weir	1	0	1
Upper Stranger Pond	1	2	3
West Belconnen	3	1.5	4.5
Yerrabi	3	1	4
B14			1
B28			4
T2			5.5
T3			3
T4			2
W19			5.5
W27			5.5
WC15			3
WC19			4.5
WC4			2
G23			1
NC14			5.5
NC18			5.5
NC911			5.5
W0			6
W2			1
WC0			5.5

The new ponds show a wide range of responses with some likely to have water regimes that support diverse macrophyte communities while others have a very low potential similar to current ponds without harvesting. This array of responses reflects the variation in return intervals for prolonged dry periods and highlights an important difference between the old and new ponds. In old ponds the almost constant water level was responsible for low macrophyte diversity scores. The low scores for new ponds are also due to infrequent long dry periods but in these smaller ponds this results from rapid rise and fall in water levels which means that macrophytes cannot easily establish without being drowned out by the returning water. For example, pond W2 experiences high frequency, large-scale fluctuations in water level which means that emergent vegetation does not benefit from the long dry periods needed to boost diversity. Despite these differences, the average macrophyte diversity scores were not very different between the current and new ponds (Table 26).

Phytoplankton risk in ponds

The ARI for the critical number of days when the pond turnover is sufficiently low that a bloom of phytoplankton has a probability of occurrence is shown for each pond in Table 23 under harvesting conditions. The full data set is shown in Table 95 but as harvesting made little difference to the value in existing ponds the base case is not discussed further here. The old ponds have a higher probability of phytoplankton blooms (Table 26) with a range of ARI for the critical value of 0.5–1.4 and a mean of 0.81 (n=14, SE=0.08) compared with the new ponds where ARI's range from 0.8 to 5.3 with a mean of 1.9 (n=17, SE=0.3). Thus some of the new ponds are likely to have annual blooms but on average the likelihood of blooms in new ponds is every second year. Ponds B14 and W2 have particularly low bloom probabilities with ARIs of 4.5 to 5.5 years. The general reduction in turnover time for the new ponds reflects the different design criteria when an emphasis is on stormwater harvesting and a desire for ponds to re-fill more frequently so that excessive drawdown is avoided. As a result the new ponds are generally smaller per unit of inflow and their mean turnover time substantially less than the current ponds (Table 26).

Table 23: Critical pond turnover ARI for harvesting conditions

Pond name (existing)	**Critical turnover ARI (years)**	**Pond name (proposed)**	**Critical turnover ARI (years)**
David St	1.2	B14	5.3
Jarramlee (Dunlop Pond 1)	1.1	B28	2.2
Fassifern (Dunlop Pond 2)	0.8	T2	1.2
Ginninderra	0.5	T3	1.1
Gungahlin	0.7	T4	1.9
Isabella Pond	1.4	W19	1.4
Lake Tuggeranong	0.5	W27	1.3
Lower Stranger Pond	0.7	WC15	2.3
Nichols Pond	0.7	WC19	1.6
Point Hut Pond	0.6	WC4	2.6
Tuggeranong Weir	0.8	G23	1.2
Upper Stranger Pond	1.2	NC14	1.0
West Belconnen	0.5	NC18	1.1
Yerrabi	0.6	NC911	1.8
	5.3	W0	0.8
	2.2	W2	4.5
	1.2	WC0	1.2

Impact on water quality

The nutrient retention efficiency and nutrient load reduction indicators are shown for each pond in Table 26 and in Table 96.

The nutrient retention efficiencies vary between 22 and 83% for existing ponds with a mean of 60.6 (n=14, SE=4.9) and between 0 and 53% for new ponds with a mean of 21.8 (n=17, SE=5.1) (Table 26). The generally poorer nutrient retention of the proposed new ponds is in line with their more rapid turnover which as discussed in the previous section, also reduces the probability of phytoplankton blooms occurring.

The calculation of retention does not account for the removal of nutrients by harvesting but this is included in the load analysis. The load reduction indicator is estimated as the difference between base and harvesting loads and is expressed as the change in the mean daily load as a fraction of the phosphorus concentration. If inflowing phosphorus concentrations are assumed to be similar across all ponds then these factors can be directly compared, but if phosphorus concentrations are different for each pond then factors need to be multiplied by the relevant concentration to estimate the actual change in phosphorus load achieved by harvesting from a particular pond. As detailed nutrient concentration data is not available the effectiveness of the ponds is assessed from a direct comparison of the indices. A positive value occurs if the base load is greater than the harvesting load and the larger the number the greater the reduction in nutrient load. Load reduction due to harvesting from the old ponds ranges from 0 to 1.4 with a mean of 0.3 whereas in the new ponds the range is 0 to 7.2 with a mean of 1.12 (Table 26). As noted earlier, the large load reduction achieved with some of the new ponds is due to both increased nutrient retention due to the pond construction and the reduction in flow due to harvesting. Consequently the load reduction achieved by the current and new ponds cannot be compared, but the indices show the improvement that would be achieved if the stormwater harvesting proposal was implemented.

Stream flow changes

Alterations in the ARI of flows that are expected to cause the greatest disturbance to macroinvertebrates are used to assess the impact of stormwater harvesting on the ecological condition of the urban streams. The influence of harvesting on the flows that occur with an ARI of one month and three months are shown in Table 24 along with the percentage reduction in occurrence. For existing ponds the range of reductions was between 3 and 77% with an average decrease of 30% in the one-monthly ARI flows (Table 26). In the new ponds the range of reductions for one-monthly ARI flows was 2 to 32% with a mean of 11%, substantially less than for the current ponds (Table 26). The reason for this difference is once again that the current ponds are generally much larger than the proposed new ponds. The three-monthly ARI flows are also reduced by introduction of the stormwater harvesting proposal, by an average of 16% in existing ponds and 4% in new ponds (Table 26).

Any reduction in the one and three-monthly ARI flows is likely to be beneficial to macroinvertebrates and the ecology of the urban streams, but whether these reductions are sufficient to significantly improve invertebrate community composition is difficult to gauge without establishing target flows. These could be set either by analysis of pre-regulation flows if they were available, or by consideration of hydrodynamic characteristics within the channel, but this was beyond the scope of the current project. The extent of any benefit will also be influenced by the condition of the urban stream, in particular whether it remains in a natural state or has been converted to a concrete channel. In this analysis the flow reductions are considered equally beneficial to all channel types as there was no consistent assessment of channel condition available.

Table 24: The one month and three month ARI flows (ML/d) that impact on macroinvertebrate communities, and their percent reduction due to stormwater harvesting

	1-in-1 month				**1-in-3 month**	
	Base	**Harvesting**	**% reduction**	**Base**	**Harvesting**	**% reduction**
David St Wetland	4.5	4.3	3	9.8	9.6	2
Dunlop Pond 1 (Jarramlee)	1.5	1	37	3.4	2.7	20
Dunlop Pond 2 (Fassifern)	0.7	0.2	73	1.6	1	40
Lake Ginninderra	131.8	95.2	28	320	283	12
Gungahlin Pond	65.9	51.7	22	158	137.8	13
Isabella Pond	67.1	51.3	24	147.3	117.3	20
Lake Tuggeranong	98.7	72.5	27	235.9	185.6	21
Lower Stranger Pond	12.1	11.1	8	27.9	26.8	4
Nichols Pond	1.9	1	48	5.5	4.4	19
Point Hut Pond	19.7	17.3	13	49.7	47.3	5
Tuggeranong Weir	69	52.7	24	154	123.2	20
Upper Stranger Pond	9.9	9.1	9	22.2	21.3	4
West Belconnen Pond	1.4	0.3	77	6	4.7	22
Yerrabi Pond	20.5	14	32	55.9	47.5	15
B14	17.2	17.2	0	37.2	37.2	0
B28	6.7	6.5	3	14.5	14.4	1
T2	7.7	6.7	13	16.6	16.1	3
T3	19.2	17.7	7	41.5	40.5	2
T4	27.6	23.7	14	59.7	54.6	9
W19	15.3	13.5	12	33	32.1	3
W27	10.8	9.4	13	23.4	22.7	3
WC15	6.2	6.1	2	13.5	13.5	0
WC19	2.9	2.7	9	6.3	6.2	2
WC4	24.4	23.9	2	52.7	52.9	0
G23	18.7	17.8	5	40.4	39.7	2
NC14	8.8	6	32	19.1	16.9	12
NC18	33.3	24.9	25	72	60.8	16
NC911	11.7	11	6	29.7	29.2	2
W0	59.7	46.1	23	129.1	112	13
W2	54.4	50.6	7	117.8	116.2	1
WC0	33.8	30.2	11	73.1	70.8	3

Dry spells in streams also influence macroinvertebrate populations and the index derived to assess this is the number of months during summer when macroinvertebrates are unaffected by dry spells (Table 24). Results for existing ponds are shown with and without harvesting along with the resulting percentage reduction in duration due to harvesting. For proposed ponds the duration is shown only with harvesting. The periods when macroinvertebrate populations are unaffected by dry spells with an average return interval of one year all exceed three months duration (Table 26), even with harvesting, although for existing ponds there is generally a small decrease in the index (**Error! Not a valid bookmark self-reference.**). Dunlop 2 and West Belconnen show an opposite response with harvesting causing substantial increases in the index. The periods for which macroinvertebrates are unaffected by dry spells with a two-year ARI are significantly less than with the one-year ARI for the current ponds (Table 26) and many are substantially reduced by harvesting (**Error! Not a valid bookmark self-reference.**). Overall 16 of the ponds have the index for dry spells with a two-year ARI reduced to less than three months by harvesting leaving more than half the summer affected by dry spells. The data in Table 98 (0) contains information on the length of the dry spells and in the worse case under harvesting the two-year dry spell ARI reaches 152 days, virtually the whole summer.

Table 25: Length of summer period (months) during which macroinvertebrate populations are uninfluenced by dry spells and the percent change due to stormwater harvesting

	1-in-1 year				**1-in-2 years**	
	Base	**Harvesting**	**% change**	**Base**	**Harvesting**	**% change**
David St	4.18	3.98	-5	3.89	3.60	-8
Dunlop Pond 1 (Jarramlee)	3.98	3.57	-10	3.60	1.58	-56
Dunlop Pond 2 (Fassifern)	3.73	4.27	15	2.84	-0.07	-102
Lake Ginninderra	3.70	3.53	-5	2.81	1.69	-40
Gungahlin Pond	3.96	3.48	-12	3.57	2.54	-29
Isabella Pond	4.17	4.12	-1	3.86	3.69	-4
Lake Tuggeranong	3.84	3.33	-13	3.12	2.22	-29
Lower Stranger Pond	3.88	3.73	-4	3.25	2.89	-11
Nichols Pond	3.59	3.43	-4	2.70	1.23	-54
Point Hut Pond	3.72	3.57	-4	2.84	2.52	-11
Tuggeranong Weir	4.04	3.92	-3	3.64	3.38	-7
Upper Stranger Pond	4.01	3.77	-6	3.60	2.92	-19
West Belconnen Pond	3.57	4.29	20	0.80	1.15	44
Yerrabi Pond	3.59	3.53	-2	2.72	1.65	-39
B14		4.43			4.27	
B28		4.04			3.65	
T2		3.73			2.88	
T3		3.92			3.55	
T4		4.02			3.64	
W19		3.76			2.92	
W27		3.73			2.87	
WC15		4.11			3.68	
WC19		3.89			3.28	
WC4		4.17			3.82	
G23		4.03			3.71	
NC14		3.57			2.45	
NC18		3.84			3.08	
NC911		3.84			3.15	
W0		3.62			2.77	
W2		4.32			4.02	
WC0		3.83			3.01	

Cumulative downstream impacts were assessed on the Murrumbidgee and Molonglo Rivers. Using the same indices applied to the urban streams (i.e. changes in the one-month and three-month ARI flows and the duration of zero flow periods). In the Murrumbidgee River there was no change in flow conditions resulting from the stormwater harvesting (Figure 34).

In the Molonglo River, there was no significant change in the distribution of peak flows, but harvesting did introduce a small change in the occurrence of zero flows with an ARI of one year. These changed from duration of around eight days to 13 days. This change is not considered to be significant.

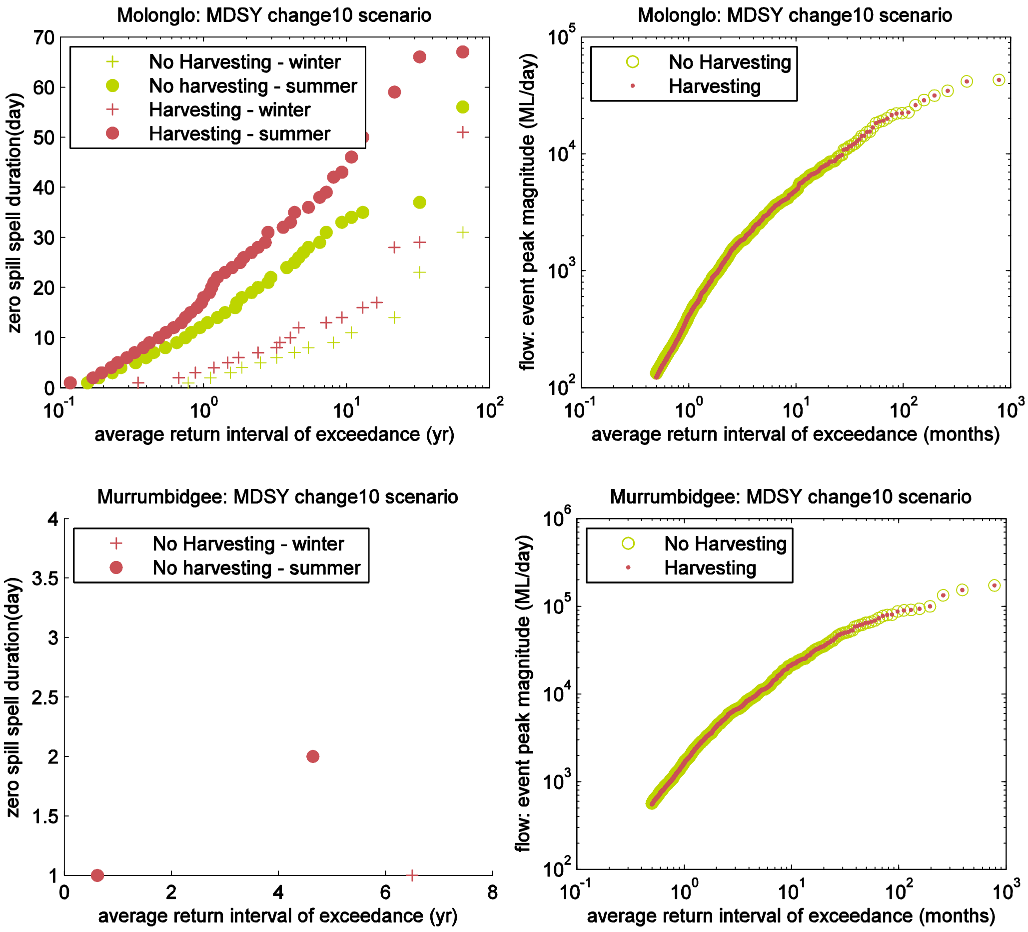


Figure 34: Impact of harvesting on zero flow spells and flow peaks in the Molonglo and Murrumbidgee Rivers

8.5 Discussion

This chapter describes the potential ecological and environmental effects of introducing a stormwater harvesting scheme that involves installing new ponds on a number of urban streams and abstracting water from both these new ponds and an intermingled number of existing ponds (Figure 14). Hydrological and ecological measurements were selected from a wide range of possibilities based on the data that were available and the environmental characteristics for which it was felt robust analyses could be devised. Predicting the environmental effects of changing hydrological conditions in urban streams is not a simple task and so the analyses used in this study may provoke considerable discussion. However, it is hoped they are sufficiently reliable to provide a broad-scale view of the potential changes stormwater harvesting may cause, even though they ignore many of the subtleties and use a very restricted set of indicator organisms.

In essence, the hydrological characterisation has involved frequency analyses of time series to describe pond draw down patterns, frequency of shore line dry spell durations and pond turnover times. Flow data has also been analysed to describe the frequency distributions of zero flow periods and peak flow events in the associated urban streams. These hydrological characteristics, although informative in their own right, were further interpreted with respect to proposed effects on particular biota. In these analyses shoreline dry spells are associated with macrophyte diversity, pond turnover with the likelihood of phytoplankton blooms and peak flows and dry spells in urban streams with the conditions supportive of enhanced occurrences of macroinvertebrates. The pond turnover patterns were also associated with their nutrient retention efficiency and the consequent load reduction to downstream systems.

The results of the hydrological and ecological analyses are summarised in Table 26. All of the ecological indices use an increase in magnitude to designate an improvement in conditions, but the scales are quite different in terms of both range and magnitude. This makes it difficult to compare responses between indices and to combine indices to determine an overall score or response for a pond and its adjacent stream reaches. To address this problem the scores have been used in a deliberative multi-criteria evaluation to develop a synthesised view of the function of each pond.

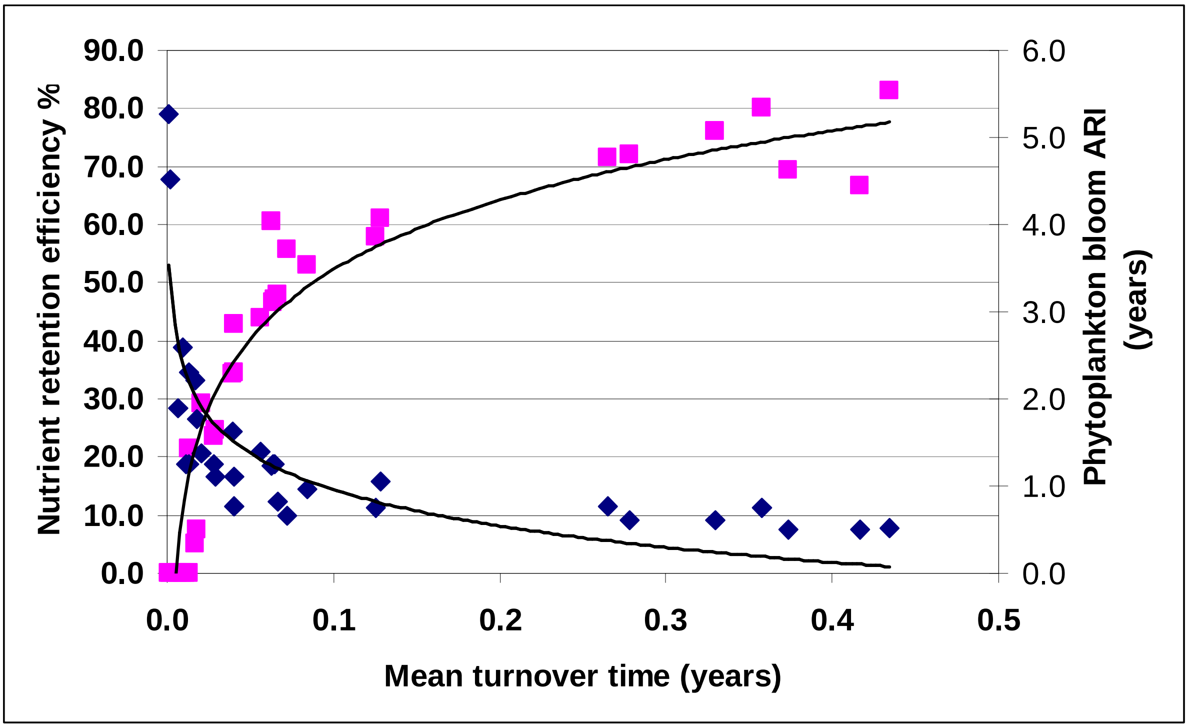


Figure 35: Change in nutrient retention efficiency and the index of phytoplankton bloom ARI as a function of the mean turnover time of ponds

The difficulty of synthesising a single measure from the ecological indices is demonstrated by the data shown in Figure 35. Both the nutrient retention efficiency and the index of phytoplankton bloom ARIs are functions of pond turnover time, as expected from the description of the formulation of these measurements. However, the phytoplankton index improves as mean turnover time increases whereas the nutrient retention efficiency declines. The significance for a pond of the final balance between these two will be site specific, and any judgement is likely to be influenced by social and economic considerations as much as ecological benefits, especially in urban systems. Some other indices are complex functions of water level changes resulting from the balance of inflows, harvesting and outflows and they cannot be expressed as simple graphs. In these cases too, statistical maximisation procedures provide a way to assess the overall ecological benefits that might be accrued.

It is generally expected that the incorporation of wetland water quality control ponds in urban systems will improve their ecological condition, helping to reduce the effects of poor water quality and enhanced flows that result from urban run-off. The individual analyses describe general patterns that inform on the usefulness of the proposed stormwater harvesting scheme from an ecological and water quality context. Of course other issues will also influence decisions on the benefits of constructing wetland ponds including maintenance costs and the acceptance of ponds by local communities. These issues are discussed in other sections of the report.

Most lakes and ponds in the system will experience frequent and large-scale water level fluctuations, to drawdown depths exceeding 1 m. In some there will be prolonged periods of time, particularly in dry summers, of large areas of exposed shore. The impact of this harvesting on pond ecology will be on the emergent vegetation, which in turn determines the nature of the habitat for other species. The conditions resulting from harvesting can favour a greater diversity of emergent aquatic vegetation, and so improve pond ecosystem health, but this will rely on appropriate plant species being present at the pond edge. There will be a need to ensure pond edges are populated with appropriate plant species for these conditions if vegetation is to be maintained.

On average, the macrophyte diversity scores were not very different between the current and new ponds despite large differences in their volumes, hydraulic loadings and volumetric turnover, and on average a moderate level of diversity was supported across both groups of ponds (Table 26). However, as pointed out earlier, the poor ability of some ponds to support macrophytes had different causes for the current and new ponds. Current ponds with a low ability to support macrophytes also have a low drawdown activity (Table 26) and it is the relatively constant water level that constrains the development of macrophyte diversity. In comparison, the new ponds with low macrophyte scores show large drawdown activity as do most other ponds in the scheme, including those with high macrophyte scores. The different responses in the high drawdown ponds are due to the pattern and duration of drawdown periods. This was explored using drawdown spell analyses and is reflected in the 20 cm and 50 cm combined vegetation scores in Table 26**.** These both show low values when the diversity score is low despite drawdown fluctuations beyond 0.5 m for a considerable part of the summer. These different patterns in water level will need to be considered when establishing macrophytes.

Large differences in hydraulic loading, or the closely related volumetric turnover, between current and new ponds accounts for the differences in the phytoplankton bloom ARI and nutrient retention efficiency, both of which tend to be lower in new ponds (Table 26). The new ponds are relatively small with a high turnover rate, both filling and flushing rapidly. Such a design contributes to a high volumetric reliability and a low risk of algal blooms. The variability in their water levels is high, and these ponds can experience extremes in water level with a much higher frequency than the large ponds. Their high flushing rates entail a fairly low nutrient retention capacity; however they offer a marked improvement in nutrient load reduction through the combined effect of direct abstraction of water (and so nutrients) and an increased retention efficiency relative to no pond.

Their small size renders the new ponds invisible to large flows, and the modelling suggests little if any attenuation, of the highest flows. Rather than curbing these extreme flows, the harvesting scheme has its greatest impact on low flows in summer. Reduced summer low-flow rates and an increase in the duration of zero-flow days in summer are expected impacts of the stormwater harvesting scheme. This is reflected in the macroinvertebrate indices (Table 26) that rely on changes in the one- and three-month ARI peak flows and the period of summer not influenced by zero flows. In the case of peak flows the harvesting causes a significant reduction in both flow peaks and this is expected to benefit the urban streams. Conversely, harvesting reduces the period of summer that is not affected by zero flows, especially for those with an ARI of two years, and this is likely to have a detrimental effect on the macroinvertebrate community. Further analyses of these findings, through comparison with natural flow regime patterns or by consideration of channel hydrodynamics would help interpret the stream conditions.

Interconnections in the system are very important. While individual lake and pond analyses have been presented, it is important to recognise that the results hold only for this particular combination of ponds. The performance of any single pond can be greatly affected by upstream ponds. A dynamic hydrological model connected to the ecological analyses would provide a useful tool for managers to explore the effects of having different combinations of ponds.

It is apparent that there are tradeoffs between the design requirements for volumetric reliability, flood control, nutrient retention or provision of ecological habitat, and it is recommended that these tradeoffs be recognised explicitly in any subsequent, more detailed decision and pond design process. The results provided in this report provide some initial indicators based on modelling which can inform more detailed planning.

Table 26: Summary of pond characteristics including hydrological attributes and ecological effect indices

	Volume (ML)	Surface area (ha)	Mean annual inflow (ML)	Hydraulic loading (m/yr)	Mean turnover rate inflow/vol (y-1)	Mean turnover time vol/inflow (yr)	Harvesting % of summer that drawdown exceeds 0.5m	20-cm harvesting combined veg score	50-cm harvesting combined veg score	Macrophyte diversity score	Phytoplankton critical turnover ARI(years)	Nutrient retention efficiency (%)	Load reduction indicator	Macroinvert indicator % reduction in 1 month ARI flows	Macroinvert indicator % reduction in 3 month ARI flows	Macroinvert indicator Months uninfluenced by 1 year ARI dry spell with harvesting	Macroinvert indicator Months uninfluenced by 2 year ARI dry spell with harvesting
David St	3.025	0.3	229.7	76	76	0.01	15.8	5	1	3	1.2	21.5	0.0	3	2	4.0	3.6
Dunlop Pond 1	13.97	0.7	108.5	16	8	0.13	21.0	6	6	6	1.1	60.9	0.0	37	20	3.6	1.6
Dunlop Pond 2	13.91	0.7	52.4	8	4	0.27	13.4	6	1	3.5	0.8	71.6	0.0	73	40	4.3	-0.1
Ginninderra	3555.2	105.6	9527.4	9	3	0.37	20.1	6	6	6	0.5	69.3	1.4	28	12	3.5	1.7
Gungahlin	554.17	23.8	4409.4	19	8	0.13	19.8	6	5	5.5	0.7	57.8	0.8	22	13	3.5	2.5
Isabella Pond	72.001	5.8	3445.4	60	48	0.02	0.5	1	1	1	1.4	29.3	0.3	24	20	4.1	3.7
Lake Tuggeranong	2551.5	56.7	6128.5	11	2	0.42	17.0	6	5	5.5	0.5	66.7	0.7	27	21	3.3	2.2
Lower Stranger Pond	61.56	4.1	851.3	21	14	0.07	1.0	3	1	2	0.7	55.7	0.1	8	4	3.7	2.9
Nichols Pond	48.001	4.0	134.2	3	3	0.36	25.5	3	6	4.5	0.7	80.1	0.0	48	19	3.4	1.2
Point Hut Pond	336	16.8	1207.7	7	4	0.28	8.9	6	1	3.5	0.6	72.2	0.1	13	5	3.6	2.5
Tuggeranong Weir	144	9.6	3558.4	37	25	0.04	0.7	1	1	1	0.8	42.7	0.3	24	20	3.9	3.4
Upper Stranger Pond	45.1	4.5	717.5	16	16	0.06	5.9	5	1	3	1.2	60.5	0.1	9	4	3.8	2.9
West Belconnen	100	10.0	230.1	2	2	0.43	23.3	3	6	4.5	0.5	83.1	0.0	77	22	4.3	1.2
Yerrabi	444.17	26.7	1346.9	5	3	0.33	18.6	5	3	4	0.6	76.2	0.2	32	15	3.5	1.7
B14	1.728	0.1	1235.7	1430	715	1.40E-03	14.1	1	1	1	5.3	0.0	0.0	0	0	4.4	4.3
B28	8.22	0.4	480.6	117	58	1.71E-02	17.8	5	3	4	2.2	5.1	0.2	3	1	4.0	3.7
T2	35.66	1.8	550.1	31	15	6.48E-02	20.2	6	5	5.5	1.2	47.2	0.8	13	3	3.7	2.9
T3	28	1.4	971.2	69	35	2.88E-02	18.8	5	1	3	1.1	24.6	0.8	7	2	3.9	3.6
T4	9.26	0.5	1350.4	292	146	6.86E-03	18.0	3	1	2	1.9	0.0	0.2	14	9	4.0	3.6
W19	61.68	3.1	1095.2	36	18	5.63E-02	20.0	6	5	5.5	1.4	43.8	1.6	12	3	3.8	2.9
W27	49.24	2.5	775.2	31	16	6.35E-02	20.2	6	5	5.5	1.3	46.7	1.2	13	3	3.7	2.9
WC15	6.024	0.3	448.0	149	74	1.34E-02	17.3	5	1	3	2.3	0.0	0.1	2	0	4.1	3.7
WC19	8.24	0.4	209.0	51	25	3.94E-02	19.0	6	3	4.5	1.6	34.3	0.2	9	2	3.9	3.3
WC4	16.41	0.8	1741.5	212	106	9.42E-03	16.7	3	1	2	2.6	0.0	0.2	2	0	4.2	3.8
G23	10.54	0.5	946.1	180	90	1.11E-02	19.1	1	1	1	1.2	0.0	0.2	5	2	4.0	3.7
NC14	37.9	1.9	447.8	24	12	8.46E-02	20.9	6	5	5.5	1.0	53.0	0.8	32	12	3.6	2.5
NC18	67	3.4	1681.3	50	25	3.99E-02	19.1	6	5	5.5	1.1	34.6	2.1	25	16	3.8	3.1
NC911	13.58	0.7	746.7	110	55	1.82E-02	19.9	6	5	5.5	1.8	7.6	0.3	6	2	3.8	3.2
W0	240	12.0	3595.7	30	15	6.67E-02	21.3	6	6	6	0.8	47.9	7.2	23	13	3.6	2.8
W2	6.892	0.3	3672.0	1066	533	1.88E-03	16.7	1	1	1	4.5	0.0	0.9	7	1	4.3	4.0
WC0	65.7	3.3	2351.3	72	36	2.79E-02	22.5	6	5	5.5	1.2	23.5	2.3	11	3	3.8	3.0
Average current	567.3	19.2	2282.0	20.6	15.3	0.21	13.7	4.4	3.1	3.8	0.8	60.5	0.3	30.4	15.5	3.8	2.2
Average new	39.2	2.0	1311.6	232.2	116.1	0.03	18.9	4.6	3.2	3.9	1.9	21.7	1.1	10.8	4.2	3.9	3.3
Median current	86.0	7.7	1029.5	13.2	5.8	0.20	16.4	5.0	2.0	3.8	0.7	63.8	0.1	25.5	17.0	3.7	2.4
Median new	16.4	0.8	971.2	71.6	35.8	0.03	19.1	6.0	3.0	4.5	1.4	23.5	0.8	9.0	2.0	3.9	3.3

9 SOCIAL ASSESSMENT OF STORMWATER HARVESTING

The aim of the social analysis component of the study was to provide criteria for evaluating social implications of stormwater harvesting. It also generates the context for interpreting the criteria and their importance for the community. In this chapter, we provide an overview of the rationale of the social analysis, the methods applied and preliminary insights.

9.1 A Social Perspective on Water Management

Provision of water to a community depends on certain institutional arrangements, infrastructure in place and bulk resource flows. We shall call such an arrangement a socio-technological regime. A transition in such a regime is usually difficult, because it represents a stable arrangement and depends on large investment and long investment cycles.

Systems such as the water supply system in a city tend to be complex and therefore the number of possible perspectives on them is large and it is harder to prove any of them to be wrong in simple terms. To make sense of different viewpoints we employ the notion of discourse in our analysis. A discourse enables those who subscribe to it to interpret information and put information together into coherent storylines. Each discourse rests on assumptions, judgements and contentions that provide the basic terms for analysis, debates, agreements and disagreements. Discourses are also bound to power. It is a sign of power if actors can get the discourse they subscribe to accepted by others (Dryzek 1997; Foucault 1980).

From an engineering point of view, water is a resource to be managed effectively in accordance with rational management principles. From a sociological perspective, there are many other issues to consider. For a range of reasons, issues such as access to water and water quality have direct effects on other aspects of social systems, such as property prices (Leggett and Bockstael 2000). We know from a wide range of social and geographic research that water and water courses have different instrumental and cultural values (Gibbs 2006; Jackson et al. 2008). Other recognised social dimensions are amenity and equity (Espeland 1998; Howard 2008). For these reasons, it is important to understand the shared storylines and ways of thinking when aiming at intervening into a system to bring about change. The summary on the main storylines (narratives) that occurred in the focus group meetings are very helpful to identify critical issues when implementing a new management system (see for example Measham et al. 2007 for a discussion). The findings from the focus group process were then further explored and tested through the survey component of the study. Finally, a set of social criteria were established and a social impact matrix was constructed in a community workshop. The full methods of the social assessment are explained in the following section.

9.2 Approach

The social analysis component of the urban waterways project proceeded in two phases. The first of these was a series of focus groups and the second was a web-based questionnaire. The first phase was designed to explore the range of social dimensions of water in the ACT in general and discuss the proposed options in broad terms with informed residents and representatives of regional stakeholder groups. The focus group design and subsequent analysis was based on a grounded theory approach (Strauss and Corbin 1998) and focused on qualitative analysis. In our research we employed an approach that enabled us to generate insights and formulate a theory about the phenomena we were studying, namely the social implications of changes in water management in the Canberra region. Our approach was based on the principles of social impact assessment (Vanclay 2003) and involved the engagement of representatives of the larger community including resident associations, environmental organisations, senior's groups, religious and welfare and organisations). Participants also included representatives from potential water users, including schools, clubs and recreation groups.

Representatives of the community were involved in the research in two ways. We organised four focus group meetings to discuss what community representatives think about water management in Canberra, and the changes they envisaged would occur if alternative sources of water (such as stormwater) were to be used. Focus groups were held in Weston Creek, Gungahlin, Yarralumla and O'Connor and involved 32 participants in total. We followed the general process of focus group design (i.e. a screened or qualified group of respondents was gathered to discuss a set of issues). The discussion was loosely structured, and the facilitator encouraged the free flow of ideas. The participants were asked to respond to a set of questions (see 0) (Krueger et al., 2001).

Table 27: Criteria for assessment of social impacts

Criteria	Explanation of the indicator
Impact on the community	Expected overall impact on the place and the community
Impact on households	Expected overall impact on households
Appropriateness of pond location	Degree to which the location of a pond is appropriate
Quality of overall project	Degree to which the type of pond (new, existing, ephemeral) and the type of surrounding infrastructure is appropriate
Equity of access to water	Agreement to the user structure of supplied water
Equity of access to pond	Access for communities and individuals to pond sites
Potential recreational value	Impact on recreation including playing fields, walking tracks, aesthetic appeal
Potential for community education	Educational value of pond site for schools, families and community
Indigenous cultural values	Impact on indigenous cultural values
Health impact	Impact on human health
Safety impact	Impact on human safety
Impact on future housing development	Limits or enhancements to future development areas
Impact on future land prices	Impacts on land value
Compliance with regulation/legislation	Does not compromise existing regulations and laws
Ecological habitat	Degree to which the pond provides habitat for species
Political support	Support from people and the community

Focus groups usually gather people who are more engaged and willing to contribute to change. In a way, participants represent an elite with regard to the openness for new ideas. For these reasons, we proceeded with the second stage of the methods in the form of a web-based questionnaire in order to test whether our focus group results were biased by the self selection of focus group participants and to allow the community at large to respond to the issues around the envisage changes in water provision and management. Respondents to the survey were recruited in two ways:

1. Using a snowball system people who had participated in the focus groups were invited to distribute the questionnaire to their networks.
2. This was followed up with a press release and the questionnaire was advertised in radio and print media to gain a second wave of responses.

In total, 495 respondents answered the questionnaire – an acceptable response rate for research of this kind (see full questionnaire in 0).

Based on the focus groups' discussion and the results from the questionnaire, we identified sixteen criteria for the social assessment of options identified in the master plan (Table 27).

Based on the pre-selection of options the performance evaluation for each criterion with regard to each option can be done in two ways:

- either by involving a larger community consultation to arrive at a quantitative input for the multi-criteria assessment or
- by targeting a restricted stakeholder group.

In this study, 50 community representatives from all sectors were involved to assess the technical options for stormwater harvesting, sewer mining and underground storage and recharge with regard to their social impacts. The participants were asked to use a rating scale for their assessment.

9.3 Results

9.3.1 Findings from focus group discussions

Water is everyone's responsibility

There was a strong sense that water management is a whole-of-community responsibility, from individuals to organisations, and in all areas of society from politics to research:

> *…water is everybody's responsibility… I think everybody has to really focus on ways that we can cut down water consumption, individuals, businesses, politicians, hydrologists, the lot…It has to be a cultural change (FG2)*

In the case of the private sector, ACTEW in Canberra, golf courses, construction companies and nurseries were thought to be particularly relevant in terms of responsibility for water use and management. In the case of public entities, it was widely acknowledged that ACTEW has a crucial role in water planning and strategies for addressing issues of water supply.

> *…in terms of developing a strategy for the way in which water gets used and who is allowed to use it and where they source it from, that has to be…the responsibility of the government and ACTEW (FG4)*

In addition, the ACT Government in general was thought to have a very high level of responsibility through its legislative and practical roles through infrastructure and parks management.

> *…in water management, to a large extent…it really does have to be a government thing, because at the end of the day, [it's] a lot of it is engineering…We can have a role in it…and be consultative, but the bigger picture, I believe, does have to be government (FG1)*

In addition, the Australian Government was also noted as holding some responsibility, and at the time of the focus groups was seeking greater responsibility, as demonstrated by the move to take over management of the Murray–Darling River basin, as well as its role in distributing grants for water management projects.

Separate from the various institutional responsibilities, water was very strongly perceived as the responsibility of individual citizens, as represented by one participant who saw the individual efforts of residents through his work:

> *Where I work, there's a few hundred residents and I actually see how much a lot of them have committed themselves to their own input (FG1)*

An important aspect of water being everyone's responsibility is the issue of supporting behavioural change. In part this involves working with planners, builders, and designers to support changes in behaviour, particularly given a push to build new suburbs and increase Canberra's population.

Complexity and Governance failure

Another narrative that ran across the focus groups was the complexity of the institutional arrangements for managing water in Canberra. This complexity was problematic such that water management in Canberra was characterised by failures of governance. It was noted that a whole-of-Canberra perspective was needed for water management, from stormwater collection through to water storage and supply. The worst cases of governance failure and complexity related to water management for Lake Burley Griffin:

> *… about who is responsible for this area in the ACT. From our perspective, it's very confusing, whether it's the ACT Government or whether it's the Commonwealth Government or the National Capital Authority. We're getting very confused messages from all those people (FG2)*

In other cases, there was a strong concern that a piecemeal approach and a narrow focus on financial efficiency from a single government agency might lead to a failure in the broader roles of a given project.

> *I don’t see that sort of broader vision…[beyond]… Let’s dig a hole, let’s get as much water in there… That’s my concern about the government approach to doing anything like this (FG1)*

A strong theme was a concern about the lack of clear information that is accessible to the public, in terms of what types of water supply options are available, whether from groundwater, lake water or other sources. The same criticism was made for information about stream flows and water consumption rates for different areas and types of users.

> *You should be able to get flow rates… we don’t know what the flow rate impact is, you should be able to ask for it and they should know that (FG4)*

Other participants said some information was available but it was impenetrable for the general public due to the way it is presented. Overall, complexity and lack of access to information led to an overall perception of lack of transparency on behalf of government agencies, which in turn led to a lack of trust:

> *I think there is a bit of distrust from many residents of Canberra of ACTEW’s role in supplying water and also the Government’s charging of water. We almost need an advocate, an impartial independent type person…so that people can get advice, they can get information [that is] is trusted (FG3)*

The concerns over transparency occurred throughout the focus groups but were strongest in relation to Lake Burley Griffin. Participants felt left in the dark about the different access rights of different users, and also the cost they pay for water, including, golf courses, the National Capital Authority, public parks and gardens such as the National Botanic Gardens. Furthermore, there was a perceived lack of transparency on the pricing of water for irrigation purposes, with perceptions that some users might be paying more for their water. Of particular concern was the idea that some public organisations may be paying more than private entities. One potential way to address this would be through a trading system.

The concerns along this theme relate strongly to the narrative on equity and access issues (see discussion below), as well as concerns over what should and what should not be watered under times of limited access to water, with golf courses standing out as a point of contention.

Another aspect of government failure concerned the impacts of the poorly managed policies when government agencies apply criteria that discourage some aspects of the community from showing initiative. An example from within the Commonwealth sphere of politics was presented through recent changes to the policy for community water grants. While on the one hand the policy made the grants more accessible, innovative organisations that had been given grants in the past based on early initiative were penalised because their initial grants limited the amount available to them under the revised scheme.

Finally, due to Canberra’s location, further complications relate to the sites of the water catchments, such as the catchment for Googong Reservoir being located in NSW. It was pointed out that this means the ACT Government has limited ability to influence matters such as land use and subdivision in the relevant catchment area.

Managing a common good under a market system

A key narrative was the tension that arises between managing a common good (such as water) and the need to generate revenue. It was noted that this problem was not specific to Canberra, as there were plenty of examples from around Australia of tension between the need to maintain public water infrastructure and the need to make a profit. One way of representing this idea was the idea of a tension between the gamekeeper and the poacher:

> *…there's an inherent problem between the game keeper and the poacher where ActewAGL on the one hand is seeking to sell water, and make a profit, and on the other trying to be a responsible supplier and managing each part of the water cycle (FG3)*

A more critical view was that governments abused their role in providing a common good to generate revenue beyond the cost of delivering the service. One participant likened this idea to generating revenue through poker machine taxes:

> *…it's a bit like the poker machine taxes—governments have become addicted to it and… governments in the urban areas… have treated water as an unobtrusive way of taxing… Now taxes are fine…,[but]… it means that it's in the interests of the Government…to actually keep water supply down (FG3)*

The implication here was that having an abundance of water supply will lower prices. Another view on the tension between managing a common good and the need to generate revenue was the suggestion that water authorities have been experiencing difficulties because their water consumption and conservation measures have been working 'too well'. The net result being that they are not selling enough water and this can lead to revenue problems. The actual impacts of managing a common good under a market system were not always clear, but there was suggestion that if certain management actions, such as increasing supply or being too effective at conservation, were not economically attractive, these will not proceed under a profit-focused system.

> *I think there's a huge problem there…because ACTEW is making money out of the water, and I think that we need … a water commission of the ACT, which would not be money seeking, (FG2)*

Above all, there was a strong recognition of the potential for problems to arise from this situation. As such the recommended resolution to this situation was to have a public commission, such as there is for the MurrayDarling River system that is independent of such interests.

Beyond just ponds: more than just supplying water

Across all the focus groups was a theme that water, and water harvesting activities need to be considered as part of a bigger picture, and be reflected in that broader picture, such that any particular initiative is mindful of the water management system and its social and ecological context.

> *I think it's also part of the big picture of environmental and sustainable design. This is one element of that. I think we need to be mindful of all the other relevant things… that everyone needs to be looking at not just water, but… a sustainable environment (FG1)*

At least in part, this broader thinking means revising the way we approach water in general, such that issues of reducing demand are on the table in addition to focusing on supply, along with better matching water quality to its use. As one participant pointed out:

> *I think the realisation is, it's not a case of Canberra hasn't got enough water. It's what we're using the water for… It's not acceptable to use… drinking water for flushing toilets, for operating a commercial car wash, for irrigating ovals and lawns (FG4)*

There was a sense of tremendous potential for water recycling and better water management in Canberra, but the tendency towards stormwater harvesting through ponds was seen to be of limited benefit from a water saving point of view. For example:

> *I just think there is an incredible potential, but … the ponds… that's a very narrow way of looking at it. It might sound great to have all these ponds and stormwater, but…there's problems with that, because the ponds evaporate… You can't suck too much water out of the ponds (FG2)*

Another way of looking at this was that the ponds are a welcome step in the right direction, provided they are big enough and sufficiently well designed to supply the surrounding sports fields and related areas. However they needed to be thought of as more than simply a way of capturing and supplying water. Several participants thought aesthetics and education were important. For example in considering a stormwater pond and wetland area for Weston Creek, residents emphasised the aesthetic benefits of the proposal.

> *... from an aesthetic point of view, [it would be of] …enormous value in the Weston Creek area (FG1)*

In other focus groups, participants agreed that aesthetic aspects were important and noted the need to avoid offensive smells that could be associated with stagnant water.

In addition to aesthetic dimensions, supporting education and recreation were thought of as extremely important aspects to potential water harvesting projects. For some aspects of the community these dimensions could be just as important as the water saving measures themselves. An example of an idea which would combine recreation, education and water harvesting was presented for an area in Gungahlin:

> *An opportunity to have… very natural wetlands with some closed water, some open water…some bike trails, some walking trails…it would be a great place to go for a walk at lunchtime. But also you've got the schools to be stewards of it and as well as use it to learn (FG3)*

A crucial part of this was the importance of considering an area that served as a place for people to be able to go exercise, do some bird watching or take their kids to play.

Access is more of a concern than safety

Safety was discussed across the interviews and several participants noted the need to consider it, particularly in terms of keeping unsupervised children from getting too close to the water. In the case of sewer mining there was general agreement that residents would accept it provided it is perceived to be safe including community education on the health aspects. However, compared with the issue of safety, a stronger concern was restricting access to an area suitable for recreation. In essence, safety needs to be sufficient for people to make use of recreational areas, but not so excessive that people are discouraged from active use:

> *[there has]… to be at a reasonable level for safety and for people to go out and enjoy their parks (FG3)*

There was also an aesthetic dimension to safety. Many participants found the idea of fences to be unattractive, and could be excessive in some contexts. Some participants expressed criticism of the public ‘hysteria’ that can result from extreme measures relating to protecting water safety. There was a sense that by preventing access through fences and signs, the public become ‘disconnected’ from water and its management in a way that makes them vulnerable to ignorance and fear. Participants remembered the past laws against residential water tanks, both in Canberra and elsewhere, which further emphasised this disconnect and the negative consequences that stem from it.

Above all, participants expressed their concern about exaggerating safety risks out of proportion. For example in the case of ponds, it was emphasised that projects would need to be designed carefully, but that the risks of injury would be very low and manageable.

> *It’s no greater risk than what we have all around the edge of Lake Burley-Griffin (FG1)*

Participants noted that existing ponds that had been designed appropriately in the Canberra area did not have high risks of injury due to the gradient of the shore and the use of thick reedy vegetation which serves to limit access to the water yet provides the public with the opportunity to visit the area and enjoy recreation and health benefits.

A need to re-naturalise the water system

Another narrative was that the water system which evolved naturally in the Canberra region has been highly modified through hard surfaces that change run-off and concrete drains which rapidly move water out of the environment. Several participants conveyed the notion that these changes which formed part of Canberra’s settlement have damaged or at least interrupted natural processes. This included changes in the water table, or depleting the groundwater as a result of engineering developments. For these reasons, participants were careful with calling watercourses ‘creeks’ that are essentially parts of the stormwater system:

> *Sullivans Creek… is simply an extension of the stormwater system. It’s not a natural creek. It doesn’t follow the natural creek lines that were first in existence (FG4)*

Others described a long-term trend of damaging the environment that needs to be redressed.

> *I've seen a lot of change in the rivers and everything. …to go back to our natural state is really important. All these things these people have been talking about are really fantastic. I would like to see Canberra go back to that… (FG1)*

In this context, there was a sense that the move towards storing water in ponds and wetlands is part of a process to re-naturalise the water system. An example of this theme is represented by the following:

> *Whilst this is a good start, what we're doing is occasionally interrupting this concrete canyon and what we should be doing is gradually working back from this and breaking up the concrete culvert and creating these ponds and areas all the way along (FG1)*

In this regard, a single pond or wetland needs to be designed with reference to the ecological processes that occurring downstream and upstream.

Comparing with simple stormwater ponds, participants emphasised the potential of ephemeral wetland areas that could store water in the soil, trap sediments and nutrients from moving downstream and provide an area for recreation and education through interpretive walkways. Wetland areas support biodiversity and were perceived as effective in helping to re-charge groundwater which could provide a valuable resource.

If stormwater ponds are to be developed, it would be important to develop them with surrounding wetland areas to help purify the water in the ponds and to help perform a wider suite of functions than a single pond can do, such as supporting a wide range of wildlife.

Part of the re-naturalising narrative was the notion that water management projects should look natural. Participants had a general view of what natural looked like, at least in terms of the sorts of elements that constituted an attractive natural system, such as reeds, rocks, vegetation and avoiding concrete as much as possible. For example:

> *Facilitator: To clarify that discussion there, how would you like it to look?*
> *Participant1: Green.*
> *Facilitator: What else?*
> *Participant2: Reeds are good…I think as natural as possible. As little like a constructed thing.*
> *Facilitator: You mentioned concrete before, is that what you're meaning?*
> *Participant2: I think that looks very unattractive myself, yes.*
> *Facilitator: What would make it look attractive or make it look natural?*
> *Participant2: Rock.*
> *Participant3: Reeds. A bit like on Sullivan's Creek - what's that suburb, where they've got the wetland...*
> *Participant2: O'Connor. Yes, that looks very attractive… (FG2)*

As such the pond and wetland project in O'Connor was a generally seen as a precedent in terms of appearance, even though participants noted this pond is not supplying water for irrigation as such.

In contrast – though they were not thought of as natural – several participants emphasised the importance of maintaining the health of a number of prominent exotic trees in the central part of Canberra that were perceived to have historic value due to their age and their role in the landscape design of Canberra. Under drought conditions these trees were considered highly vulnerable, yet it was perceived it would be a tragedy to see them die given their role in Canberra's heritage.

Economics of water and recycling

The economics of water and its management occurred throughout the focus groups. At a very broad level, there was a strong recognition that water is extremely valuable, even though that is not always reflected in the way it is priced. To put it differently there was a sense that what we pay for water doesn't reflect its value to us. Some participants thought that this would change over the long term, as water shortages become more acute, either through increases in demand through an expanding population or through decreases in supply associated with climate change. One participant expressed:

> *We value water a lot more than we pay [for] it, already I believe, and we'll be paying one day what we actually value it for (FG2)*

Participants also noted that the treating of recycled water can be expensive, and varies according to the original state of the water and the grade it needs to reach. It was also noted that the costs of setting up water recycling projects can be expensive and complicated, with a split between private and public investment which is not always in line with commercial viability, at least compared to current prices for potable water. Given the potential cost of energy and equipment for treating waste water, there was preference to focus on stormwater for re-use rather than sewage water where possible. Yet even with stormwater harvesting the cost–benefit issue applies as noted by some participants who had looked into the matter:

> *I think they're a wonderful idea... yet we're still facing 75 percent of potable water charges. It almost comes down to a benefit analysis. Do we use potentially contaminated water at 75 per cent of the price or do we just continue to turn the tap on and use potable water that we know is pure and clean?(FG4)*

There was a strong recognition that the economics of water re-cycling dictate the potential uses of water. Whilet nominally any water could hypothetically be treated to any standard, there was general agreement that current circumstances are suitable to treating relatively clean water for non-potable uses such as public sporting facilities or golf courses:

> *…it can be for any use, depending on how purified you make it. I mean, the first use is going to be places like Royal Canberra or sporting fields, isn't it? Economics makes it that way (FG2)*

The energy required to treat waste at sites such as Southwell Park and Duntroon was considered to be very high and not suitable for commercial application. However it was noted that recent technological advances made the treating of sewerage water more affordable, as demonstrated in other parts of Australia. The issue of economic viability for recycling sewerage water was generally a larger concern than safety issues.

In terms of economics of water management, it was noted that the ACT institutions involved in managing water tend towards large, centralised systems which rely on principles of economic rationalism such as standardisation and economies of scale. However an alternative view focused on the opportunities for decentralised management options:

> *…the alternative way of looking at it as a decentralised system… that has many more components, spread across the landscape… and the technology is now available for us to do that (FG3)*

It was argued that decentralised systems can be more locally tailored and that this makes them economically effective on a case-by-case basis.

Equity issues – who has access?

An important narrative focused on the issue of who should have access to the water in any given context, from society-wide questions such as the amount of water used in agriculture, to site-specific issues such as the stormwater harvested through new projects. A case in point was inequities in the subsidies for household water tanks: for some locations tanks are mandatory, and in some areas there are no subsidies available at all. A significant point of contention for those in central Canberra was how existing water extraction is distributed from Lake Burley Griffin. For example,

> *…as we understand it, there's a limit of 710 megalitres a year, which the ACT Government has determined can be taken out of Lake Burley Griffin for irrigation purposes, and there are a number of licence extractors …the question is how that's divided up amongst the authorised extractors (FG2)*

A point of contention was that the National Capital Authority (NCA) exercises a high degree of control over the lake, and at the time of the focus group was perceived to be denying access to other water users whilst at the same time increasing its own extraction through the installation of new infrastructure.

> *Participant: they control the lake, and they don't want other groups pumping more water out, but they're putting… more pumps in.*
>
> *Facilitator: Do you see that as an equity issue…?*
>
> *Participant: Yes, very much so. I guess in the end, it comes down to which bit you want to keep green (FG2)*

Use of water in dry times for maintaining lawns (both public and private) was another point of debate. Golf courses in particular were a point of contention for many participants. Partly this was simply because they use a lot of water to maintain their facilities which stand out as green when surrounding areas are brown. However, a crucial component to this was that the access to the irrigated fairways is limited to those who purchase membership, rather than being open to the public.

> *I think it's a great waste… to use water - potable or non-potable - on lawns and I think that the NCA… watering Commonwealth Park and the Parliamentary area to have lawns… that's a complete waste of water. I'm not that stuck on sports fields or golf*

> *courses either - especially golf courses, because …sports fields are obviously used… by much more people (FG2)*

It was generally agreed that sports fields, school playgrounds and parks that perform a role in broader public health, through supporting exercise and outdoor play were accepted as areas to be watered in the interests of supporting a healthy population. However, it was pointed out that in recently developed areas such as Gungahlin, even schools and sports fields were struggling to maintain serviceable grass due to the lack of public investment in water harvesting projects.

Another issue concerning access was not just for the water but access to the non-water benefits of projects, such as the education and recreation potential. For example, in considering a potential project in Weston Creek, the group demonstrated the importance of access to the site.

> *Facilitator: From your point of view, who should have access to such a pond?*
>
> *All Interviewees: Everybody (FG1)*

Participants emphasised that they could not discuss water and who has access to it without discussing the purposes that water is used for. This is partly a cultural issue and several participants drew attention to the ‘green lawn and lush gardens’ mentality that characterised much of Canberra’s desired landscape. In this way, the narrative on equity and access relates also to the theme of what is natural, and what should be watered in the Canberra environment.

The community is ready for change, but needs some guidance

A strong theme across the focus groups was that the community is ready for change. Some participants represented this as a groundswell of change on water, whilst others spoke of passing a cultural threshold due to extended water shortages.

> *I think we’ve crossed a threshold where for most of my life, water was seen as just another commodity which you purchased as an input…I think that’s profoundly changing… I think it’s to do with the sheer shortages that we’re now facing. People are beginning to realise that we have to think about this in different sorts of ways (FG3)*

This change was noted as being particularly applicable to Canberra due to the high degree of urban water shortages in the region. The effect of this growing awareness was widely perceived to be translated into a raft of individual efforts, from capturing water through modified behaviour to novel ways of using water in the garden.

> *I don’t know anyone who isn’t doing something new to save water. I don’t know anyone (FG2)*

Others suggested that this groundswell was strong but not universal. Moreover, a large proportion of Canberra residents are willing but need guidance.

> *…we’ve got the power, but we can only do so much…we need guidance by the authorities, help… financial[ly] or other ways. I think everybody… really wants to do it…we can do it but we can’t do it alone (FG3)*

At the very least the focus groups demonstrated that there is capacity in the community that can serve as a lever for change amongst those who are less capable. Given the varying levels of knowledge and acceptance that are present amongst the Canberra population, an important task lies in how to foster the sorts of changes that may be required to bring about improvements in water management. Participants cited the high level of uptake of using greywater for watering gardens, however as noted by one participant, residents may require more education on the nutrients and chemicals in grey water which may be detrimental to plants.

Final comments

In considering the rising tide of change in terms of approaches to water management, there was some concern throughout the focus groups that if all that occurs from an integrated water management project is a handful of stormwater ponds then this may have been a missed opportunity rather than a catalyst for fostering major changes in water management in Canberra. A strong message was that: Stormwater ponds alone are not enough, we need to consider how one pond fits into a bigger system.

In addition, the focus groups suggested a spatial trend to the responses which would be important to look at in further detail through survey responses. For example, in more established areas, it was noted that education and recreation were the main focus yet for Gungahlin the need for water is greater.

9.3.2 Results from the questionnaire

Comparing demographic data for Canberra as a whole, with stated characteristics of waterways survey respondents

A first step in the analysis of the questionnaire is to control the respondents for biases based on certain socioeconomic characteristics, such as gender, income or education. Demographic data for survey participants are given in Table 28 to Table 34.

These tables use interim survey data, as at 11 am 5 February 2008 before the press release; and final survey data, as at 18 February 2008.

Table 28: Gender breakdown

	Canberra census 2006 (%)	**Interim survey respondents (%)**	**Final survey respondents (%)**
Male	49.3	48.8	49.3
Female	50.7	51.2	50.7

Table 29: Age groups

	Canberra census 2006 (%)	Interim survey respondents (%)	Final survey respondents (%)
15–24 years	19.5	3.5	3.9
25–34 years	19.2	20.8	20.3
35–44 years	18.7	23.8	24.0
45–54 years	17.6	23.0	22.8
55–64 years	13.0	22.5	22.1
65 and over	12.1	6.5	6.8

Table 30: Number of adults in household

	Canberra census 2006	Interim survey respondents	Final survey respondents
Average number of people (mean)	2.6	2.3	2.3

Note: Did not include outliers that were probably typographical errors

Table 31: Number of children in the household

	Canberra census 2006	Interim survey respondents	Final survey respondents
Average number of children (mean – per household with children)	1.8	1.8	1.9

Note: Did not include outliers that were probably typographical errors

Table 32: Dwelling type

	Canberra census 2006 (%)	Interim survey respondents (%)	Final survey respondents (%)
Unit/apartment	6.4	6.2	6.7
Townhouse/duplex	10.3	11.0	10.7
Detached house	83.1	82.3	82.1
Retirement village	(not a census question)	0.5	0.2
Caravan/temporary dwelling	0.1	0.0	0.2

Table 33: Highest education level

	Canberra census 2006 (%)	Interim survey respondents (%)	Final survey respondents (%)
Primary school	4.5	0.2	0.2
Secondary school	36.8	6.2	6.1
TAFE/trade	15.0	5.0	5.2
Diploma	9.6	6.2	6.6
Tertiary degree	22.4	34.6	34.3
Postgraduate	11.7	47.8	47.5

Table 34: Annual gross income

	Interim survey respondents (%)	Final survey respondents (%)
Under $25K	5.4	6.1
$25K – $50K	14.1	14.7
$50K – $75K	37.0	36.2
$75K – $100K	27.0	26.7
Over $100K	16.5	16.3

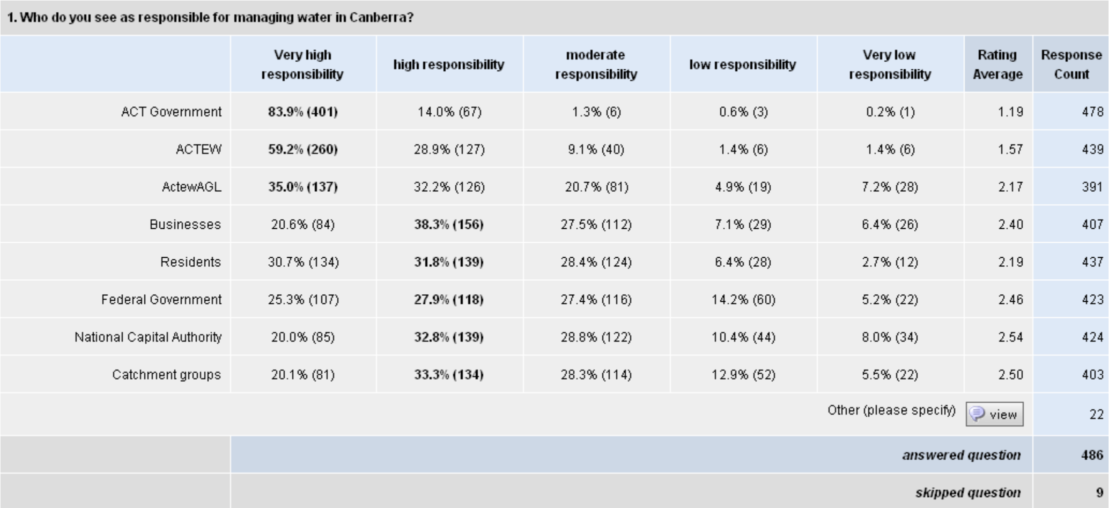
Note: Our question was in blocks of $25 K/yr but this is not how census data were collected so they are not directly comparable. 2006 census data as follows:

Median individual income	$723/week	($37 596 /yr)
Median family income	$1773/week	($92 201 /yr)
Median household income	$1509/week	($78,463 /yr)

The preliminary results in the following sections show the average for the total sample. In a next step we will disaggregate the sample into subsamples using education, income and gender as splitting variables, to identify the influence of those variables on the responses.

Analysis of questionnaire results

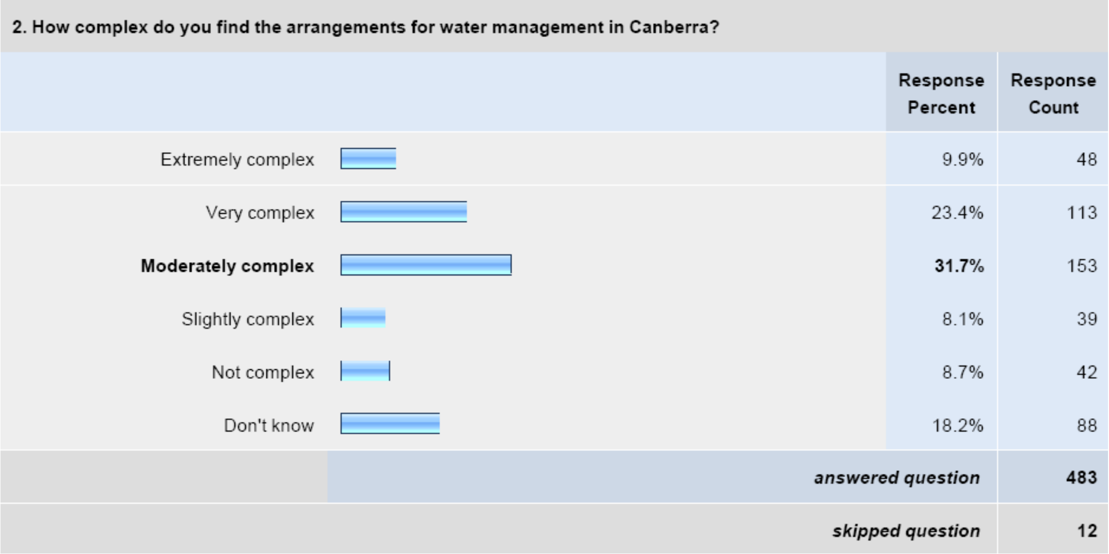
With regard to the responsibility for water management and also the ability to bring change about, respondents assign a very high responsibility to the ACT Government. We see this as an encouraging result, suggesting that people generally acknowledge that the Government is in charge and has a high ability to restructure the existing management system. At the same time, the respondents see a high responsibility for the whole community to contribute to good outcomes for water management in Canberra. When cross-tabulations were run to see whether certain demographic groups felt more strongly than others, for Question 1, we discovered that female survey respondents were significantly more likely than male respondents, to say that businesses, residents, the Australian Government, the National Capital Authority, and catchment groups had a high level of responsibility for managing water in Canberra.



1. Who do you see as responsible for managing water in Canberra?

	Very high responsibility	high responsibility	moderate responsibility	low responsibility	Very low responsibility	Rating Average	Response Count
ACT Government	**83.9% (401)**	14.0% (67)	1.3% (6)	0.6% (3)	0.2% (1)	1.19	478
ACTEW	**59.2% (260)**	28.9% (127)	9.1% (40)	1.4% (6)	1.4% (6)	1.57	439
ActewAGL	**35.0% (137)**	32.2% (126)	20.7% (81)	4.9% (19)	7.2% (28)	2.17	391
Businesses	20.6% (84)	**38.3% (156)**	27.5% (112)	7.1% (29)	6.4% (26)	2.40	407
Residents	30.7% (134)	**31.8% (139)**	28.4% (124)	6.4% (28)	2.7% (12)	2.19	437
Federal Government	25.3% (107)	**27.9% (118)**	27.4% (116)	14.2% (60)	5.2% (22)	2.46	423
National Capital Authority	20.0% (85)	**32.8% (139)**	28.8% (122)	10.4% (44)	8.0% (34)	2.54	424
Catchment groups	20.1% (81)	**33.3% (134)**	28.3% (114)	12.9% (52)	5.5% (22)	2.50	403
					Other (please specify)	view	22
						answered question	**486**
						skipped question	**9**

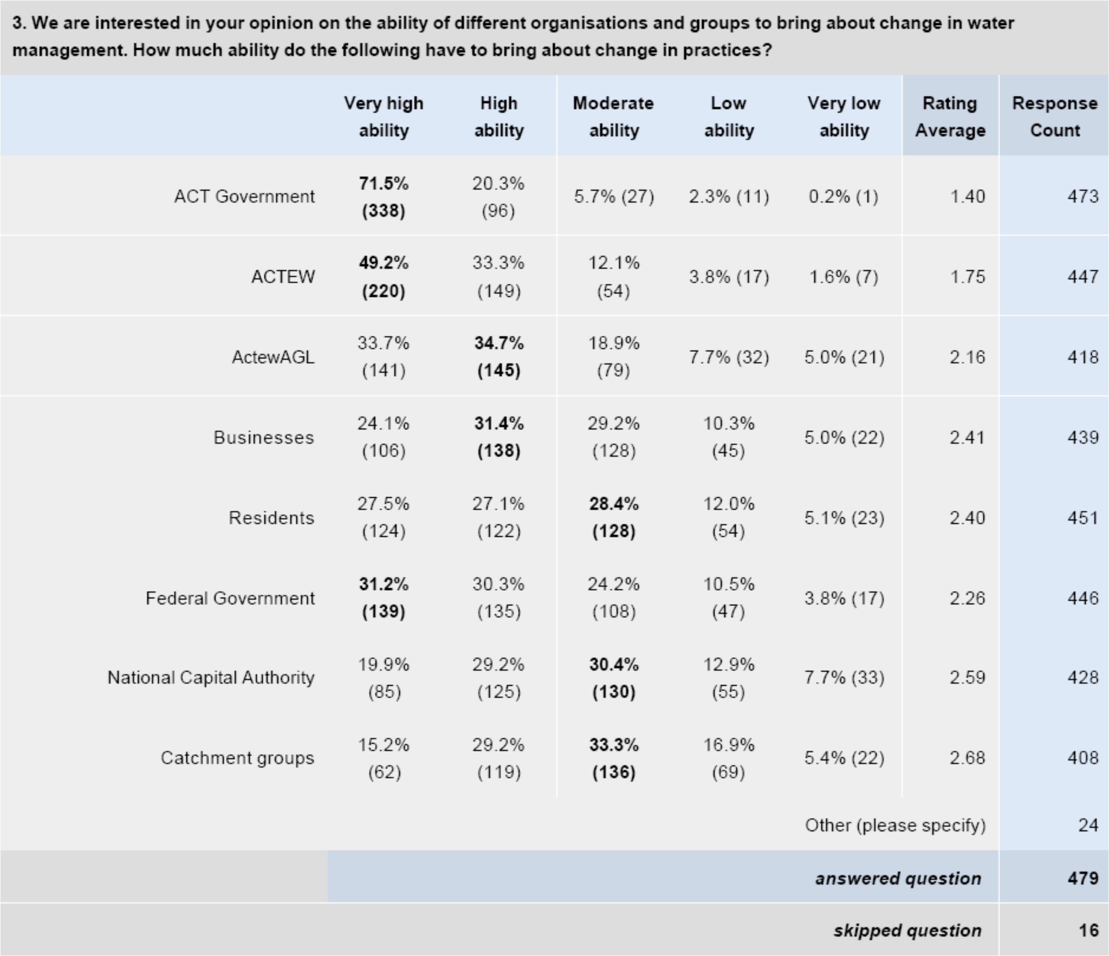
While the focus groups have identified the arrangements for water management in Canberra as highly complex, the survey respondents did not completely share this view. A majority saw the arrangements as only moderately complex. More women than men rated the arrangements as 'very complex' or 'extremely complex'.



2. How complex do you find the arrangements for water management in Canberra?

	Response Percent	Response Count
Extremely complex	9.9%	48
Very complex	23.4%	113
Moderately complex	**31.7%**	153
Slightly complex	8.1%	39
Not complex	8.7%	42
Don't know	18.2%	88
	answered question	**483**
	skipped question	**12**

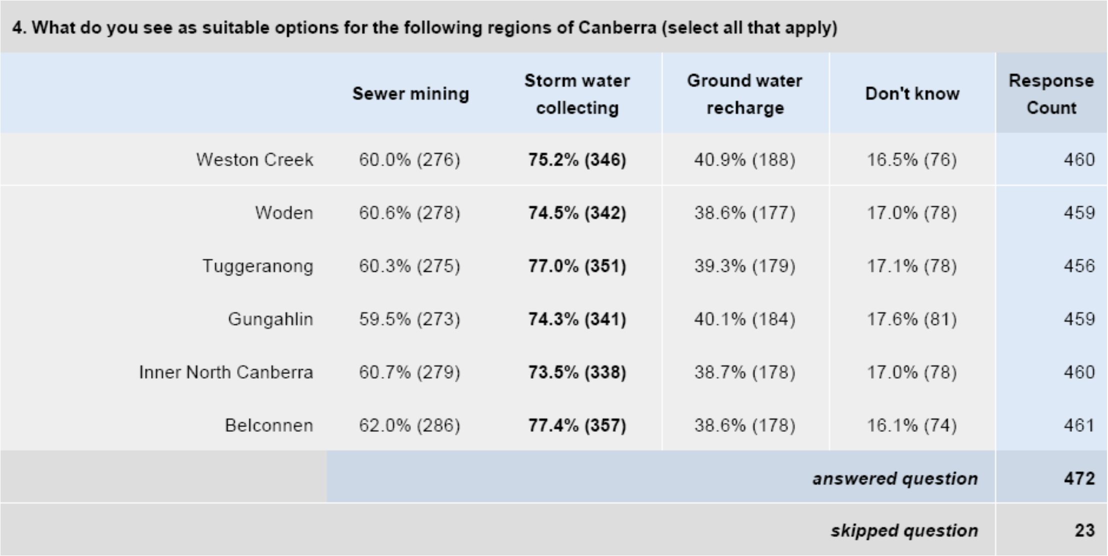
In Question 3, most respondents said that they felt the ACT Government had a 'very high ability' to bring about change in water management. Cross-tabulations indicated that women felt more strongly about the ability of the ACT Government, ActewAGL, businesses, the Australian Government, the NCA and catchment groups to bring about change, than men did.



3. We are interested in your opinion on the ability of different organisations and groups to bring about change in water management. How much ability do the following have to bring about change in practices?

	Very high ability	High ability	Moderate ability	Low ability	Very low ability	Rating Average	Response Count
ACT Government	**71.5% (338)**	20.3% (96)	5.7% (27)	2.3% (11)	0.2% (1)	1.40	473
ACTEW	**49.2% (220)**	33.3% (149)	12.1% (54)	3.8% (17)	1.6% (7)	1.75	447
ActewAGL	33.7% (141)	**34.7% (145)**	18.9% (79)	7.7% (32)	5.0% (21)	2.16	418
Businesses	24.1% (106)	**31.4% (138)**	29.2% (128)	10.3% (45)	5.0% (22)	2.41	439
Residents	27.5% (124)	27.1% (122)	**28.4% (128)**	12.0% (54)	5.1% (23)	2.40	451
Federal Government	**31.2% (139)**	30.3% (135)	24.2% (108)	10.5% (47)	3.8% (17)	2.26	446
National Capital Authority	19.9% (85)	29.2% (125)	**30.4% (130)**	12.9% (55)	7.7% (33)	2.59	428
Catchment groups	15.2% (62)	29.2% (119)	**33.3% (136)**	16.9% (69)	5.4% (22)	2.68	408
						Other (please specify)	24
						answered question	**479**
						skipped question	**16**

In the next part of the online survey, respondents were asked about whether they felt particular water saving options were appropriate for different regions of Canberra and for their own suburb. Stormwater harvesting was the most popular option in both cases, followed by sewer mining, while groundwater recharge was relatively unpopular. Cross-tabulations indicated that, for Questions 4 and 5, there were no significant differences in people’s responses, based on their gender, income levels or education levels.



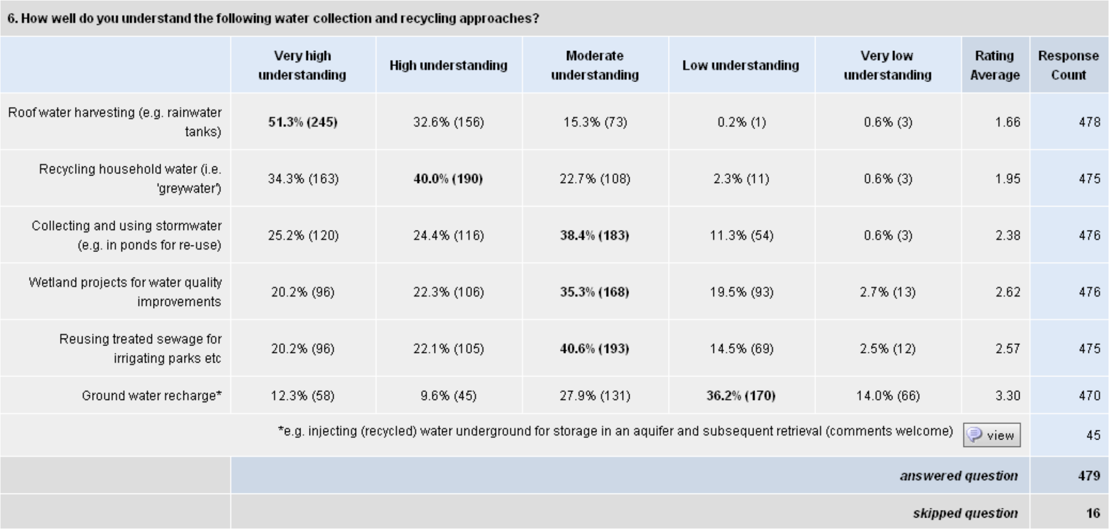
4. What do you see as suitable options for the following regions of Canberra (select all that apply)

	Sewer mining	Storm water collecting	Ground water recharge	Don't know	Response Count
Weston Creek	60.0% (276)	**75.2% (346)**	40.9% (188)	16.5% (76)	460
Woden	60.6% (278)	**74.5% (342)**	38.6% (177)	17.0% (78)	459
Tuggeranong	60.3% (275)	**77.0% (351)**	39.3% (179)	17.1% (78)	456
Gungahlin	59.5% (273)	**74.3% (341)**	40.1% (184)	17.6% (81)	459
Inner North Canberra	60.7% (279)	**73.5% (338)**	38.7% (178)	17.0% (78)	460
Belconnen	62.0% (286)	**77.4% (357)**	38.6% (178)	16.1% (74)	461
				answered question	**472**
				skipped question	**23**

5. What do you see as suitable options for your suburb? (select all that apply)

	Response Percent	Response Count
Don't know	11.2%	52
Sewer mining	59.8%	278
Storm water havesting	**83.7%**	389
Ground water recharge	38.1%	177
	Other (please specify)	60
	answered question	**465**
	skipped question	**30**

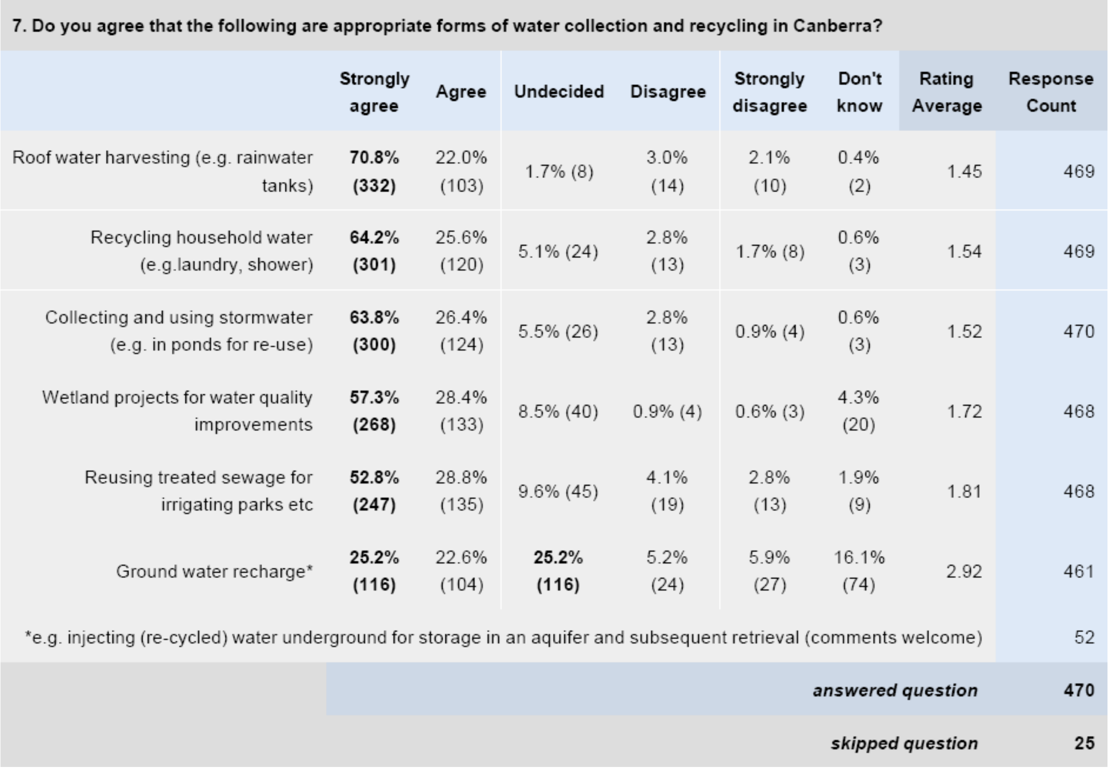
Asked whether they understood particular approaches to water collection and recycling, the survey participants professed a greater level of knowledge about household-based methods, such as the use of rainwater tanks and greywater, than about approaches requiring more complex infrastructure. There was, however, a significant gender difference in responses to this question, with male respondents reporting a greater level of understanding of stormwater pond use, wetlands projects, sewer mining and groundwater recharge methods, than female respondents.



6. How well do you understand the following water collection and recycling approaches?

	Very high understanding	High understanding	Moderate understanding	Low understanding	Very low understanding	Rating Average	Response Count
Roof water harvesting (e.g. rainwater tanks)	**51.3% (245)**	32.6% (156)	15.3% (73)	0.2% (1)	0.6% (3)	1.66	478
Recycling household water (i.e. 'greywater')	34.3% (163)	**40.0% (190)**	22.7% (108)	2.3% (11)	0.6% (3)	1.95	475
Collecting and using stormwater (e.g. in ponds for re-use)	25.2% (120)	24.4% (116)	**38.4% (183)**	11.3% (54)	0.6% (3)	2.38	476
Wetland projects for water quality improvements	20.2% (96)	22.3% (106)	**35.3% (168)**	19.5% (93)	2.7% (13)	2.62	476
Reusing treated sewage for irrigating parks etc	20.2% (96)	22.1% (105)	**40.6% (193)**	14.5% (69)	2.5% (12)	2.57	475
Ground water recharge*	12.3% (58)	9.6% (45)	27.9% (131)	**36.2% (170)**	14.0% (66)	3.30	470
*e.g. injecting (recycled) water underground for storage in an aquifer and subsequent retrieval (comments welcome)						view	45
						answered question	**479**
						skipped question	**16**

Interestingly, the methods best understood by respondents, were also the ones they felt were most appropriate for Canberra, as shown in Question 7. For this question, women were significantly more likely to argue in favour of greywater re-use and wetlands projects, than men.



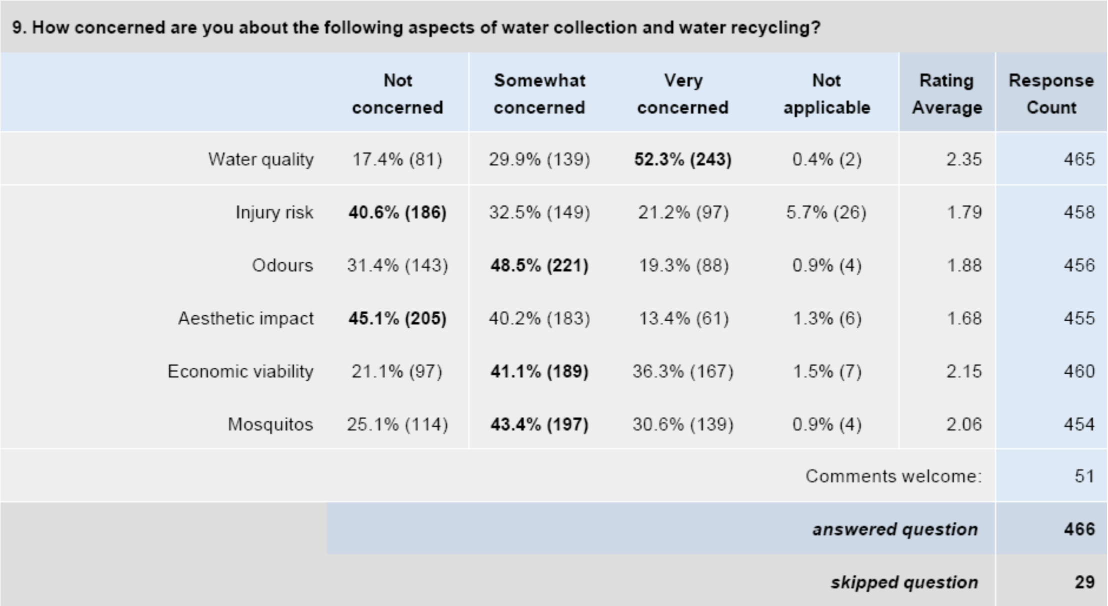
7. Do you agree that the following are appropriate forms of water collection and recycling in Canberra?

	Strongly agree	Agree	Undecided	Disagree	Strongly disagree	Don't know	Rating Average	Response Count
Roof water harvesting (e.g. rainwater tanks)	**70.8% (332)**	22.0% (103)	1.7% (8)	3.0% (14)	2.1% (10)	0.4% (2)	1.45	469
Recycling household water (e.g.laundry, shower)	**64.2% (301)**	25.6% (120)	5.1% (24)	2.8% (13)	1.7% (8)	0.6% (3)	1.54	469
Collecting and using stormwater (e.g. in ponds for re-use)	**63.8% (300)**	26.4% (124)	5.5% (26)	2.8% (13)	0.9% (4)	0.6% (3)	1.52	470
Wetland projects for water quality improvements	**57.3% (268)**	28.4% (133)	8.5% (40)	0.9% (4)	0.6% (3)	4.3% (20)	1.72	468
Reusing treated sewage for irrigating parks etc	**52.8% (247)**	28.8% (135)	9.6% (45)	4.1% (19)	2.8% (13)	1.9% (9)	1.81	468
Ground water recharge*	**25.2% (116)**	22.6% (104)	**25.2% (116)**	5.2% (24)	5.9% (27)	16.1% (74)	2.92	461
*e.g. injecting (re-cycled) water underground for storage in an aquifer and subsequent retrieval (comments welcome)								52
							answered question	**470**
							skipped question	**25**

Results from Question 8 indicate that survey respondents are fairly unsure where stormwater should be stored, with 'don't know' appearing as the second most popular answer. There was a gender difference however, with females most likely to say 'don't know' and males most likely to say 'in existing ponds'.

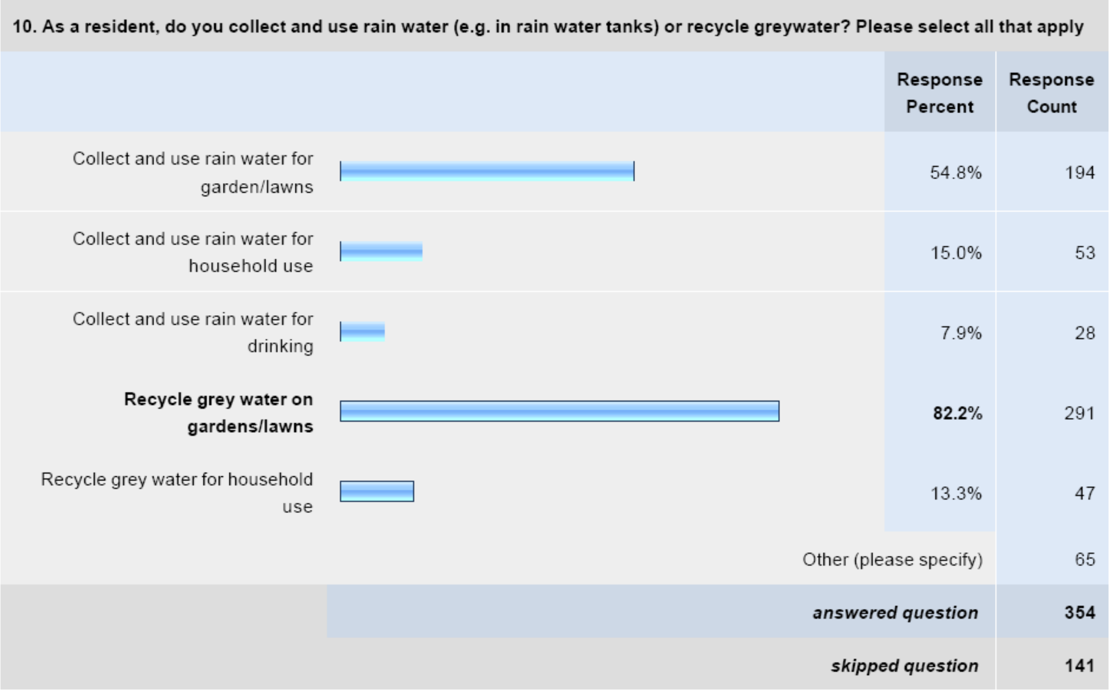
8. If stormwater were to be collected, which is the best way to store it? (please choose only one)	Response Percent	Response Count
In new ponds (which could run dry in summer)	9.2%	42
In existing ponds and lakes (so water level could vary)	**31.6%**	144
Underground in tanks	14.0%	64
Underground in the groundwater system	16.4%	75
Don't know	26.3%	120
Don't care	2.4%	11
Other (please specify)		56
answered question		**456**
skipped question		**39**

Question 9 asked which aspects of water collection and recycling prompted concern in residents, and water quality was clearly the most important issue for people completing the survey. Two demographic differences showed up in this question, with females indicating significantly more concern over economic aspects of water recycling than males, and people without tertiary qualifications expressing more concern about potential odours, than people with tertiary qualifications.



9. How concerned are you about the following aspects of water collection and water recycling?	Not concerned	Somewhat concerned	Very concerned	Not applicable	Rating Average	Response Count
Water quality	17.4% (81)	29.9% (139)	**52.3% (243)**	0.4% (2)	2.35	465
Injury risk	**40.6% (186)**	32.5% (149)	21.2% (97)	5.7% (26)	1.79	458
Odours	31.4% (143)	**48.5% (221)**	19.3% (88)	0.9% (4)	1.88	456
Aesthetic impact	**45.1% (205)**	40.2% (183)	13.4% (61)	1.3% (6)	1.68	455
Economic viability	21.1% (97)	**41.1% (189)**	36.3% (167)	1.5% (7)	2.15	460
Mosquitos	25.1% (114)	**43.4% (197)**	30.6% (139)	0.9% (4)	2.06	454
Comments welcome:						51
answered question						**466**
skipped question						**29**

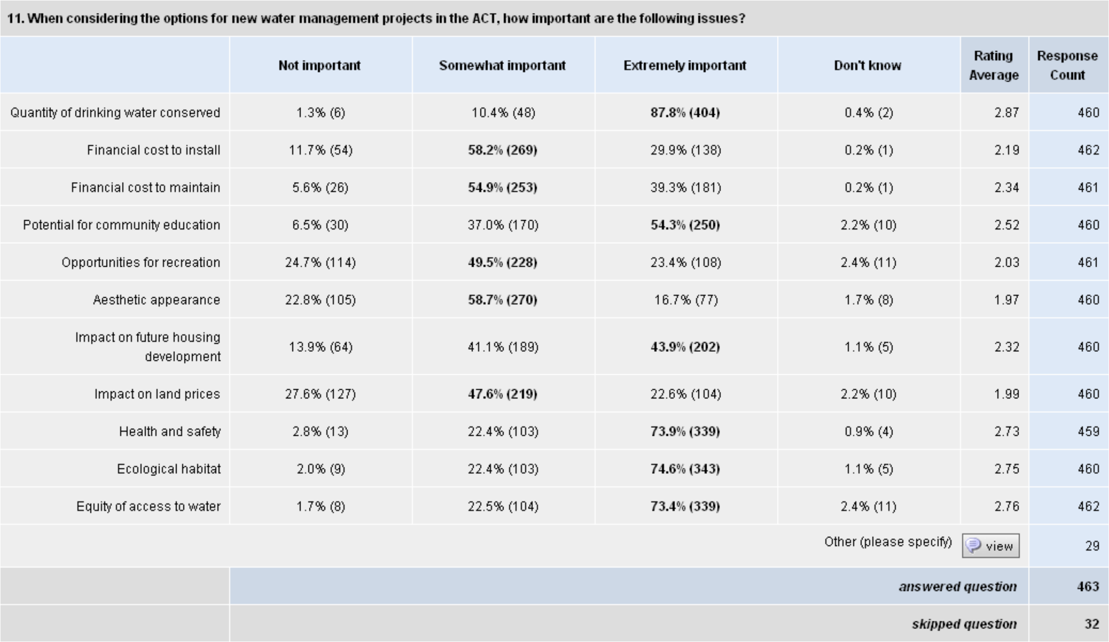
Asked whether they participated in certain forms of water collection and re-use, a very significant proportion of respondents indicated that they did:



10. As a resident, do you collect and use rain water (e.g. in rain water tanks) or recycle greywater? Please select all that apply

	Response Percent	Response Count
Collect and use rain water for garden/lawns	54.8%	194
Collect and use rain water for household use	15.0%	53
Collect and use rain water for drinking	7.9%	28
Recycle grey water on gardens/lawns	**82.2%**	291
Recycle grey water for household use	13.3%	47
Other (please specify)		65
answered question		**354**
skipped question		**141**

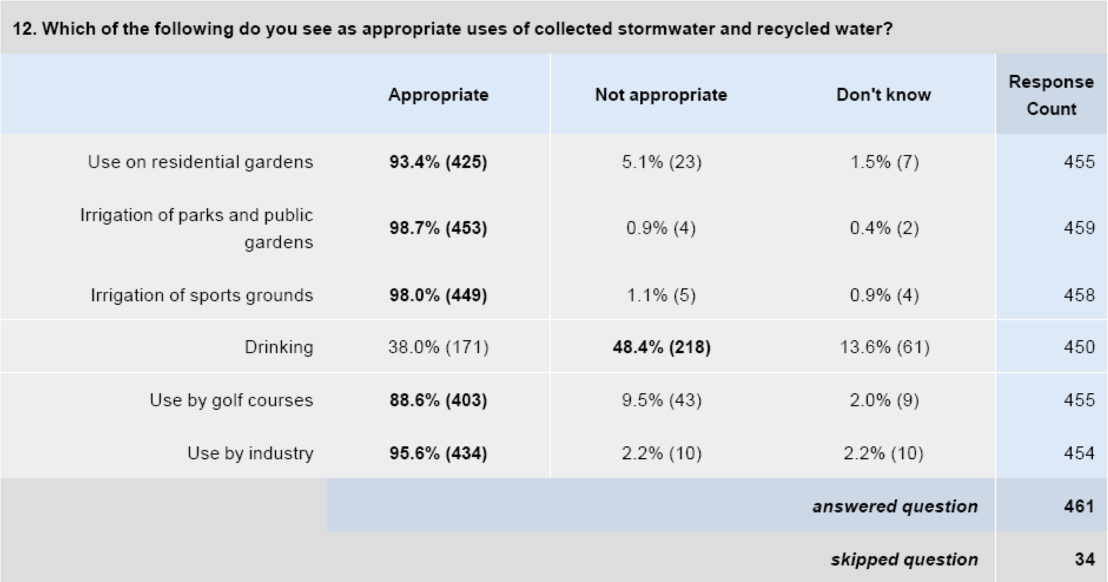
Our survey respondents were very clear in the issues they felt were important in planning new water management projects for Canberra, as shown in Question 11. A number of demographic differences emerged in the answers to this question. Female respondents were more concerned than males about the quantity of drinking water conserved, the potential for community education, and the safety of ecological habitat. Male respondents were more concerned than females about the aesthetic appearance of the options. People earning less than $50 000 per year felt more strongly about community education issues than those on higher incomes, and people earning between $50 000 and $75 000 indicated more concern about equity of access to the water, than those earning less than $50 000 or greater than $75 000. The responses also indicated that tertiary-educated people placed greater emphasis on aesthetic issues, than those without tertiary qualifications.



11. When considering the options for new water management projects in the ACT, how important are the following issues?

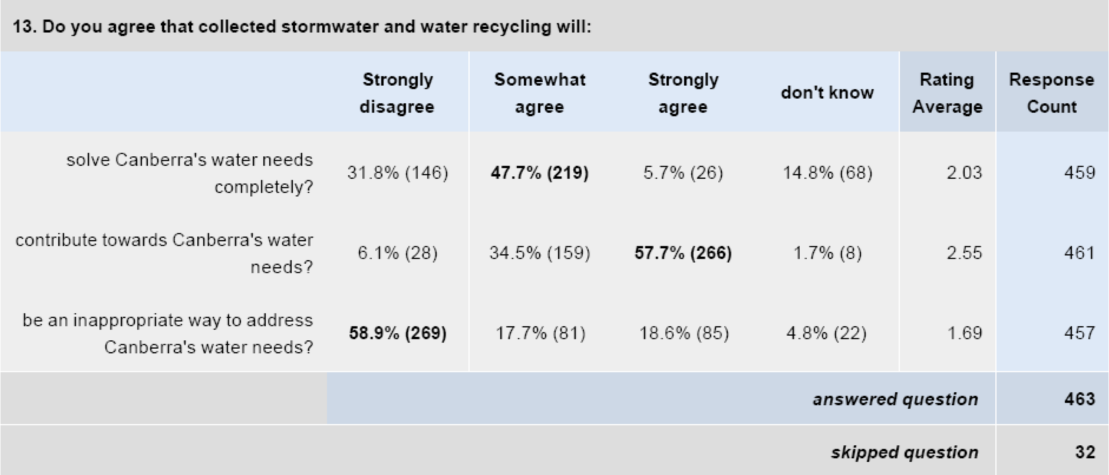
	Not important	Somewhat important	Extremely important	Don't know	Rating Average	Response Count
Quantity of drinking water conserved	1.3% (6)	10.4% (48)	**87.8% (404)**	0.4% (2)	2.87	460
Financial cost to install	11.7% (54)	**58.2% (269)**	29.9% (138)	0.2% (1)	2.19	462
Financial cost to maintain	5.6% (26)	**54.9% (253)**	39.3% (181)	0.2% (1)	2.34	461
Potential for community education	6.5% (30)	37.0% (170)	**54.3% (250)**	2.2% (10)	2.52	460
Opportunities for recreation	24.7% (114)	**49.5% (228)**	23.4% (108)	2.4% (11)	2.03	461
Aesthetic appearance	22.8% (105)	**58.7% (270)**	16.7% (77)	1.7% (8)	1.97	460
Impact on future housing development	13.9% (64)	41.1% (189)	**43.9% (202)**	1.1% (5)	2.32	460
Impact on land prices	27.6% (127)	**47.6% (219)**	22.6% (104)	2.2% (10)	1.99	460
Health and safety	2.8% (13)	22.4% (103)	**73.9% (339)**	0.9% (4)	2.73	459
Ecological habitat	2.0% (9)	22.4% (103)	**74.6% (343)**	1.1% (5)	2.75	460
Equity of access to water	1.7% (8)	22.5% (104)	**73.4% (339)**	2.4% (11)	2.76	462
				Other (please specify)	view	29
					answered question	**463**
					skipped question	**32**

They also demonstrated strong opinions about how collected water could be used (Question 12), but were divided on whether the projects had the potential to alleviate Canberra's water challenges (see Question 13 below). There were no significant differences amongst demographic groups, for Questions 12 and 13.



12. Which of the following do you see as appropriate uses of collected stormwater and recycled water?

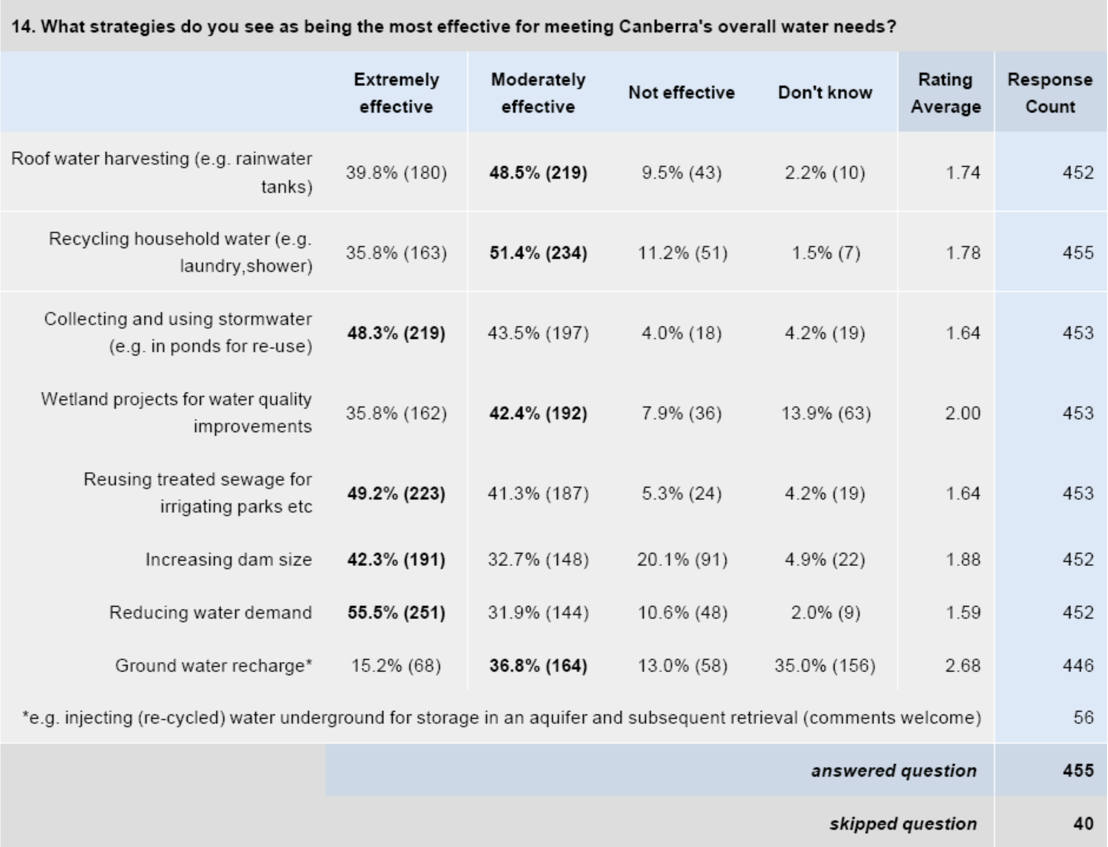
	Appropriate	Not appropriate	Don't know	Response Count
Use on residential gardens	**93.4% (425)**	5.1% (23)	1.5% (7)	455
Irrigation of parks and public gardens	**98.7% (453)**	0.9% (4)	0.4% (2)	459
Irrigation of sports grounds	**98.0% (449)**	1.1% (5)	0.9% (4)	458
Drinking	38.0% (171)	**48.4% (218)**	13.6% (61)	450
Use by golf courses	**88.6% (403)**	9.5% (43)	2.0% (9)	455
Use by industry	**95.6% (434)**	2.2% (10)	2.2% (10)	454
			answered question	**461**
			skipped question	**34**



13. Do you agree that collected stormwater and water recycling will:

	Strongly disagree	Somewhat agree	Strongly agree	don't know	Rating Average	Response Count
solve Canberra's water needs completely?	31.8% (146)	**47.7% (219)**	5.7% (26)	14.8% (68)	2.03	459
contribute towards Canberra's water needs?	6.1% (28)	34.5% (159)	**57.7% (266)**	1.7% (8)	2.55	461
be an inappropriate way to address Canberra's water needs?	**58.9% (269)**	17.7% (81)	18.6% (85)	4.8% (22)	1.69	457
					answered question	**463**
					skipped question	**32**

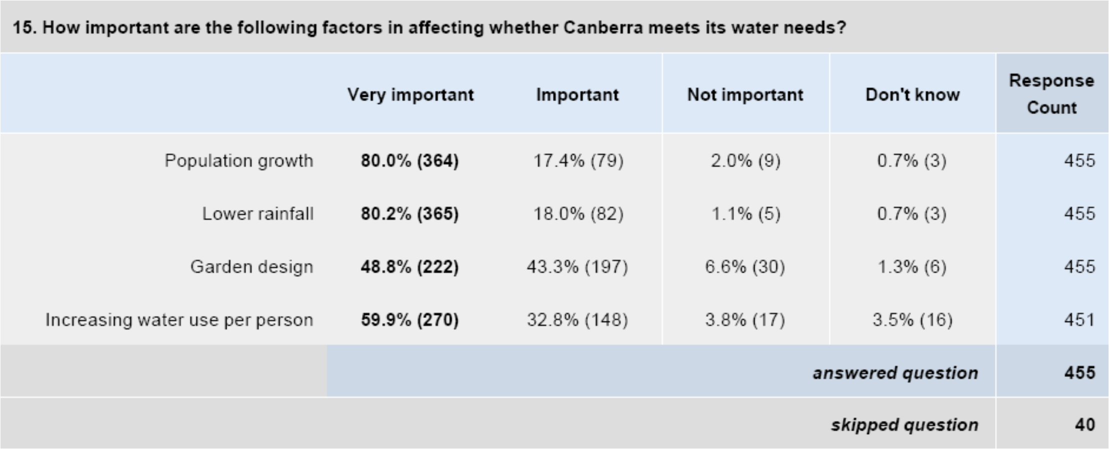
Interestingly, when asked which strategies would best meet Canberra’s water needs (Question 14), respondents rated 'reducing water demand' most highly, followed by infrastructure solutions such as sewer mining, stormwater ponds and bigger dams. There were a number of significant differences between groups, in the answers to Question 14. Women favoured the use of rainwater tanks, stormwater ponds and wetlands projects more than men, while men favoured increasing dam sizes and recharging groundwater supplies, more than women. Tertiary-qualified people were more likely to see demand reduction as an effective strategy, than people without tertiary qualifications. Rainwater tanks were seen as a more effective option by people earning less than $50 000 per year, than by those with higher incomes.



14. What strategies do you see as being the most effective for meeting Canberra's overall water needs?

	Extremely effective	Moderately effective	Not effective	Don't know	Rating Average	Response Count
Roof water harvesting (e.g. rainwater tanks)	39.8% (180)	**48.5% (219)**	9.5% (43)	2.2% (10)	1.74	452
Recycling household water (e.g. laundry,shower)	35.8% (163)	**51.4% (234)**	11.2% (51)	1.5% (7)	1.78	455
Collecting and using stormwater (e.g. in ponds for re-use)	**48.3% (219)**	43.5% (197)	4.0% (18)	4.2% (19)	1.64	453
Wetland projects for water quality improvements	35.8% (162)	**42.4% (192)**	7.9% (36)	13.9% (63)	2.00	453
Reusing treated sewage for irrigating parks etc	**49.2% (223)**	41.3% (187)	5.3% (24)	4.2% (19)	1.64	453
Increasing dam size	**42.3% (191)**	32.7% (148)	20.1% (91)	4.9% (22)	1.88	452
Reducing water demand	**55.5% (251)**	31.9% (144)	10.6% (48)	2.0% (9)	1.59	452
Ground water recharge*	15.2% (68)	**36.8% (164)**	13.0% (58)	35.0% (156)	2.68	446
*e.g. injecting (re-cycled) water underground for storage in an aquifer and subsequent retrieval (comments welcome)						56
					answered question	**455**
					skipped question	**40**

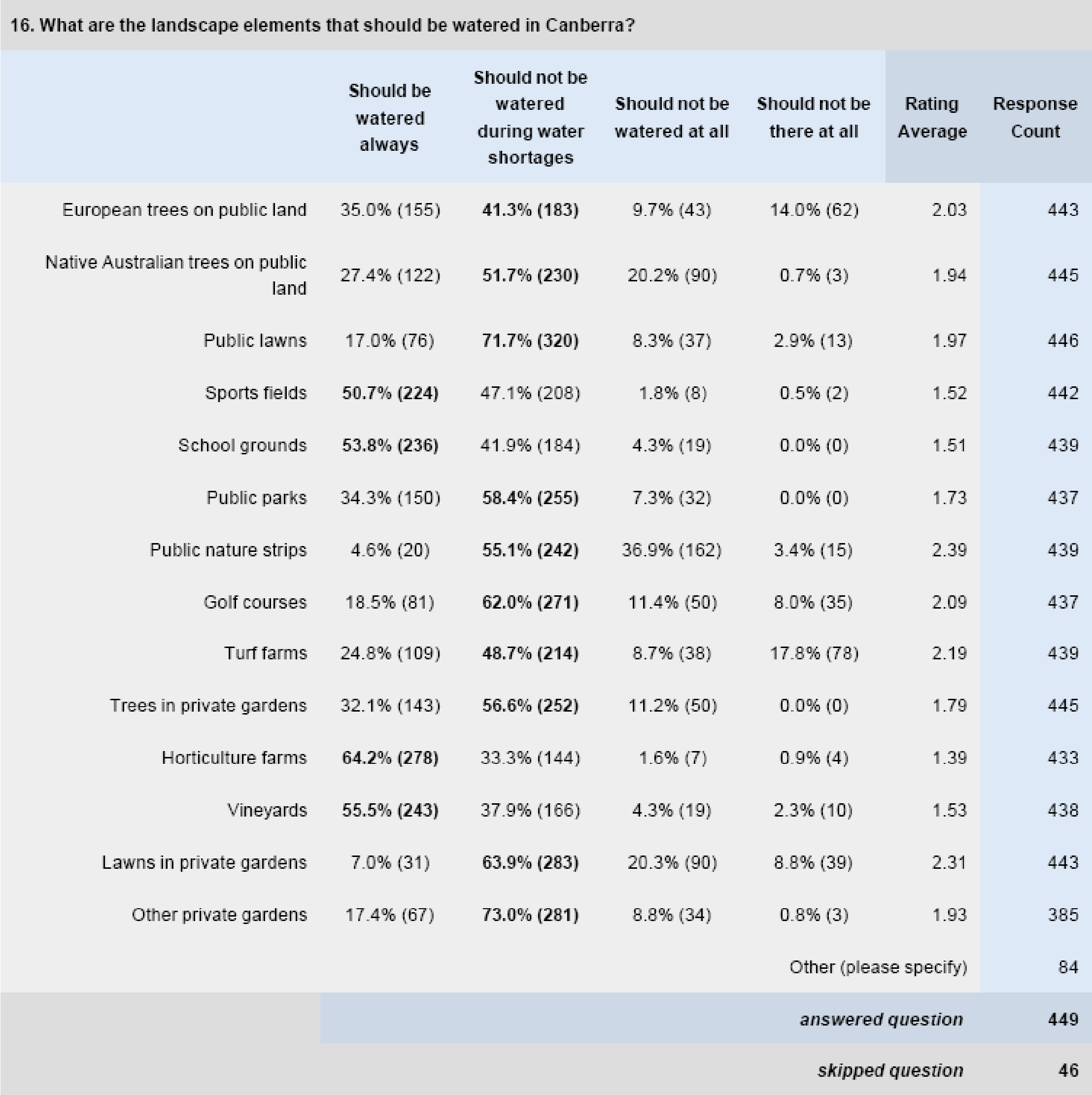
Population growth and rainfall were the two factors seen as most important, in determining whether Canberra has sufficient water. Female respondents were significantly more likely to rate rainfall as important in this question, than male respondents.



15. How important are the following factors in affecting whether Canberra meets its water needs?

	Very important	Important	Not important	Don't know	Response Count
Population growth	**80.0% (364)**	17.4% (79)	2.0% (9)	0.7% (3)	455
Lower rainfall	**80.2% (365)**	18.0% (82)	1.1% (5)	0.7% (3)	455
Garden design	**48.8% (222)**	43.3% (197)	6.6% (30)	1.3% (6)	455
Increasing water use per person	**59.9% (270)**	32.8% (148)	3.8% (17)	3.5% (16)	451
				answered question	**455**
				skipped question	**40**

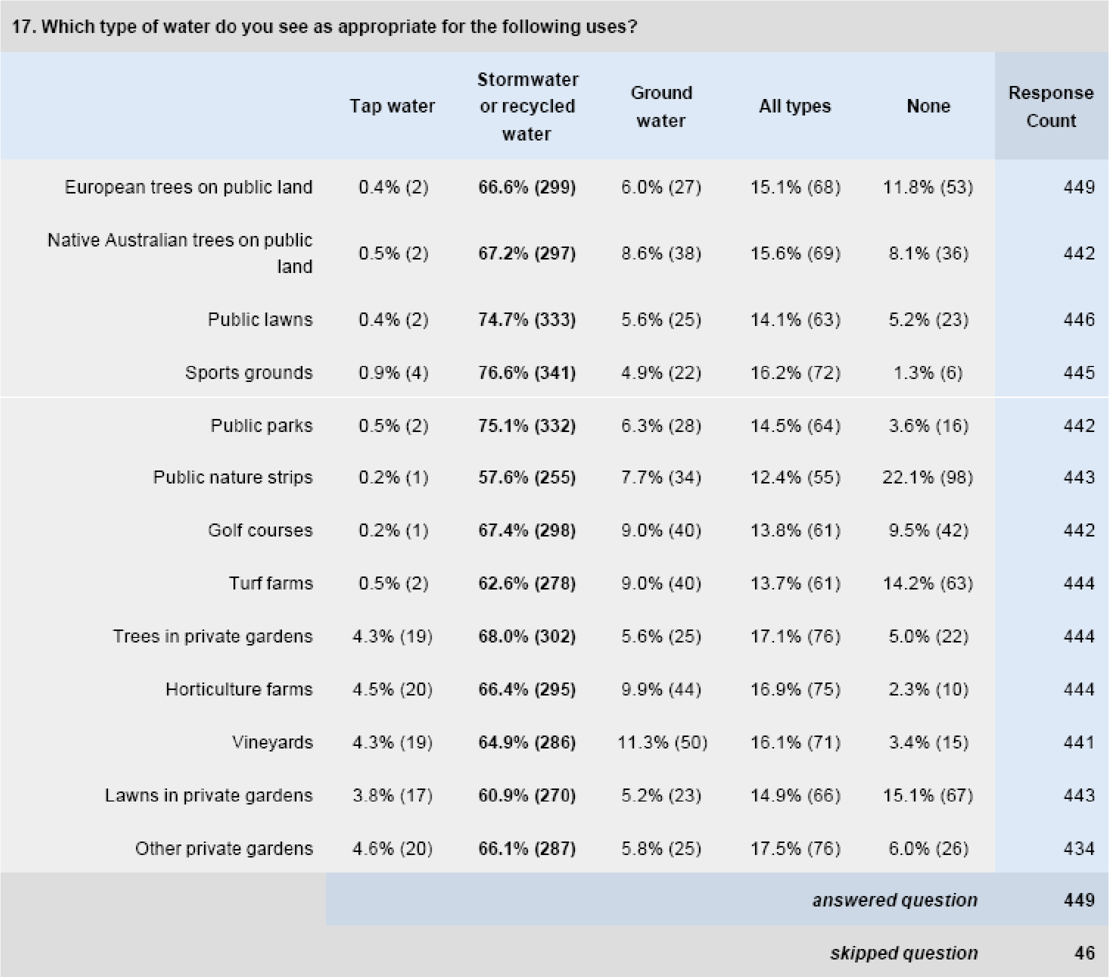
Questions 16 and 17 provided a valuable insight into which aspects of Canberra’s landscape respondents thought should be preserved, and the types of water they wanted to be used in different situations. There were some differences in responses between groups for Question 16, with more women than men stating that native trees should be watered, more men than women stating that private lawns should be watered, and people without tertiary qualifications feeling more strongly about the importance of watering sportsgrounds, than those with tertiary qualifications.



16. What are the landscape elements that should be watered in Canberra?

	Should be watered always	**Should not be watered during water shortages**	**Should not be watered at all**	**Should not be there at all**	**Rating Average**	**Response Count**
European trees on public land	35.0% (155)	**41.3% (183)**	9.7% (43)	14.0% (62)	2.03	443
Native Australian trees on public land	27.4% (122)	**51.7% (230)**	20.2% (90)	0.7% (3)	1.94	445
Public lawns	17.0% (76)	**71.7% (320)**	8.3% (37)	2.9% (13)	1.97	446
Sports fields	**50.7% (224)**	47.1% (208)	1.8% (8)	0.5% (2)	1.52	442
School grounds	**53.8% (236)**	41.9% (184)	4.3% (19)	0.0% (0)	1.51	439
Public parks	34.3% (150)	**58.4% (255)**	7.3% (32)	0.0% (0)	1.73	437
Public nature strips	4.6% (20)	**55.1% (242)**	36.9% (162)	3.4% (15)	2.39	439
Golf courses	18.5% (81)	**62.0% (271)**	11.4% (50)	8.0% (35)	2.09	437
Turf farms	24.8% (109)	**48.7% (214)**	8.7% (38)	17.8% (78)	2.19	439
Trees in private gardens	32.1% (143)	**56.6% (252)**	11.2% (50)	0.0% (0)	1.79	445
Horticulture farms	**64.2% (278)**	33.3% (144)	1.6% (7)	0.9% (4)	1.39	433
Vineyards	**55.5% (243)**	37.9% (166)	4.3% (19)	2.3% (10)	1.53	438
Lawns in private gardens	7.0% (31)	**63.9% (283)**	20.3% (90)	8.8% (39)	2.31	443
Other private gardens	17.4% (67)	**73.0% (281)**	8.8% (34)	0.8% (3)	1.93	385
					Other (please specify)	84
					answered question	**449**
					skipped question	**46**

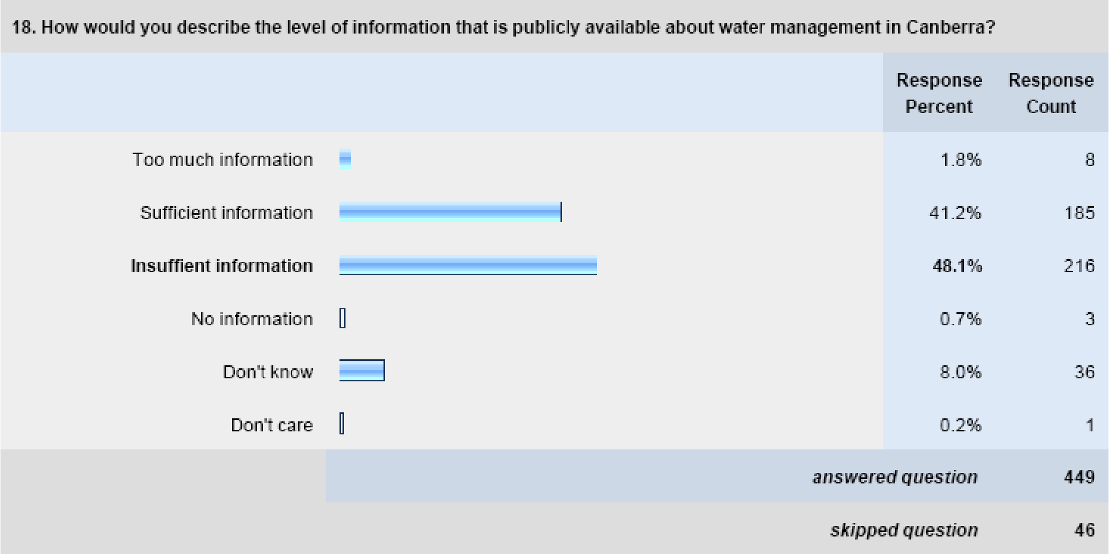
Question 17, especially, indicated that people did *not* want to see potable water used for watering parks and gardens:



17. Which type of water do you see as appropriate for the following uses?

	Tap water	Stormwater or recycled water	Ground water	All types	None	Response Count
European trees on public land	0.4% (2)	**66.6% (299)**	6.0% (27)	15.1% (68)	11.8% (53)	449
Native Australian trees on public land	0.5% (2)	**67.2% (297)**	8.6% (38)	15.6% (69)	8.1% (36)	442
Public lawns	0.4% (2)	**74.7% (333)**	5.6% (25)	14.1% (63)	5.2% (23)	446
Sports grounds	0.9% (4)	**76.6% (341)**	4.9% (22)	16.2% (72)	1.3% (6)	445
Public parks	0.5% (2)	**75.1% (332)**	6.3% (28)	14.5% (64)	3.6% (16)	442
Public nature strips	0.2% (1)	**57.6% (255)**	7.7% (34)	12.4% (55)	22.1% (98)	443
Golf courses	0.2% (1)	**67.4% (298)**	9.0% (40)	13.8% (61)	9.5% (42)	442
Turf farms	0.5% (2)	**62.6% (278)**	9.0% (40)	13.7% (61)	14.2% (63)	444
Trees in private gardens	4.3% (19)	**68.0% (302)**	5.6% (25)	17.1% (76)	5.0% (22)	444
Horticulture farms	4.5% (20)	**66.4% (295)**	9.9% (44)	16.9% (75)	2.3% (10)	444
Vineyards	4.3% (19)	**64.9% (286)**	11.3% (50)	16.1% (71)	3.4% (15)	441
Lawns in private gardens	3.8% (17)	**60.9% (270)**	5.2% (23)	14.9% (66)	15.1% (67)	443
Other private gardens	4.6% (20)	**66.1% (287)**	5.8% (25)	17.5% (76)	6.0% (26)	434
					answered question	**449**
					skipped question	**46**

Many survey respondents indicated, in Question 18, that they would like more information on how Canberra's water supplies are managed:



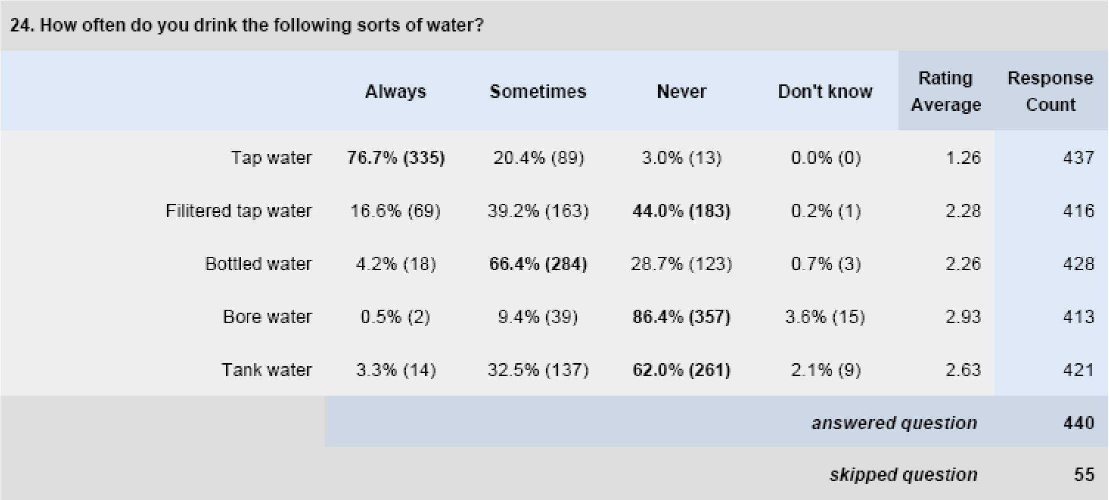
18. How would you describe the level of information that is publicly available about water management in Canberra?

	Response Percent	Response Count
Too much information	1.8%	8
Sufficient information	41.2%	185
Insuffient information	**48.1%**	216
No information	0.7%	3
Don't know	8.0%	36
Don't care	0.2%	1
answered question		**449**
skipped question		**46**

Questions 19–23 and 25–26, which cover the demographics of the survey respondents, were summarised in an earlier section of this report.

Question 24 canvassed respondents’ drinking water sources. Although the question was rather imprecise (for example, 'sometimes' could be interpreted as once per day, or once per year) it provided an interesting glimpse of survey respondents’ choices. Some cross-tabulations were also run to see whether people who drank particular types of water had expressed particular views in the survey. Findings from the cross-tabulation included:

- More females than males 'always' or 'sometimes' drink bottled water (Q19 x Q24)
- People who never drink bottled water claim to have a very high understanding of tank water (Q6 x Q24)
- People who always drink filtered tap water are very concerned about water quality (Q9 x Q24)
- People who 'always' or 'sometimes' drink tap water, think that ecological habitat is extremely important (Q11 x Q24)
- People who always drink bottled water think that land prices are extremely important (Q11 x Q24)
- People who always drink tap water are most likely to think that sewer mining would be effective (Q14 x Q24)
- People who always drink tap water are most likely to think that increased dam sizes would be effective (Q14 x Q24)
- People who never drink tap water are most likely to say that sports fields should not be watered during water shortages (Q16 x Q24)
- People who never drink tap water are most likely to say that public lawns should not be watered ever (Q16 x Q24)
- People who always drink tap water are most likely to say that school grounds should always be watered (Q16 x Q24)



24. How often do you drink the following sorts of water?

	Always	Sometimes	Never	Don't know	Rating Average	Response Count
Tap water	**76.7% (335)**	20.4% (89)	3.0% (13)	0.0% (0)	1.26	437
Filitered tap water	16.6% (69)	39.2% (163)	**44.0% (183)**	0.2% (1)	2.28	416
Bottled water	4.2% (18)	**66.4% (284)**	28.7% (123)	0.7% (3)	2.26	428
Bore water	0.5% (2)	9.4% (39)	**86.4% (357)**	3.6% (15)	2.93	413
Tank water	3.3% (14)	32.5% (137)	**62.0% (261)**	2.1% (9)	2.63	421
					answered question	**440**
					skipped question	**55**

9.3.3 Results from the community workshop

The research team confronted 50 participants of a community workshop with the 29 supply–demand options for using existing lakes and new ponds, some of them in combination with sewer mining and underground storage, and asked for an assessment of those options in regard to 14 major social impacts.

To enable the assessment, the technical options were introduced to the workshop participants in as much detail as possible. The appropriateness of the list of social criteria to reflect all social impacts was also discussed. Once the participants had gained a sound knowledge of the options and had agreed on the list of criteria for the assessment they were asked to debate and assess a number of options, usually such options they had good knowledge of, because they either lived or worked in the areas where the ponds or lakes were based. The assessment was done in groups of six people allowing for rich debate and compromise. The assessment was done using a rating scale from ‘5 to 1’ where a value of ‘5’ represented ‘very positive impact, very favourable’ and a value of ‘1’ represented ‘very negative impact, very unfavourable’.

For most supply–demand options 2–4 independent assessments were received and averages for the impact matrix (described in Chapter 10) were used. For two options, however, we were not able to establish an assessment at all. They went into the impact matrix with a dummy value of ‘3’. These two options were W19 Eddison Park in the Woden town centre and W27 at Mawson and Pearce. This has to be kept in mind for the later multi-criteria assessment, where results for those two options have to be read with some caution.

In a next step, the 12 social impact assessment criteria were summarised into six main clusters to avoid an overrepresentation of social criteria in the MCA. The clustering was based on a factor analysis and distinguished between impacts on the community and households, and separated equity issues and the likelihood of community support for a certain option. Two criteria refer to economic and ecological domains from the perspective of the community representatives.

Overall, the community assessment was positive (Figure 36) and the perception of the community about the usefulness and the advantage of the suggested options was highlighted. The criteria of ‘community support’ received the highest positive assessment suggesting that support from community may be expected when implementing new supply–demand schemes or establishing new ponds. Similarly favourable, were the assessments for overall community impact and equity issues as well as economic and ecological impact. The community representatives shared the perspective that an extension of ponds and the use of water for irrigation would not just improve the water supply system for Canberra but would have beneficial aspects in all dimensions by improving amenity, land prices, ecological habitat and would create more liveable communities.

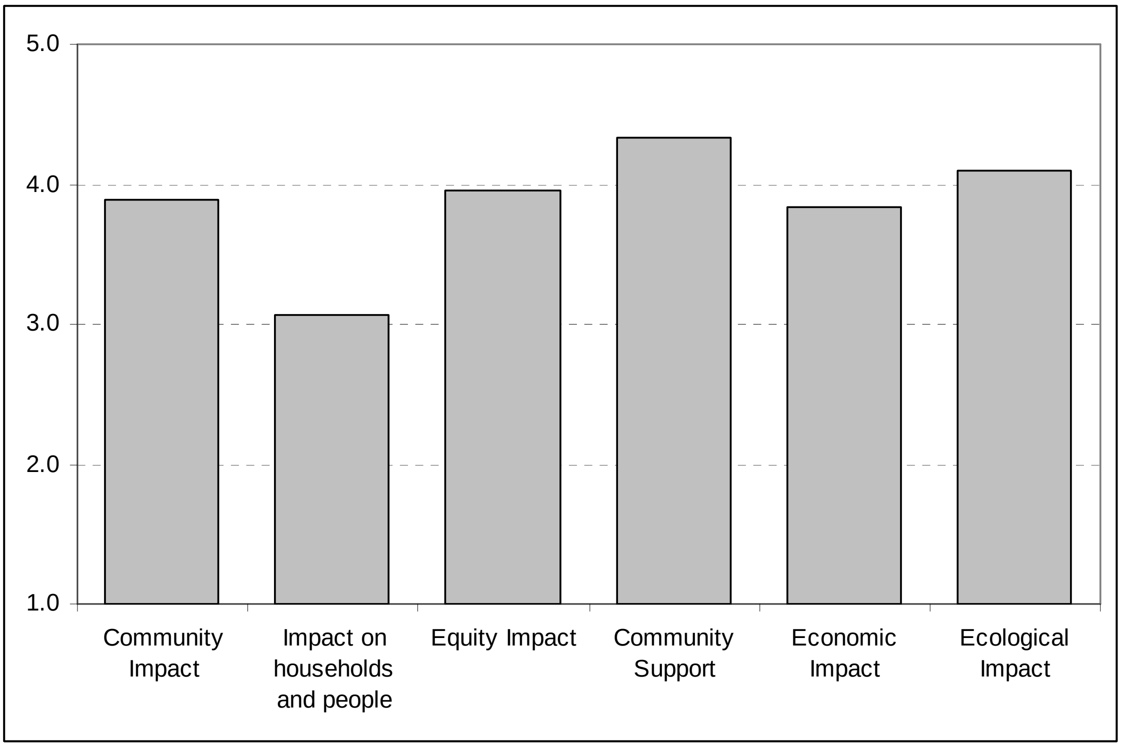


Figure 36: Overall assessment results for supply–demand options

The criteria of impacts on households capture more individual aspects than other criteria, and integrate the criteria of health and safety. In this area, community assessment was more cautious indicating that concern around health and safety issues exists and that this has to be proactively addressed when designing new ponds or changing the use of existing ponds.

Despite the overall very positive feedback from community there is considerable variability in regard to the assessment of single options (see overview graphs).

In addition to the quantitative assessment, the participants at the community workshop agreed that the assessment of social impacts depends critically on the design of the new ponds and re-design of existing ponds. Participants presented a strong view that the positive social impact would depend on well-designed solutions for ponds. To enable this, planning and design should not stop at the edges of the pond but should integrate the areas surrounding the ponds for creating the most benefit in terms of recreational, educational and amenity potentials.

9.4 Discussion

In framing the introduction to the study, attention was drawn to a range of values associated with water beyond its instrumental resource value. Although a generally recognised issue, the relationship between water quality and property values was not explicitly raised (Leggett and Bockstael 2000). In a similar way, the broadly acknowledged cultural dimensions of water and water courses were not directly raised (Gibbs 2006; Jackson et al. 2008), although certain cultural tendencies were apparent (e.g. the vast majority of survey participants who recycle their domestic greywater on their gardens). Moreover, two major social issues – amenity and equity – were strongly raised throughout both the focus groups and the survey stages –

Amenity is broadly recognised as an important issue for the management of water and water courses (Howard 2008). The focus groups considered amenity issues were prominent in terms of aesthetic appearance and potential for recreation reflected in their strong desire ensure access to the sites, and concerns about them being locked away due to institutional fear of personal injuries and the potential for litigation. Furthermore, there was an emphasis on providing facilities such as walking tracks and landscaping in order to foster the amenity dimensions.

Equity was a major issue both in the focus groups and the survey. Focus groups drew attention to precedents in the ACT such as Lake Burley Griffin where access to the water was highly restricted and viewed as inequitable in some cases. and participants emphasised the need to pay careful attention to equity issues in future projects. In a related way, there were very strong trends within the survey about appropriate uses of water. Most respondents indicated that residential gardens, irrigating parks and public gardens, sports grounds, industry and golf courses were all considered generally appropriate water uses. However, there was an important qualification about uses of water in times of water shortages. In particular, most participants stated that certain elements of the landscape *should not be watered* in times of water shortages, in particular golf courses, public lawns and public parks. By contrast, a majority of respondents indicated that school grounds and sports fields should always be watered along with some private water uses including vineyards and horticulture farms.

It is also worth noting that the highest community concern about water collecting and recycling was water quality. This may help to explain the survey finding that stormwater harvesting was overall preferable to sewer mining and ground water recharge. Finally, as a general comment there was perception that the community is ready for change but seeks guidance on how to achieve the changes that are required.

10 TRIPLE BOTTOM LINE ASSESSMENT

In this chapter, we describe triple bottom line (TBL) assessment of stormwater harvesting options in the Master Plan A (Chapter 7). Options in Master Plan A represent least-cost options in levelised cost terms. They have the following characteristics:

- each option has a volumetric supply reliability of 95% or more
- all options contribute to achieving 3 GL/yr potable water saving target
- most of the options are clustered around three of Canberra's waterways: Ginninderra, Sullivans and Tuggeranong Creeks (see Figure 13 and Figure 14). Options that are clustered around a waterway are likely to be hydrologically connected (i.e. flows of one option affect flows of other options), which means options in the master plan are not independent

In general, when the TBL assessment method is used in a feasibility assessment of different options, its purpose is to compare different options in terms of a set of criteria in social, economic and environmental dimensions. The assessment process accounts for preferences of stakeholders on assessment criteria and provide a ranking for each option. The options with higher ranking are considered as preferred options for detailed engineering feasibility assessment, which is essential before the implementation of preferred options.

Ranking of options within a TBL assessment framework is meaningful, if options are independent and individual options have the potential to achieve the objective of the assessment. Unfortunately, options included in a master plan are not independent of each other due to the hydrologic connectivity. In addition, individual options do not have the ability to meet the overall objective of the assessment (i.e. potable water savings of 3 GL/yr). Therefore, it is important to understand that the purpose of undertaking TBL assessment is to indicate relative benefits of each option in the master plan in economic, social and environmental dimensions, and to elucidate the opinions of stakeholders. Moreover, outcomes of the TBL assessment should not be used for ranking of options in the master plan.

10.1 The Deliberative Multi-Criteria Evaluation Process

In this study, TBL assessment was carried out using a decision-aiding process called deliberative multi-criteria evaluation (DMCE) (Proctor and Drechsler, in press). This method combines the facilitation, interaction and consensus building features of the Citizens' Jury process (Crosby 1999; Dienel and Renn 1995) with the structuring and integration features of multi-criteria evaluation (Proctor 2005; Massam 1998; Munda et al. 1994).

The features of the Citizens' Jury are:

- relevant participants are engaged and given a specific charge
- the process is facilitated (by a 'judge')

- expert witnesses are engaged to provide information where needed
- participants are given time to discuss, debate and deliberate
- consensus is often reached but exact consensus is not always necessary to deliver a favoured outcome.

Table 35: Criteria used for TBL assessment

No.	List of criteria	Indicator
	ECONOMIC	
1	Levelised cost	($/kL)
2	Volumetric reliability	(in %)
	SOCIAL	Scale from 1 to 5
3	Impact on the community	1 means: very negative, very undesirable 5 means: very positive, very desirable
4	Impact on households	
5	Appropriateness of pond location	
6	Equity of access to water	
7	Equity of access to pond	
8	Potential recreational value	
9	Potential for community education	
10	Health impact	
11	Safety impact	
12	Impact on future housing development	
13	Impact on future land prices	
14	Compliance with regulation/legislation	
15	Ecological habitat	
16	Political support	
	ENVIRONMENTAL	
17	Potential for emergent vegetation diversity (with harvesting)	
18	Change in potential for emergent vegetation diversity (difference between base and harvesting)	
19	Drawdown – harvesting	% of time (between November and April) with drawdown >= 0.5 m
20	Difference in drawdown between harvesting and base	
21	Nutrient load reduction indicator	

The DMCE process was undertaken through several meetings conducted over a twelve-month period with representative stakeholders providing input into the decision process. Various stormwater harvesting options that were shortlisted for assessment were the focus of consideration by the stakeholders. The first two meetings were designed to disseminate greater information about the options and to agree on the relevant criteria which were to be used in prioritising them. Once the options and criteria had been agreed, an extensive research process was undertaken to gather information on how each option performed against the decision criteria that would be used to assess them. The stakeholders were also asked to provide their priority weightings on how well they thought each of the criteria should influence the overall performance of the options. The deliberative process during the final meeting used this information to come up with an overall ranking of each of the stormwater pond options, and to draw out the key issues, concerns and trade-offs that would be associated with implementing the preferred options.

As part of the DMCE process, assessment or decision criteria were developed in social, economic and environmental dimensions (see Table 35). Social analysis (see Chapter 9) defined the decision criteria in social dimension whereas the ecological analysis (see Chapter 8) defined decision criteria in the environmental dimension.

An impact matrix, showing the estimated impact of each of the criteria under each of the chosen options was then developed (see Table 36). Priority weightings for each of the criteria by each of the participants were established.

Once the criteria weightings and impact matrix have been established, a deliberative process is carried out with the aid of a facilitator and multi-criteria evaluation software. The software is used interactively during the process and the results of each iteration displayed to the participants. The objective of the deliberations (known as ‘the charge’ in the jury process) is for the participants to agree on a set of weightings for the decision criteria that would indicate an overall stormwater pond option and a ranking of all options.

It is important to stress that the process is designed primarily to aid in learning complex decision problems and not necessarily to solely arrive at an optimal outcome or scenario. The process of deliberation allows many different insights, preferences and items of knowledge to be shared and debated and thus aids in uncovering perhaps otherwise neglected pieces of important knowledge.

Table 36: Impact assessment matrix

POND NAME	**West Belconnen Pond**	**Dunlop Pond 1**	**Dunlop Pond 2**	**B14 Ginninderra Drive & Kingsford Smith, Florey**	**B28 North of Southern Cross Drive, Latham**	**Lake Ginninderra**	**Nicholls Pond**	**Gungahlin Pond**	**Yerrabi Pond**	**G23 Sullivans Creek, Mitchell & Kenny**	**David Street Wetland**	**NC9-11 Tributary of Sullivans Creek, Lyneham**	**NC18 Sullivans Creek, Mitchell**	**Lake Tuggeranong**	**Isabella Pond**	**Upper Stranger Pond**	**Point Hut Pond**	**T2 Fadden & Chisholm**	**T3 Tuggeranong Creek, Calwell**	**T4 Next to Tuggeranong Homestead, Richardson**	**W0 Yarralumla Creek, Curtin**	**W2 Yarralumla Creek, Curtin**	**W19 Eddison Park, Woden Town Centre**	**W27 Mawson & Pearce**	**WC0 Weston Creek, Lower Molonglo**	**WC4 Weston Creek, Holder**	**WC14-15 Duffy & Holder**	**WC19 Adjacent to Waramanga District Playing Fields, Waramanga**	**NC14**
ECONOMIC																													
Levelised cost ($/kL)	4.7	1.6	2.7	3.71	5.66	2.4	0.7	1.3	1.1	5.41	0.5	5.85	4.99	1.8	3.2	1.3	2.3	6.9	6.02	7.01	7.37	3.47	5.4	6.2	4.81	5.7	6	7.48	6.6
Volumetric reliability	98	95	95	95	95	98	95	96	98	100	95	100	100	98	100	100	100	95	95	95	100	100	95	95	95	95	95	95	100
SOCIAL																													
Impact on the community	5.0	5.0	5.0	4.0	4.5	5.0	3.0	5.0	5.0	5.0	4.5	5.0	5.0	3.0	4.0	2.0	5.0	2.0	2.0	3.0	5.0	4.0	3.0	3.0	5.0	5.0	4.0	4.5	3
Impact on households	2.0	2.0	2.0	2.0	2.0	3.0	3.0	3.0	3.0	3.0	4.0	4.5	3.0	3.0	4.0	2.0	5.0	3.0	3.0	3.0	5.0	4.0	3.0	3.0	5.0	3.0	4.0	4.5	3
Appropriateness of pond location	5.0	5.0	5.0	4.7	4.3	3.0	3.0	3.0	3.0	5.0	5.0	4.5	4.5	5.0	4.0	4.0	5.0	3.0	3.0	2.5	4.0	4.0	3.0	3.0	5.0	5.0	5.0	3.5	3
Equity of access to water	5.0	5.0	5.0	4.0	5.0	3.0	3.0	3.0	3.0	4.0	4.0	4.0	4.0	5.0	4.0	2.0	5.0	4.0	4.0	5.0	4.0	4.0	3.0	3.0	4.0	4.0	4.0	4.5	3
Equity of access to pond	5.0	5.0	5.0	3.5	4.5	3.0	3.0	3.0	3.0	5.0	4.0	5.0	5.0	4.0	4.0	2.0	5.0	4.0	4.0	1.0	4.0	4.0	3.0	3.0	5.0	5.0	5.0	5.0	3
Potential recreational value	5.0	5.0	5.0	3.3	4.3	3.0	3.5	3.5	3.5	3.5	4.0	3.5	4.0	5.0	4.0	1.0	5.0	2.5	2.5	2.5	4.0	3.0	3.0	3.0	5.0	3.0	5.0	4.5	3
Potential for community education	4.5	4.5	4.5	4.3	4.3	3.0	3.5	3.5	3.5	3.5	4.0	4.0	3.5	5.0	5.0	1.0	5.0	2.5	2.5	2.5	4.0	4.0	3.0	3.0	4.0	4.0	4.0	5.0	3
Health impact	2.0	3.0	3.0	3.3	3.3	5.0	2.5	3.5	3.5	2.5	3.3	3.5	2.5	3.0	4.0	1.0	5.0	3.0	3.0	3.0	4.0	4.0	3.0	3.0	3.0	3.0	3.0	2.0	3
Safety impact	1.0	1.0	1.0	2.0	1.7	4.0	2.5	3.0	3.0	2.5	3.3	3.0	2.5	3.0	4.0	1.0	5.0	1.5	1.5	3.0	4.0	4.0	3.0	3.0	4.0	4.0	4.0	3.0	3
Impact on future housing development	5.0	5.0	5.0	5.0	4.5	3.0	3.0	3.0	3.0	4.0	3.0	3.0	4.0	3.0	4.0	3.0	5.0	4.0	4.0	1.0	5.0	4.0	3.0	3.0	5.0	3.0	5.0	3.5	3

POND NAME	**West Belconnen Pond**	**Dunlop Pond 1**	**Dunlop Pond 2**	**B14 Ginninderra Drive & Kingsford Smith, Florey**	**B28 North of Southern Cross Drive, Latham**	**Lake Ginninderra**	**Nicholls Pond**	**Gungahlin Pond**	**Yerrabi Pond**	**G23 Sullivans Creek, Mitchell & Kenny**	**David Street Wetland**	**NC9-11 Tributary of Sullivans Creek, Lyneham**	**NC18 Sullivans Creek, Mitchell**	**Lake Tuggeranong**	**Isabella Pond**	**Upper Stranger Pond**	**Point Hut Pond**	**T2 Fadden & Chisholm**	**T3 Tuggeranong Creek, Calwell**	**T4 Next to Tuggeranong Homestead, Richardson**	**W0 Yarralumla Creek, Curtin**	**W2 Yarralumla Creek, Curtin**	**W19 Eddison Park, Woden Town Centre**	**W27 Mawson & Pearce**	**WC0 Weston Creek, Lower Molonglo**	**WC4 Weston Creek, Holder**	**WC14-15 Duffy & Holder**	**WC19 Adjacent to Waramanga District Playing Fields, Waramanga**	**NC14**
Impact on future land prices	5.0	5.0	5.0	5.0	4.5	3.0	3.0	3.0	3.0	4.0	3.0	4.0	4.0	3.0	4.0	3.0	5.0	5.0	5.0	1.0	5.0	4.0	3.0	3.0	5.0	3.0	5.0	5.0	3
Compliance with regulation/legislation	3.0	2.0	2.0	2.0	2.0	5.0	5.0	5.0	5.0	5.0	5.0	4.0	5.0	1.0	3.0	1.0	5.0	4.0	4.0	5.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3
Ecological habitat	4.5	4.5	4.5	4.0	4.0	3.0	4.0	4.0	4.0	4.5	4.3	5.0	5.0	4.0	5.0	1.0	5.0	4.0	4.0	3.5	4.0	5.0	3.0	3.0	5.0	4.0	5.0	5.0	3
Political support	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	4.0	1.0	5.0	4.5	4.5	3.0	4.0	4.0	3.0	3.0	4.0	4.0	5.0	3.5	3
ENVIRONMENTAL																													
Potential for emergent vegetation diversity (with harvesting)	0.5	0.5	3	2	4	0.5	0.5	1	2	2.5	3.5	3	3	2.5	2	1.5	2	1	4	4	1	2.5	1	1	3	4	4	3	1
Change in potential for emergent vegetation diversity (difference between base and harvesting)	-2.5	-1.5	1	2	4	-3	-2.5	-1	0.5	2.5	1.5	3	3	0	0	-0.5	-1.5	1	4	4	1	2.5	1	1	3	4	4	3	1
Drawdown - Harvesting	23	21	13	14	18	20	25	20	19	19	16	20	19	17	1	6	9	20	19	18	21	17	20	20	23	17	17	19	21
Difference in drawdown between harvesting and Base	16	21	13	0	0	19	24	19	18	0	16	0	0	17	0	6	8	0	0	0	0	0	0	0	0	0	0	0	0
Nutrient load Reduction indicator	0.0	0.0	0.0	0.0	0.2	1.4	0.0	0.8	0.2	0.2	0.0	0.3	2.1	0.7	0.3	0.1	0.1	0.8	0.8	0.2	7.2	0.9	1.6	1.2	2.3	0.2	0.1	0.2	0.8

10.2 Results of Multi Criteria Evaluation

After the first two workshops, 21 social, economic and environmental criteria were agreed to assess the various pond options (see Table 35 for criteria and their descriptions). An assessment of how each of the options performed with respect to the criteria is provided in the impact matrix in Table 36.

10.2.1 Initial preference weightings

The fourteen stakeholders in the workshop were asked to give their weightings after being presented the facts from different experts and discussing several points that were unclear at the beginning. The stakeholders were asked to distribute 100 points over the various criteria to depict how important they felt that each of the criteria contributed to choosing an optimal pond (with more points depicting more importance). Figure 37 shows the weightings that were assigned.

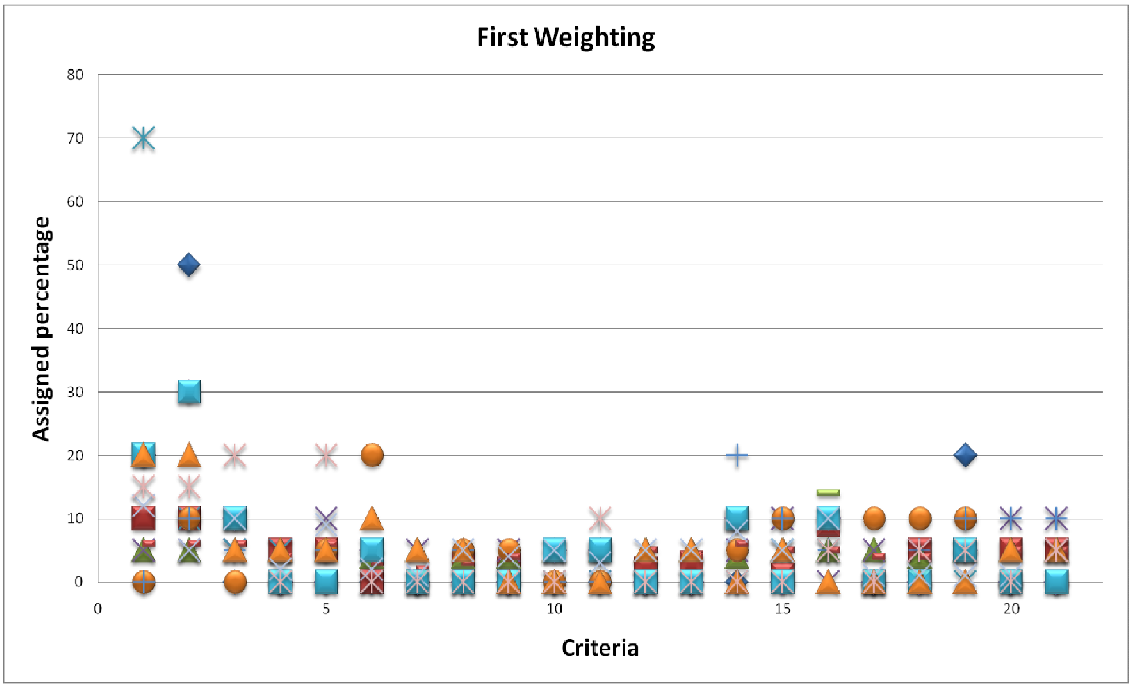


Figure 37: First set of criteria weightings

A large spread occurs in the weightings of the different criteria, especially with regard to the two economic criteria. Levelised costs showed the largest spread – ranging from 0 to 70. Also the second criterion, the volumetric reliability of the different options, was rated very dissimilarly, with the highest weight being 50 and the lowest being 5. Five more criteria received a range of weights from 0 to 20 with the remaining criteria being assessed more homogeneously (in the range of 0 and 15).

The multi-criteria assessment tool (MCAT) was used to provide a ranking of the ponds based on the weights and impacts provided:

- 32.6 % of the weights were given to the economic criteria on average
- 50.5 % to the social and

- 16.9 % to the environmental criteria.

Figure 38 illustrates the outcome of the first weighting, showing how much of the overall score for all options (entire bar) can be attributed to each option. The options performing best are clearly Point Hut Pond and NC18, followed by G23, Lake Tuggeranong and Isabella Pond followed by W2, NC9-11, Yerrabi Pond, David Street Wetland and Upper Stranger Pond.

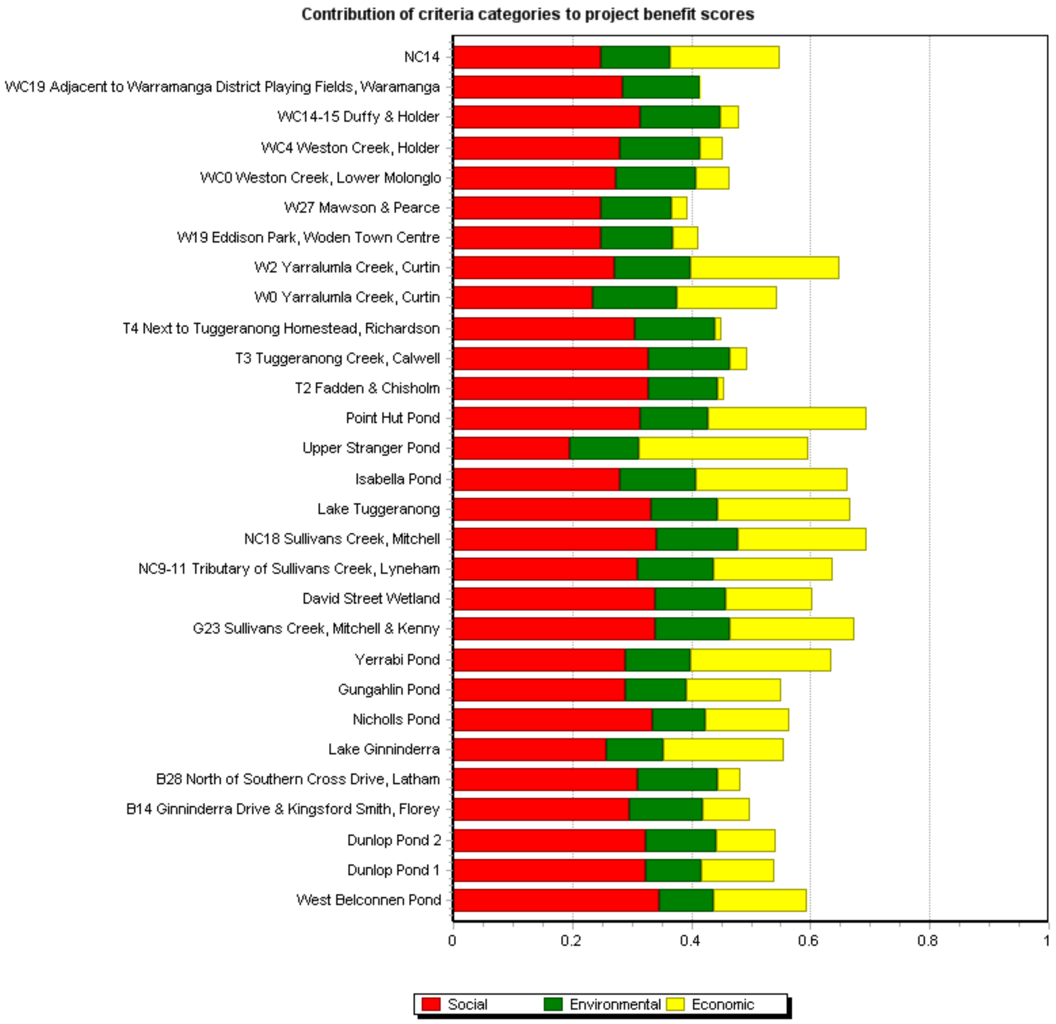


Figure 38: Contribution of criteria categories to project benefit scores

Figure 38 also shows the contribution of economic, social and environmental categories to the project benefit scores (this time in absolute, not relative values) of each option. The best ranked options do not only get high contributions from the social and environmental criteria but do also receive high scores from the economic criteria. The mean contributions to the overall benefit score are 0.3 for the social criteria, 0.12 for the environmental criteria and 0.13 for the economic criteria. The big weight of the social criteria is due to the fact that they outnumber the other two criteria categories (14 social versus 5 environmental versus 2 economic criteria).

The contribution of the economic criteria to the overall benefit, however, differs quite significantly (with a standard deviation of 0.09). This result is largely owing to a high variation of the levelised costs (the variation of the second economic criterion, volumetric reliability, is rather small because only options with a reliability of at least 95% were considered). The option ranked highest (i.e. NC18), shows relatively low levelised cost ($2.3 /kL) whereas WC19 has the highest cost with $7.48 /kL and subsequently performs worst on the contribution of the economic criteria. The high performers all receive very high contributions from the economic as well as the social criteria. The environmental criteria have a very low standard deviation (0.01) and therefore do not drive the difference in benefits between options.

10.2.2 Second preference weightings

As the deliberative multi-criteria evaluation (DMCE) is directed towards reaching a consensus, an iterative process in the weighting is required. Hence, a discussion on the outliers in the previous weighting scheme was encouraged. People with extreme criteria weights were asked to disclose their reasons for giving these weights. Some criteria definitions were also clarified. After that, the jury came back to give another set of weightings. From the 14 jurors, six jurors changed their weightings, some significantly. Figure 39 represents the weights that were given in the second round.

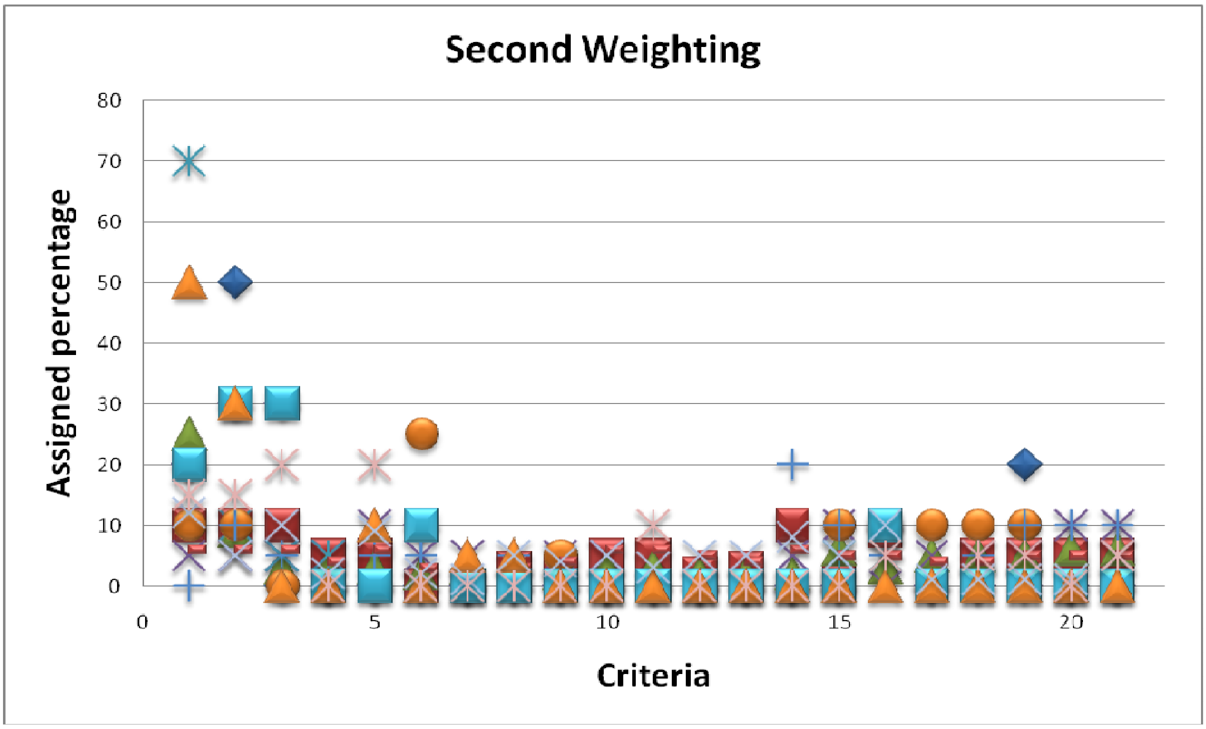


Figure 39: Percentage assigned by the jurors to the 21 criteria from above for the second weighting (same icon depicts same juror)

Several people decided to assign a higher weight to the first three criteria. In doing so, the overall gap for the two economic criteria between the highest and lowest value assigned remained the same although, on average, the bottom weightings moved up towards the outliers. The highest weighting for the third criterion (impact on the community) also increased by 10 percentage points, thus increasing the spread. This could be due to discussion proceeding ranking where it was noted that one could also regard this criterion as a summarising item for all the social criteria. Concerning the remaining criteria, no significant change occurred in the jurors' weightings. This time, on average, 38.1 % weight were assigned to the economic criteria (previously 32.6), 46.6 % to the social criteria (50.5) and 15.3 % to the environmental criteria (16.9).

The outcome of the second round of weightings was (see also Figure 40) that Point Hut Pond remains No. 1 whereas Lake Tuggeranong rises from the fourth to the second position. Isabella Pond is ranked third (previously fourth) and NC18 falls from the second to the fourth rank.

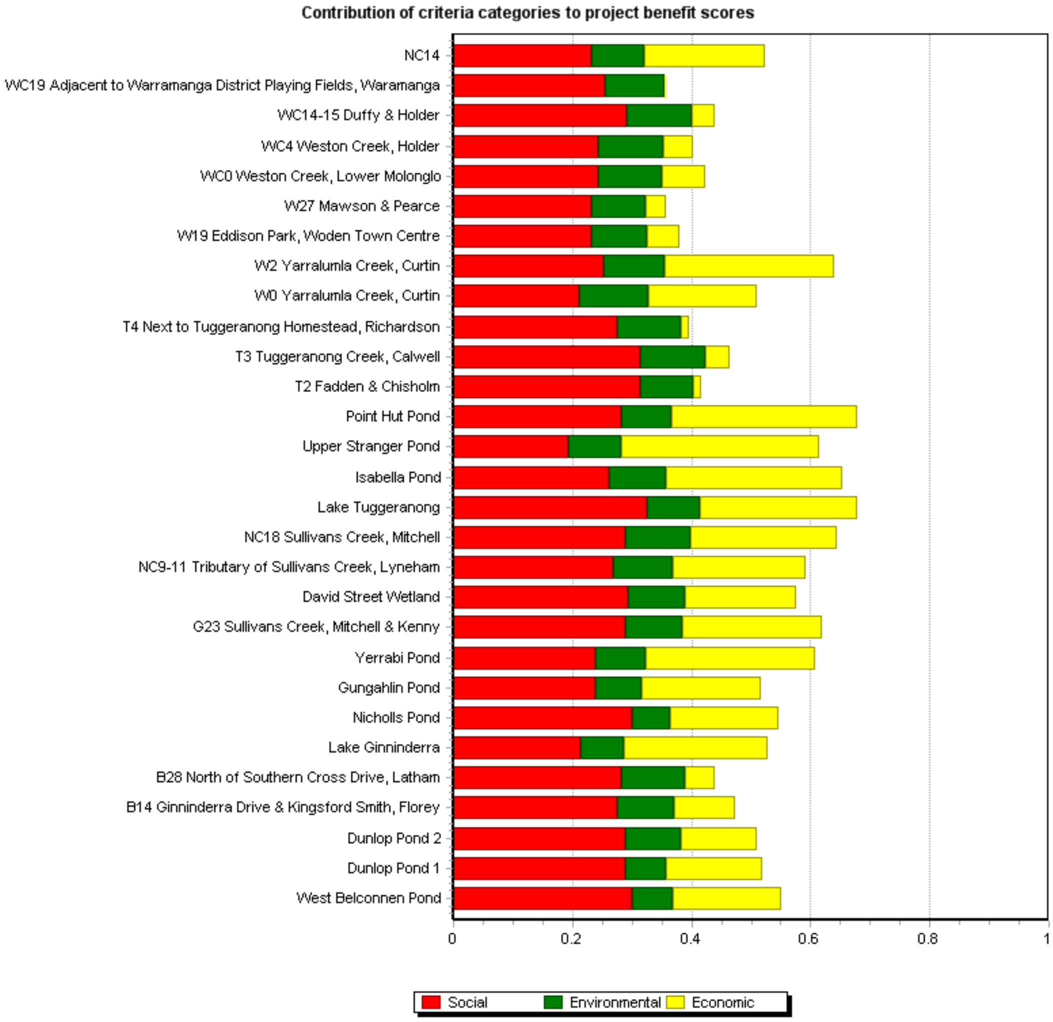


Figure 40: Contribution of criteria categories to project benefit scores in the second round

The top 10 performers from the first weighting still occupy the first ten positions (though in a different order). On the whole, 12 options have the same rank, 8 are worse and 9 are better ranked than before. Especially with regard to the options that performed best in the first weighting, the results seem to be quite robust with the biggest shift in rankings (in absolute values) being three.

Figure 40 also shows the contributions of each category to the benefit scores. Both social and environmental criteria (on average 0.27 and 0.09, respectively) now contribute less on average to each option's benefit score due to higher weightings put on the economic criteria which contribute 0.16 to the overall score (previously 0.13). Average benefits decreased by 0.03. The widest variation in the contribution can again be observed for the economic criteria (standard deviation 0.10) whereas social and environmental criteria show lower variations (standard deviations of 0.03 and 0.01, respectively).

10.2.3 Sensitivity analysis

Between the first and the second set of weightings, disagreement, particularly with regard to the economic criteria, has increased. The spread in weightings for the third criterion (impact on the community) was also considerably higher than before.

The discussion in the workshop showed that there is still much uncertainty in the understanding of levelised costs. Some jurors were arguing that levelised costs would not take into account that some of the projects are already being funded elsewhere. The second financial criterion, volumetric reliability, was also highly controversial as this figure was perceived very differently by the members of the jury. For most of the other criteria, the spread between highest and lowest percentage assigned remained approximately the same.

Since all top performers from the first ranking remained under the top 10, the result is quite robust with regard to little changes in weightings. On the whole, options with relatively low levelised costs performed better in the second ranking because of higher weights put on the financial category. Compared to the other categories, the jurors did not put much weight on the environmental criteria, thus implying that they did not consider them very important.

The final ranking of pond options was:

1. Point Hut Pond
2. Lake Tuggeranong
3. Isabella Pond
4. NC18 (Sullivans Creek, Mitchell)
5. W2 (Yarralumla Creek, Curtin)
6. G23 (Sullivans Creek, Mitchell & Kenny)
7. Upper Stranger Pond
8. Yerrabi Pond
9. NC9-11 (Tributary of Sullivans Creek, Lyneham)
10. David Street Wetland

In order to check if the results are robust against other sets of weightings, a sensitivity analysis that varies the criteria or category weightings can be carried out. In this paper, the following two variations are considered:

1. equal weights were put on all criteria which implies that the category containing more criteria gets a proportionally higher weight

2. each category received the same weight (i.e. each category has a weight of one third).

Consequently, social criteria which outnumber all other criteria have much less weight than before.

Equal criteria weights

If equal weights are assigned to the criteria, the weight of each criterion is 4.76%. This weighting differs significantly from those the jurors had assigned. The two economic criteria particularly lose much weight. Not surprisingly, the ranking was also almost completely reshaped. NC18, previously number 4, is now in lead while former best performer Point Hut Pond is ranked on tenth position only (see Figure 41). Fourteen options have deteriorated in rank, 14 have changed for the better and only one option remained on the same rank, compared to the final weighting in the workshop. For example, Upper Stranger Pond has lost 19 positions (due to a very weak social and economic performance in the impact matrix). Importantly, the options are much more densely distributed, with a standard deviation in benefits of 0.052 compared to 0.099 after the second weighting.

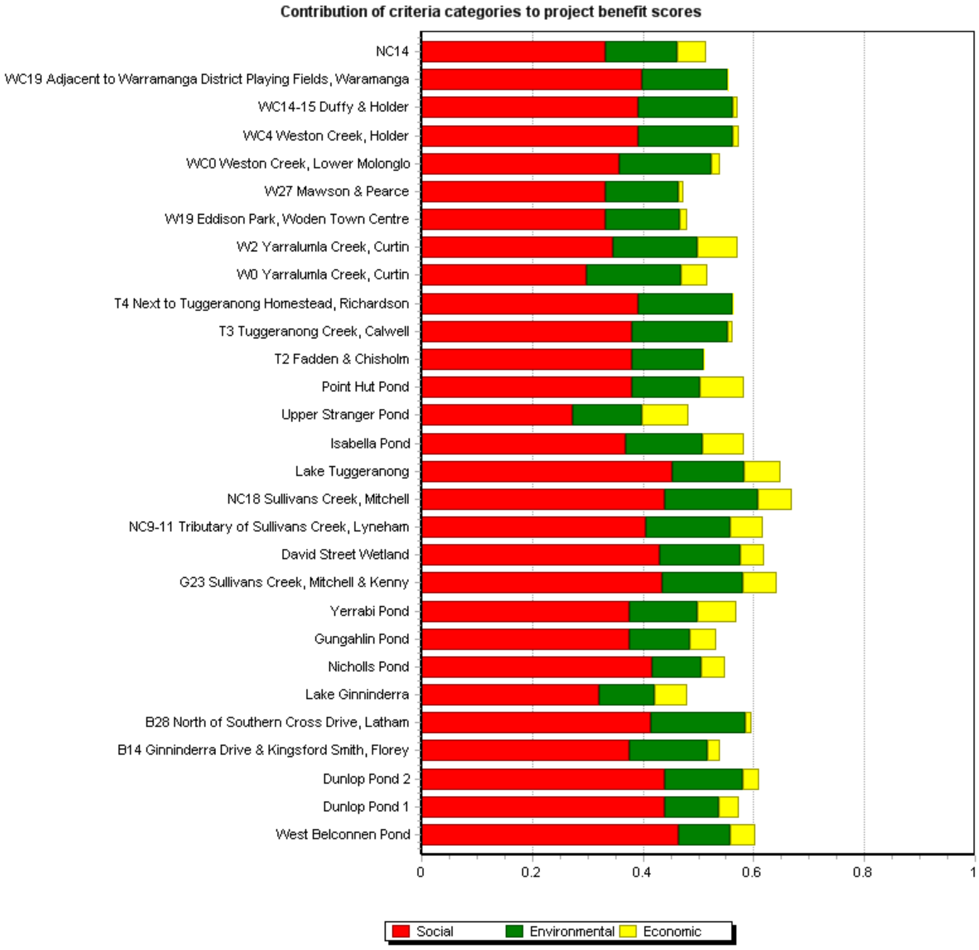


Figure 41: Contribution of criteria categories to project benefit scores under equal weights

The economic criteria (see yellow bars in Figure 41) have become less important and do not contribute very much to the overall score. Although Point Hut Pond (e.g. still performs very well with regard to economic criteria due to low levelised costs in the impact matrix), the contribution of these criteria cannot compensate for the weaker performance in social and environmental criteria and therefore Point Hut Pond falls nine levels in the ranking. The average benefit now is 0.56 (compared to 0.52 in the final workshop ranking), with 0.38 stemming from social criteria, 0.14 from environmental and the rest from economic criteria. Standard deviations for the category benefits are ranging from 0.03 (environmental and economic criteria) to 0.05 (social criteria), thus being lower on average.

Equal category weights

In this analysis, each broad category (social, environmental and economic) are given an overall equal contribution to the preferences regardless of how many sub criteria fall within these categories. Under this analysis, financial criteria have almost as much weight as they had after the second set of weightings. Furthermore, each social criterion has very little influence on the outcome (the weight for each social criterion is now 2.4 %) and the environmental criteria which were not considered very important by most of the jurors gain more influence now (their weight increased from around. 15 % in the final workshop weighting to 33 %).

The outcome when assuming equal category weights results in NC18 being ranked fourth in the final jurors' weighting, now performing best ahead of Isabella Pond (previously rank 3), W2 (previously rank 5) and Lake Tuggeranong (previously rank 2) (see Figure 42). Former winner Point Hut Pond is in fifth position now. Again, the top ten after the second weighting still rank among the first ten, with three options being on the same rank as before. On the whole, 12 options are better off, 12 are worse off and the remaining five have not changed their position. The biggest change was gaining and losing seven ranks.

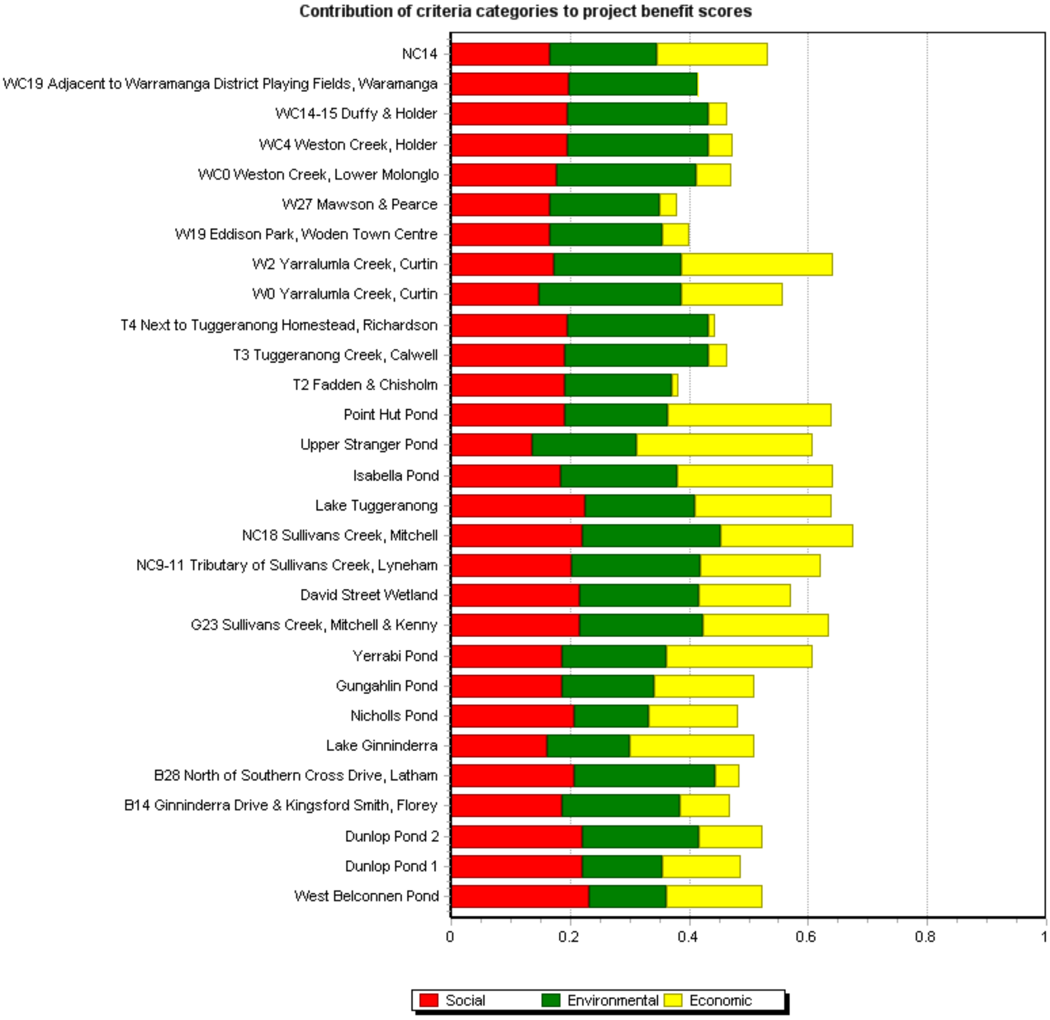


Figure 42: Contribution of criteria categories to project benefit scores under equal category weights

The average benefit score amounts to 0.53 and is only slightly higher than in the final jury ranking (0.52). The standard deviation of benefits, however, has decreased from 0.10 to 0.09 (i.e. benefits now lie closer together). Figure 42 also shows the category contributions to overall project scores. The average contribution of all social criteria is 0.19 (final ranking of workshop: 0.27), economic and environmental criteria make up 0.14 (0.16) and 0.20 (0.09), respectively. While social and environmental criteria do only have a low variation in benefits (standard deviations of 0.02 and 0.04), the category of economic criteria varies much more (standard deviation: 0.09). This implies that the economic criteria make the difference in the ranking (see Figure 42). The ten top performers do very well in the economic criteria which bring them ahead of the other options.

Refinement of decision criteria

As a result of the final meeting with stakeholders, it was decided that some of the social and environmental criteria being used to assess the options could undergo some refinement particularly with respect to possible double counting or lack of clarity of meaning. Eight of the initial social criteria were refined to a total of six and some of the scores revised accordingly. One of the environmental criteria was deleted as it was seen to double up with another and the scoring on one other refined to better reflect its representation. A new criterion was added on algal risk to reflect the responses of the workshop (see Table 37). The results as per revised decision criteria are shown in Figure 43 with the top ten pond options virtually remaining the same but in slightly different order as follows:

- Point Hut Pond
- W2 Yarralumla Creek, Curtin
- Upper Stranger Pond
- Isabella Pond
- Yerrabi Pond
- NC18 Sullivans Creek, Mitchell
- Lake Tuggeranong
- NC9-11 Tributary of Sullivans Creek, Lyneham
- Lake Ginninderra
- G23 Sullivans Creek, Mitchell & Kenny

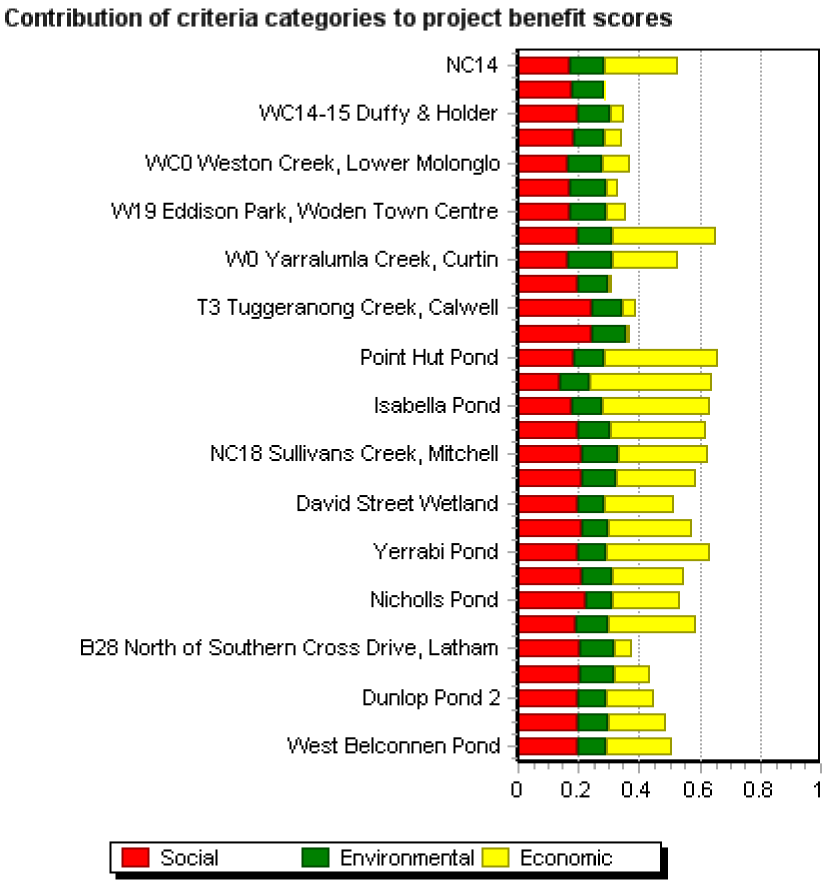


Figure 43 Contribution of criteria categories to project benefit scores under changes to some criteria

Table 37: Revised decision criteria as per stakeholder interests

No	Criteria
1	Impact on the community
2	Impact on households
3	Equity of access to water
4	Impact on land prices
5	Ecological habitat
6	Community support
7	Levelised cost
8	Aquatic vegetation
9	Algae
10	Drawdown harvesting
11	Difference in drawdown
12	Water quality
13	Volumetric reliability

Table 38: Rankings according to different weightings (the blue coloured area shows the performance of the top ten options from the first ranking, red font means that these options cannot be properly assessed because of lack of real data for the social criteria)

No.	Option description	First ranking	Second ranking	Ranking equal weights	Ranking equal category weights	Final ranking
17	Point Hut Pond	1	1	10	5	1
13	NC18 Sullivans Creek, Mitchell	2	4	1	1	6
10	G23 Sullivans Creek, Mitchell & Kenny	3	6	3	6	10
14	Lake Tuggeranong	4	2	2	4	7
15	Isabella Pond	5	3	9	2	4
22	W2 Yarralumla Creek, Curtin	6	5	13	3	2
12	NC9-11 Tributary of Sullivans Creek, Lyneham	7	9	5	7	8
9	Yerrabi Pond	8	8	15	8	5
11	David Street Wetland	9	10	4	10	15
16	Upper Stranger Pond	10	7	26	9	3
1	West Belconnen Pond	11	11	7	13	16
7	Nicholls Pond	12	12	19	19	12
6	Lake Ginninderra	13	13	27	15	9
8	Gungahlin Pond	14	16	22	16	11
29	NC14	15	14	24	12	14
21	W0 Yarralumla Creek, Curtin	16	18	23	11	13
3	Dunlop Pond 2	17	17	6	14	18
2	Dunlop Pond 1	18	15	11	17	17
4	B14 Ginninderra Drive & Kingsford Smith, Florey	19	19	21	22	19
19	T3 Tuggeranong Creek, Calwell	20	20	17	24	20
5	B28 North of Southern Cross Drive, Latham	21	22	8	18	21
27	WC14-15 Duffy & Holder	22	21	14	23	25
25	WC0 Weston Creek, Lower Molonglo	23	23	20	21	23
18	T2 Fadden & Chisholm	24	24	25	28	22
26	WC4 Weston Creek, Holder	25	25	12	20	26
20	T4 Next to Tuggeranong Homestead, Richardson	26	26	16	25	28
28	WC19 Adjacent to Warramanga District Playing Fields, Waramanga	27	29	18	26	29
23	W19 Eddison Park, Woden Town Centre	28	27	28	27	24
24	W27 Mawson & Pearce	29	28	29	29	27

10.3 Summary and Conclusions

The overall analysis shows that the top ten options for stormwater harvesting identified in the master plan are extremely robust with respect their social, economic and ecological performances. As could be expected, the equal criteria weights totally changed the overall performance of the options because weights of each criterion were of very different percentages than those assigned by the jurors. There is however, no reason why the weights should be of equal weighting but this process was just undertaken to see that a careful assessment of the weights should be carried out as their values do make a difference to the overall outcome. If equal category weights are assigned, the results are rather robust because the categories receive more similar weights now. Additionally, the top ten options from the jury weighting perform very well in economic terms. Equal category weights were applied to address some of the concerns of the stakeholders that there were many more social criteria being assessed in the process than just economic and environmental criteria and this may have a bias towards those ponds that performed well on the social criteria. Even if the overall broad category contributions are equal (assuming that social, economic and environmental considerations are given overall equal importance in a triple bottom line assessment) then it does not change the top ten rated ponds to any great extent.

The summary of the rankings for different weighting schemes are outlined in Table 38. However, as mentioned earlier, one of the key objectives of the DMCE process is not to give emphasis to a ranking of the options because of the hydrological and ecological dependencies of some options. The results described in this chapter should only be used to understand relative benefits of individual options in the master plan in social, economic and environmental terms.

11 RISK ASSESSMENT OF STORMWATER HARVESTING

The aim of this chapter is to explore possible risks of options in the master plan both for the community and the environment.

This risk assessment provides a generic understanding of risk, and offers guidance on risk issues that should be considered in future work; it does not provide a full risk assessment for individual options or complete master plan. It is beyond the scope and resources of this project to examine a detailed risk assessment of all the options included in the master plan.

Information from the hydrology, ecology, and social assessments were collated as well as other available data to answer 'what if' questions about the performance of ponds with respect to key risks, their causes and controls under a range of conditions. The three key risks are:

- water supply security
- the environment and
- public health and safety.

Australian Standard AS 4360 (Standards Australia 2004) defines risk as the chance of something happening that will have an impact on objectives. It notes that risk is often specified in terms of an event or circumstance and the consequences that may flow from it, and is measured in terms of a combination of the consequences of an event and their likelihood. In risk assessment, identifying risks and evaluating their probabilities and associated impacts are two key tasks. Equally important is to trace the decisions that cause the risks. Specific manipulations of these causes to reduce or avoid risks are called controls. Controls are defined in AS 4360 as any existing process, policy, device, practice or other action that acts to minimise negative risk or enhance positive risk (opportunities). The word 'control' may also be applied to a process designed to provide reasonable assurance regarding the achievement of objectives. A more detailed description of risk assessment and management for integrated urban water systems may be found in Blackmore et al. (2008).

In line with the definitions of AS 4360, social and political attitudes and influences, economic instruments, institutional and operation arrangements in this report are considered as controls that help reduce the level of risk. The ACT already has legislation, monitoring and maintenance procedures in place for the operation of existing ponds and lakes, and has education and awareness programs available to the community. Such controls are an essential part of any stormwater harvesting scheme, and complement the structural, geotechnical and other components, reducing the risk of failure; their proper functioning is paramount to successful operation.

Satisfactory construction and ongoing management of individual ponds will depend on local circumstances. Site-specific data, such as proximity to roadways and housing and intended access and recreational use, will be required to assist in their design. Local geotechnical data are essential if the risk of supply security is to be kept at an acceptable level. For these aspects, a full engineering risk assessment should be conducted for each pond at the detailed design stage.

It should be noted that water supply security risk considered in this report addresses only the security of supply for ponds and lakes to meet their associated irrigation demand. While this risk will impact on overall risks relating to the security of the ACT’s potable water supply (generally by reducing demand, but in some cases there could be an increase), the overall impact will depend on the complete scheme (master plan). As discussed previously, analysis of complete schemes is beyond the scope of this report.

The following issues do not figure in the remainder of the risk section of this report, but are considered to be worthy of note here.

In the *Social Impacts of Water Management in Canberra Survey* residents from Weston Creek, Woden, Tuggeranong, Gungahlin, the Inner North and Belconnen reported that stormwater harvesting was the most popular alternative supply option appropriate for different regions of Canberra and for their own suburb (Chapter 0). It would seem from this response that the risk of a particular pond or lake option being unvalued by the community is low and independent of location. General support for construction and use of stormwater ponds means they are likely to be respected by the community and suggests a low socio-political risk. The risk of unequal access to the amenity of ponds or lakes has not been considered because it is confounded by numerous factors such as the demographics of participation in field sports and the personal mobility of the population.

Geotechnical difficulties include unexpected aquifer recharge conditions, large rock obstructions and/or leaky beds of ponds encountered during excavation. Such risks are minimised but not excluded by ensuring appropriate geotechnical surveys prior to design and construction. It is also advisable to conduct testing during construction and follow-up geotechnical inspections. These measures ensure that any deviation from design assumptions is reviewed and corrective measures put in place as and where necessary. Geotechnical details for particular recycled stormwater supply options were not available at the time of writing and a risk of unexpected additional cost depends on location.

Records indicate that approximately once in every ten years the ACT experiences an extreme rain event when the precipitation is around 100 mm in a single day. While quantitative assessments vary, it can be said that generally the frequency of such extreme weather events will increase due to climate change. Potential consequences are pond overflow, temporary issues with water quality, and potential flooding to nearby roads, houses, schools and critical infrastructure.

The provision of stormwater capture and re-direction infrastructure is designed to attenuate the effects of extreme rain events. As such, the proposed plan of stormwater capture and especially the use of ponds for irrigation should present a net reduction in the risk of flooding. Indeed, Canberra is situated on a natural 1 in 100 year floodplain and the addition of stormwater ponds does not greatly affect the risk of regional flooding. Specific ponds and ASR schemes may, however, alter the immediate location of flooding when it does occur, and flood risk assessment should be carried out as part of the detailed design for individual ponds.

11.1 The Risks

The three basic risks that were identified as being of concern are:

- water supply security

- risk to public health and safety and
- environmental risk.

Each risk will be affected by many aspects of the water system. Analysis frequently relies on a systems view where combinations of results from hydrology, economics, community and ecology have a bearing on the outcome.

In considering risks it is important to consider the worst possible outcomes that might result when the system is subjected to extreme or unexpected events. It is a false economy not to acknowledge such possibilities. By understanding their potential magnitude, and where necessary ensuring that preventative or mitigation controls are in place, the potential for disaster can be greatly reduced, even if 'likelihood' cannot be fully quantified.

11.1.1 Water supply security

In line with the project objective, the water supply security risk was originally phrased as the risk of the system failing to achieve a 3 GL reduction in potable water demand. As the project evolved, this risk was overshadowed by concerns about individual ponds failing to provide a reliable supply to the nominated irrigation area. The risk of failing to achieve a 3 GL reduction is a function of which and how many ponds are included in the final scheme, and is not considered further in this report.

During Stage 1, volumetric supply reliability was nominally calculated for each pond, and ponds and ASTR were only considered in Stage 2 if their ability to supply to their respective demand centres had greater than or equal to 95% reliability. The calculation method used provided a coarse scale indication of the ability of each pond to deliver; however, evaluation was based on long-term annual averages and involved a number of simplifications and assumptions that require further investigation if the risks are to be well understood.

In this report we consider the possibility of the ponds being unreliable in particular years and at particular months within a year. We also consider the controls on supply and demand, the possibility of demand centres not abiding by water restrictions and ecological factors affecting supply security.

11.1.2 Public health and safety

Although social impacts survey respondents said that amenity was more of a priority than safety, we have to consider the remote possibilities of drowning and other immediate hazards. For the assessment of health and safety risks we also ask what are the unlikely but possible chances and consequences of misuse of harvested stormwater (e.g. children drinking from the wrong tap at a sports ground). The increase in the area of water available for mosquito breeding and the effect of climate change will elevate the (currently low) risk of vector-borne disease. These risks need to be compared against the current frequency of water-related accidents and illnesses. The effectiveness of controls put in place to mitigate these risks also needs to be considered.

11.1.3 Environmental risk

The environmental risks considered here include the potential for change in (albeit artificial) habitat, the likelihood and impact of high nutrient loads and the possibility of algal blooms.

Several constructed ponds and lakes already exist and have already had an impact on the flow regime in the ACT. However, the increased drawdown on existing ponds and lakes may further affect stream flow. Both the increased drawdown and the construction of new ponds will, for example, have some impact on flows to the downstream Murrumbidgee River.

11.2 System Pictures of Ponds and Lakes

When considering the risks related to integrated systems, it is helpful to represent the system with a concept diagram. The basic physical concepts of the Canberra Integrated Urban Waterways project are represented in Figure 44 and Figure 45. The diagrams were used as a stimulus to generate questions about what *could* happen to the system. They should be used as a guide only, and do not fully represent all important social, environmental and economic interactions.

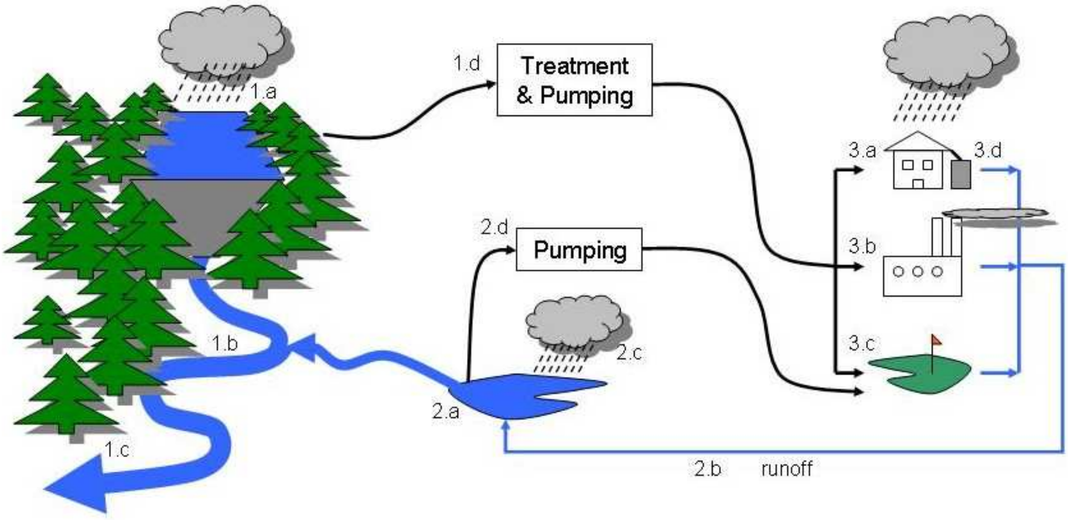


Figure 44: Basic system diagram

EXISTING SUPPLY 1.a – inflow to dams and dam level, 1.b – local stream flow, 1.c – ecological impact and downstream flows to Murrumbidgee, 1.d – centralised water treatment and delivery;
NEW OPTIONS 2.a – New and existing lakes, ponds and ASTR ponds and their connection to the Murrumbidgee, 2.b – urban run-off, 2.c – rainfall, 2.d – pumping and delivery of captured stormwater;
DEMAND 3.a – water used by residents, 3.b – water used by business, commerce and industry, 3.c – water use by parks, sportsgrounds, public and private facilities, 3.d – run-off from households after on-site capture.

Features of an individual pond and its associated irrigation area are shown in Figure 45: this figure forms the basis of the ‘what-if’ analysis, prompting us to think about all relevant issues.

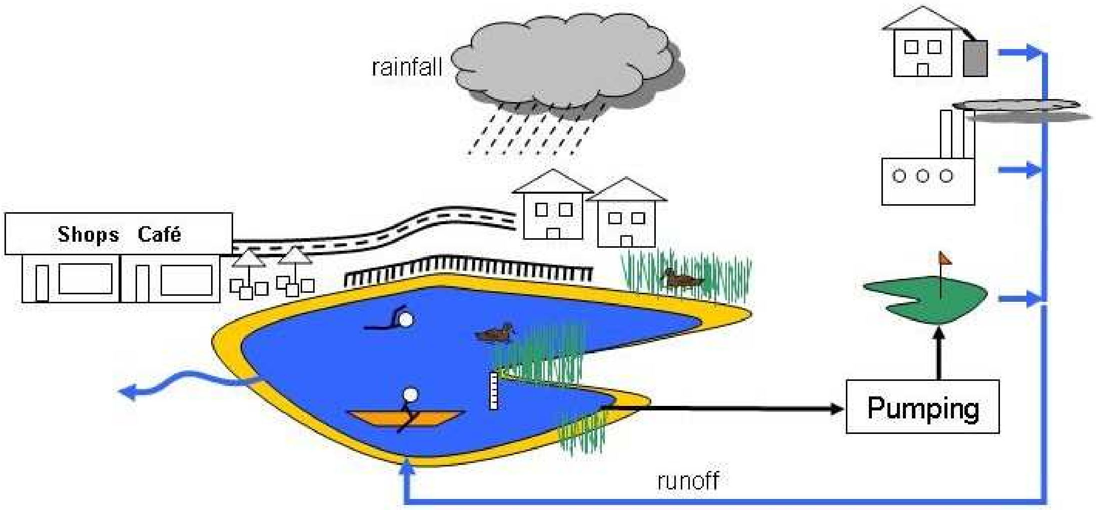


Figure 45: More detailed view of pond system. Note draw down, sloping sides, run-off from different land uses, adjacent roadway, houses, businesses, recreational use, partial surrounding fence, ecological habitat, illicit extractions and downstream flows, picnic area, and adjacent playing field with pump and pipe.

11.3 Information to Support the Risk Assessment

In assessing the likelihood and consequences of events that contribute to the identified risks, many of the calculations consider a combination of the analysis and measurements from the domains of hydrology, economics, ecology and social research. Additional data were sought from a variety of sources (see cited references) and from the analysts in the specialist areas. We sought:

1. information on the known or modelled ranges of performance for components of the system
2. the likelihood or frequency of (extreme) events that compromise that performance
3. information on thresholds, quantitative or qualitative, that:
    - represent the limit of performance of the system (e.g. total possible supply from ponds)
    - are based on legal, environmental, industry or safety standards (e.g. acceptable water quality)
    - represent other requirements or ambitions (e.g. impact on biodiversity).

11.3.1 Hydrology

The hydrological performance of the ponds fundamentally affects many of the risks directly. It also influences the social, economic and ecological assessments and thus also indirectly contributes to the evaluation of risk. For example, stormwater ponds may not be able to:

- supply the expected amount of water for irrigation

- may change flow regimes which affect the ecology and
- might flood and cause damage to nearby homes and infrastructure.

However remote these risks, they must be considered and they all rely on hydrological information.

11.3.2 Community

In addition to the hydrological drivers of risk some idea of the community's willingness to adopt and responsibly use the water from ponds and lakes for irrigation is also needed. Questions include:

- What are the chances of someone accidentally drinking stormwater from a tap at a sportsground where previously only potable water had been used?
- Do people see themselves as being responsible for managing the supply of water?
- What the possibilities are for cross connections?

While the social impacts survey produced useful results for the risk analyses, it should be remembered that results from surveys and focus groups reflect opinions and the self-assessment of participants; this may or may not translate into the *actual* behaviour of residents. Nonetheless, it is a useful indicator prior to implementation of pond and lake options.

11.3.3 Ecology

Generally there are ecological benefits from the introduction of ponds: excess nutrients are trapped and prevented from entering environmental flows, and the precipitous flow regimes, characteristic of urban run-off, are attenuated. The ecological analysis (Chapter 8) has provided information on hydrological loading and possible impacts on environmental flows to the Murrumbidgee River.

An assessment of the impacts of 50- or 100-day continuous dry periods was used to estimate impacts on shoreline vegetation under the assumptions of a 50 cm drawdown compared with the currently regulated 20 cm drawdown allowance. Note that for some ponds and lakes a 100 cm drawdown is proposed and even that may be exceeded because of evaporation or over-extraction.

The ecological assessment has provided some idea of the potential for blue-green algae blooms which affects supply security because water can not be used and informs potential health risks.

11.4 Water Supply Security Risks

11.4.1 Over extraction

The risk to supply security due to over extraction is influenced by growth in demand, excessive watering behaviour, illicit extraction or failure to comply with regulated limits. The aspect of demand growth is a risk perceived by the community with more than 80% of social impacts survey respondents identifying population growth and rainfall as two factors very important in determining whether Canberra has sufficient water (Question 15, Chapter 0).

Over extraction affects the long-term reliability of a pond or lake as there would be a more frequent loss of availability. The vulnerability to over extraction is low if regulation controls are in place and enforced. This is currently the case for existing ponds and lakes.

Calculations from the Stage 1 report assume a flat continuation of current levels of demand. However, the ACT population is forecasted to increase to between 390 000 and 460 000 by the year 2032 (ACT Chief Minister's Department, 2007). In the year 2050 the population may reach 500 000 and according to the Australian Natural Resources Atlas (Department of the Environment and Water Resources 2007) the water demand will increase to between 83 and 94 GL/yr.

Linked with population increase is the need for more housing and, particularly in Canberra, an associated need for public open space and playing fields. This may or may not significantly change demand for irrigation, but in dry times there may be the need to supplement non-potable pond irrigation supply with potable water. This has the potential to come in to conflict with potable water supply for other uses which might be under strain at the same time due to larger populations and/or dry conditions. An increase in population may also increase the non-permeable surface areas within the catchment of ponds and lakes, altering the hydrology so as to direct more stormwater towards (or away from) ponds and lakes.

Pre-existing connections means there is 'back-up' via substitution with potable water supply in times of extreme weather, although potable water connections may not exist for new irrigated areas.

The results of the social impacts survey indicate that people primarily identify the ACT Government and ACTEW as being responsible for managing water in Canberra. The survey also revealed that the community identifies itself as being responsible for achieving good water management outcomes (Question 15, Chapter 0). This suggests a low tolerance of illicit extractions and a greater likelihood of compliance with regulations.

The recent historical record of water restrictions, shown in Figure 46, demonstrates that generally there is a good correlation between the actual and target levels of water consumption during periods of water restrictions. It is notable, however, that actual consumption does regularly exceed water restriction targets during the summer months and on one occasion the difference was 50 ML/day on average for that month. That this coincides with the same months of lowest pond reliability is a concern.

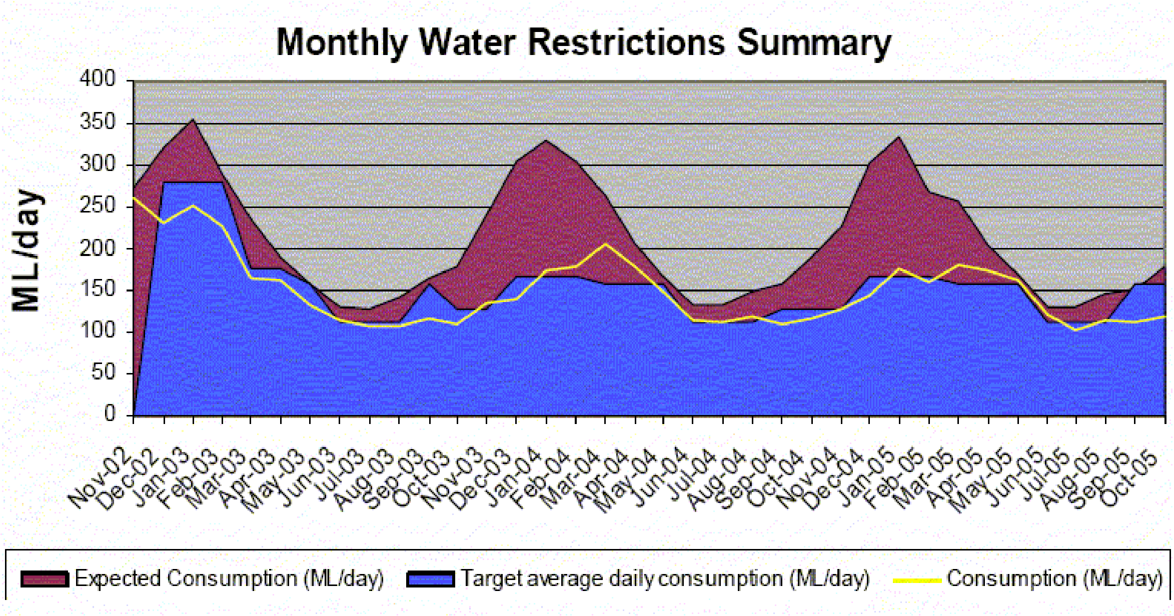


Figure 46: Summary of expected, target and actual monthly consumption of water in the ACT between November 2002 and October 2005. (ACT Chief Minister's Department 2007, p. 51).

Another aspect of the risk of over extraction is the impact of the drawdown on the aesthetic values of existing lakes. For example, as well as providing for stormwater detention, Lake Ginninderra is a popular recreation facility, supporting swimming, boating, fishing, cycling and walking and the lake foreshores are greatly valued (ACT Territory and Municipal Services, 2006). While these values are acknowledged, the risks involved due to over-extraction are difficult to quantify and are not assessed in this report.

11.4.2 Pump failure

Possible causes of pump failure include operational fatigue and gross pollutants in the system. Potential impacts are primarily a reduced availability of water and secondarily increased exposure to flooding. Pump lifetimes were assumed to be approximately 15 years and costs of operation, maintenance and replacement of pumps have been accounted for in developing the master plan. These options have greater than 95% reliability and the risk of pumps compromising supply for any extended period is low, given a properly attended maintenance schedule. There is potential for gross pollutants to block pumps although filters, gross pollutant traps and regular maintenance relegates this risk to being low. Such controls are in place for at least one existing supply location (Canberra Urban Parks and Places, 2001) and there are nearly 90 gross pollutant traps around the ACT (ACT Chief Ministers Department, 2007). Any properly designed new stormwater pond would include a gross pollutant trap where appropriate.

The event of a broken pump resulting in flooding requires that the pump malfunction would have to coincide with extreme weather and simultaneously the blockage of a spillway or weir. Such specific circumstances are highly unlikely and this risk is also estimated to be low.

11.4.3 Inter-annual rainfall variability

It will be readily acknowledged that Australia’s climate is highly variable. There is a wide range of variation in annual climate patterns with extremes in rainfall and dry periods. Consequently, volumetric reliability in a *particular* year might be lower than the 95% used for developing the master plan, which was averaged over the course of many years in a climate sequence. Using the same climate sequence, we obtained data on the daily status of success or failure for each pond to deliver the water demanded of it for irrigation. Taking an average of failure rates across all ponds for each year of a 65-year climate sequence, adjusted for climate change as per the Stage 1 report and ACTEW (2006), we derived the graph in Figure 47.

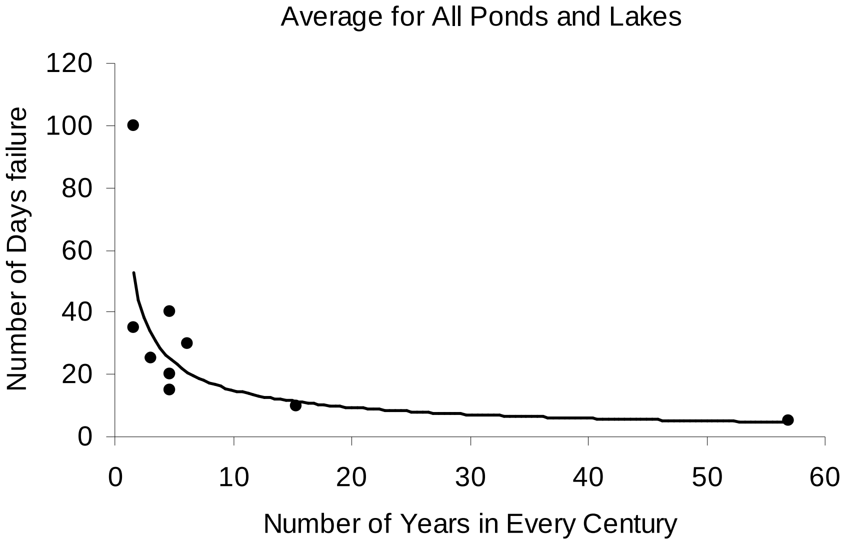


Figure 47: Rate of pond failure in days per year plotted against the number of years that rate would occur in a century. Note that there is about 1 year in every century where *all* ponds on average will not be able to supply water for 100 days. The trend line added is for guidance only.

A more detailed depiction of the risk to water supply security, for each stormwater capture option, can be seen in Table 39. The metric of 'average number of days of pond failure' has been used to rank the ponds and lakes from most reliable to least. A ranking of options based on percentage of years where more than 50 days of failure occur would seem to produce the same ranking with the notable exceptions of Lake Ginninderra and Lake Tuggeranong. 'Failure' in this context is the inability of the recycled stormwater supply option to supply water for irrigation. These calculations are derived from the hydrological analysis and are based on the 65-year projection of run-off under climate change assuming a 100 cm drawdown. While the ranking may or may not change, the average number of days of pond failure and the percentage of years where more than 50 days of failure occur would increase if the allowable drawdown was less than 100 cm.

Table 39: Rank of stormwater capture options with respect to average days of pond failure. Also shown is the percentage of years that ponds or lakes are unable to deliver water for irrigation for more than 50 days (based on the 65-year projection of rainfall under climate change and assuming a 100 cm drawdown).

Ponds	Average days of pond failure per year	% of years with 50 or more days of failure
Isabella Pond	0	0.0
Tuggeranong Weir	0	0.0
Point Hut Pond	1	1.5
Upper Stranger Pond	2	1.5
Yerrabi Pond	6	1.5
Lake Tuggeranong	6	4.6
West Belconnen Pond	7	4.6
Lake Ginninderra	8	7.7
B14	9	0.0
Gungahlin Pond	10	3.1
B28	10	3.1
WC14-15	10	3.1
WC19	10	3.1
T4	10	3.1
David St Wetland	11	3.1
WC4	11	3.1
T3	11	3.1
T2	11	4.6
W27	11	3.1
Dunlop Pond 1	13	12.3
Dunlop Pond 2	14	10.8
Nicholls Pond	14	12.3
WC0	18	12.3
W19	42	21.5

11.4.4 Monthly variability

While every pond or lake option identified in the Stage 1 report has a volumetric reliability of at least 95%, the remaining 5% are not spread evenly over months within the year. Again we used the data on the daily status of success or failure for each pond, this time calculating the failure rate per month. We took an average for each month across all ponds for the whole 65-year climate sequence adjusted for climate change as per the Stage 1 report.

From Figure 48 there is clearly a greater likelihood of pond failure occurring in the summer months. Even considering this distribution, the monthly reliability at the most affected time of year is still greater than 90% on average.

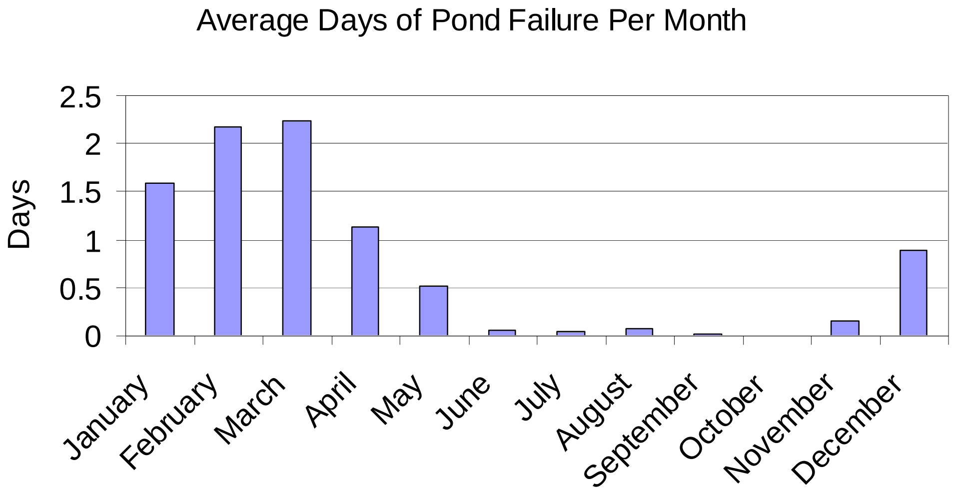


Figure 48: Average monthly rate of failure of ponds to deliver water required for irrigation. Averaged across all ponds considered in the master plan (each with a long-term average reliability of >95%) and averaged over the full climate sequence used in the Stage 1 report.

The above two results on variability rest on the same assumptions as the hydrological assessment done in Stage 1 which include a flat continuation of current levels of demand and a low level of demand for irrigation in the winter months.

11.4.5 Loss of pond capacity

Pond capacity might be compromised by silting or illegal dumping. This might lead to reduced storage capacity but is unlikely to affect water available for drawdown.

From the stakeholder meeting held on 23 June 2008, one issue that was identified was that ponds have a tendency to silt up. The need for ongoing dredging and maintenance presents a potential economic cost in proportion to the risk of silting. This, in turn, depends on the size of pond catchment areas and their land use. Monitoring and managing the ponds is essential to prevent silt blocking the designed spill ways or interfering with the functioning of pumps.

Full assessment of this aspect of pond management requires location specific geotechnical information not available to the authors. The values expressed in focus groups and in the social impacts survey suggest a level of respect for ponds and lakes in the community that places the risk of illegal dumping at a low level.

11.4.6 Water quality prohibits use

The intended end use of the stormwater captured in ponds and lakes for irrigation means that the water quality from urban run-off is unlikely to prohibit the use of the water.

However, the potential for blue-green algal blooms presents a risk that the water would be unsuitable for any use. This depends heavily on the specific hydraulic characteristics of the ponds and climate conditions.

Algae need relatively still water and access to light. This situation is unlikely to occur in the proposed new ponds as most of them have low volumes and a high turnover rate. Drawing down further on existing ponds is also unlikely to exacerbate the general threat of blue-green algae although the ecological analysis suggests that harvesting increases the chances of the extreme-case outbreaks that occur every ten years or so.

For existing ponds and lakes, thresholds for water quality and other environmental indicators have been established. In those cases the size of the ponds, hydraulic loading and regular monitoring mitigate the risk associated with water quality prohibiting use. It would be expected that the same standards of practice would be applied to new ponds.

There are high levels of uncertainty around the possibility of using aquifer storage. The study acknowledges that further investigation is required if the proposed schemes are to proceed. It is assumed that any stormwater added to the aquifers will be at least as high quality as the current reserves.

11.5 Public Health and Safety Risks

11.5.1 Drowning

Frequency of death by drowning in the ACT is low compared with other causes. According to Dugdale et al. (2006), 2% of injury-related mortality for ACT residents between 2001 and 2003 were due to drowning. There were no drowning in ponds and those associated with lakes generally involved boating accidents.

Easy access to deep water and, in particular, unrestricted access for children could result in an increase in the currently low risk of drowning. This may only be a slight increase on existing levels of risk roughly in proportion to the additional length of shoreline introduced with new ponds. If preventative measures such as gently graded lake edges, signage, zoning of lake areas and designated swimming areas are in place, the additional risk of additional ponds and lakes is still low. These provisions are generally in place for existing ponds and lakes like Lake Ginninderra.

Ponds, and open and closed large drains, present a major attraction for children. In the planning of Canberra, many of the schools have been located adjacent to urban waterways, providing an alternative movement system to roads and associated traffic hazards. ACT authorities maintain an educational program across the schools regarding water hazards and safety.

Recorded waterway drowning in the ACT have been largely associated with children being caught in high velocity open channel flows during storms, with the high velocities and steep concrete edges making escape from the channel extremely difficult. There has also been a number of drowning of children playing in ‘in-ground’ large pipe drains. The proposal for harvesting of urban stormwater, and attenuation of peak flows provided by ponds, will effectively reduce the peak flows in open channels, thereby reducing the existing drowning risks.

The edges of ponds and lakes in Canberra are graded at a slope of 1 in 7 to 1 in 10, to ensure that there is no sudden hidden increase in water depth (backyard pool situation), whereby a child would be unable to retreat from the pond. In addition, the edges are planted with aquatic plants to discourage entry by children. There is no requirement to fence ponds in the ACT.

Elevated water flow velocities in the vicinity of spillways at times of heavy rainfall represent a potential safety hazard. Fences and floating booms that exclude the public from these areas have been installed at existing lakes (ACT TaMS 2006) and such measures greatly reduce the risk of drowning during high rainfall events.

Accidental ingestion

Given the land use in their catchments urban lakes may be subject to health hazards such as toxic blue-green algal blooms or high faecal bacteria counts. Depending on local access and activities at ponds and demand centres there is a risk of the accidental ingestion of water containing algae, cryptosporidium, pollutants, and micro-organisms. The possible consequences of this might be gauged from the cryptosporidiosis outbreak in Canberra in 1998 resulting in nearly 400 notifications of sickness or hospitalisation (Dugdale et al. 2006). Fifty-three percent of social impacts survey respondents were 'very concerned' with water quality and this was clearly an important issue for people (Questions 9, 12 & 17, Chapter 0).

The likelihood of accidental ingestion is rated as unlikely because it requires the combination of at least three factors:

1. the water quality would have to be so poor it could cause illness
2. there would have to be some sort of activity involving the pond or stormwater from the pond so that water could be accidentally consumed
3. someone would have to choose to drink the water in spite of warnings to the contrary.

For existing urban lakes, the water quality is monitored by health and environmental agencies, who issue public health warnings in the event of toxic blue-green algae or faecal bacteria representing a potential risk to health. Controls on the quality of run-off can be found in Section 1.1.6 of the Design Standards for Urban Infrastructure (ACT Territory and Municipal Services, 2002).

The interception of stormwater discharges and the possibility of sewage overflow into stormwater mean that the water quality in the wetland may have elevated faecal levels. Depending on the size of the new ponds and ASR, and the variability in the quality of stormwater inflows, bacterial numbers in the wetland will likely be outside levels for safe swimming, particularly following storm events.

Where ponds and constructed wetlands are not intended to be used for swimming or other recreational activities, the risk of contact with bacterial infection is reduced. It is understood that macrophyte planting around the edges of new and existing ponds will act as a deterrent for people to enter the water.

There is some concern about the last of the three risk factors mentioned earlier:

- 38% of the social impacts survey respondents thought that drinking would be an appropriate use of collected stormwater and recycled water (Question 12, Chapter 0)
- 33% of 421 respondents said that they sometimes drink tank water and
- 9% of 413 people surveyed sometimes drink bore water.

These statistics are only a gauge and contribute no information on people’s drinking behaviour in response to warnings but, if anything, they elevate the risk of accidental ingestion.

The potential for accidental ingestion of recycled stormwater can be minimised by the adoption of different and distinctive pipe reticulation materials and fittings to potable water supply, the exclusion of surface tap outlets, the installation of warning signs and community education. The decentralised basis of the urban stormwater harvesting, supply nodes and demand centres also limits the extent and therefore access to recycled stormwater reticulation lines.

Vector borne disease

Although this study has not evaluated potential increases to mosquito breeding grounds, sensible design features such as the graded edges used at Lake Ginninderra minimise the local mosquito nuisance. It would also be expected that the design of Canberra’s lakes and ponds would aim to encourage mosquito predators.

The Department of Land and Water Conservation NSW *Constructed Wetlands Manual* incorporates a mosquito hazard risk assessment protocol (Russell & Kuginis 1998). The questions for such a risk assessment are:

- Does the area have pest mosquitoes?
- Does the area have vector mosquitoes?
- Is access to pathogen hosts uncommon or common?
- Is inflow to the wetland not sewage?
- Does the operation of the wetland give priority to mosquito control in times of peak breeding?

The protocol also calls for pre and post construction monitoring to determine likely hazards. We attempt to answer the above questions in turn.

A study of Jerrabomberra and Tuggeranong wetland areas undertaken in 1986/87 reported that 75% of trapped adult mosquitoes were ‘containers and isolated pockets of water’ related species (*Aedes notoscriptus*). Of the remaining 25%, the ‘wetland’ based species were potential vectors of diseases (*Anopheles annulipes*, *Culex annulirostris* and *C. australicus*). These surveys were based on shallow wetlands of 100 – 300 mm depth which is more conducive to mosquito breeding than the proposed depth of ponds. However, where ponds are drained significantly this may produce enlarged areas of shallow water suitable for mosquito breeding.

Where ponds replace existing areas that are flat or poor draining and subject to flooding during heavy rain, the construction of a wetland may reduce hazards by relieving the original inundated vegetated areas of mosquito habitat.

A case study of David St wetland (Mawer 2002) found that there were actually many more mosquitoes trapped around residential areas than around the wetland. There may be differing experiences in other locations and with different designs but this does show that wetlands do not necessarily increase the mosquito pest problem.

Access to pathogen hosts is uncommon. The underlying incidence of vector-borne diseases such as malaria, Ross River virus and Dengue fever in the ACT can be seen in Table 40 and Table 41 below. These rates are generally low compared with the rest of Australia except for malaria. This latter statistic is more likely to be due to travellers returning from overseas with malaria rather than local mosquito populations.

Table 40: Incidence of vector borne disease reported in the ACT for the year 2003 (Dugdale et al. 2006)

	ACT	**NSW**	**Australia**
Malaria	18	120	601
Dengue	7	69	868
Ross River virus	1	492	3841
Barmah Forest virus infection	1	451	1370

Table 41: Incidence per 100 000 of vector borne disease reported for the year 2003 (Dugdale et al. 2006)

	ACT					**NSW**	**Australia**
Year	**1999**	**2000**	**2001**	**2002**	**2003**	**2003**	**2003**
Malaria	7	5.6	5.6	4	5.6	1.8	3
Dengue	0.6	0.3	4.7	0.9	2.5	1	4.3
Ross River virus	2.5	4.9	3.1	0	0.6	7.3	19.1
Barmah Forest virus infection	0	0	0	0	0.3	6.7	6.9

Research suggests the range of disease bearing mosquito species is changing with the climate although this may be mitigated with existing or expanded medical services:

> *Climate scenarios suggest that conditions in some parts of Australia and New Zealand will become more favourable for the transmission of several vector borne diseases. However, whether this potential risk will translate into an increase in cases of disease will depend on other factors such as the maintenance and expansion of the public health surveillance and response system*. (IPCC Third Assessment Report, Chapter 3: *International consensus on the science of climate and health* p53)

For the long-term scenario of climate change (beyond the terms of this study), the projected increase in temperature suggests an increased potential for Murray River virus, Ross River virus, and malaria. This increase may be more prevalent in areas of south-eastern Australia at lower altitudes than Canberra. Increased exposure may not translate into increased risk given the medical facilities available in the ACT and community education programs.

It is understood that inflow to lakes and ponds will not be sewage and the operation of these water bodies will give priority to mosquito control in times of peak breeding. Possible controls may include chemical control agents when appropriate.

The ACT has a management approach (Russell & Kuginis, 1998) for mosquitoes that includes:

- sediment management: avoid shallow sedimentation zones which would create shallow or exposed moist sediment conducive to breeding and exclude many predators

- depths and slopes: promote deeper (2 m) wetlands with steeper (1 in 4 to 1 in 6) edges and less vegetation to minimise the potential for mosquito breeding and maximise access by predators
- vegetation: extensive dense stands of emergent plants are avoided – plants are selected to limit density and attract mosquito predators
- water level: use of variable water depth to limit extent of emergent plants, to strand vegetation and larvae at critical times, and to strand larvae before reaching the adult stage
- water quality: exclude sewage and industrial discharges high in organic material, interception and removal of gross pollutants before inflow to wetlands.

At least one of these strategies is at odds with safety management – designing steeper gradients to the edges of ponds and wetlands. There is a potential trade off in minimising the risk of mosquito pest with that of drowning that has to be considered at the design stage.

11.6 Environmental Risks

11.6.1 Local habitat change

The construction of new water bodies or wetland areas will, if anything, increase the provision for habitat and biodiversity. Any impact due to altered stream flows, increased drawdown, flooding, tourism or other human activity depends on local conditions and such design factors as the gradient of the banks.

This report only considers the risks associated with an increased drawdown on existing ponds and lakes and makes the assumption of an average gradient of 1 in 10 at the edge. Thus if a drawdown of 20 cm is allowed this could expose 2 m of shoreline. A 50 cm drawdown would expose 5 m of shoreline.

If there is a sustained dry period of 50 or 100 days which recurs about every three years, the ecological analysis suggests that this will overexpose the vegetation at the edge area. Such conditions are likely to occur during the summer months for particular lakes and ponds. Table 42 and Table 43 give details on the incidence of 50- and 100-day dry periods, with an average return interval (ARI) greater than years, for each pond. We should reiterate that even if *new* ponds are vulnerable to this effect, they will still provide a net benefit to the environmental value of the area wherever they are sited. Hence we do not consider new ponds in this risk estimate.

Table 42: Average return intervals (ARI) for 100- and 50-day dry periods and risk potential during summer harvesting assuming a 50 cm drawdown and an edge gradient of 1 in 10. Where the ARI is <3 years for either the 50- or 100-day dry periods this represents a risk to the viability of a 5 m strip of shoreline vegetation.

Pond name	ARI 100-day (years)	ARI 50-day (years)	Risk (Y/N)
Existing			
David St	44	14	
Dunlop Pond 1	8	3	Y
Dunlop Pond 2	13	5	
Ginninderra	7	3	Y
Gungahlin	13	3	Y
Isabella Pond			
LakeTuggeranong	7	4	
Nichols Pond	5	3	Y
Point Hut Pond	20	7	
Upper Stranger Pond	42	18	
West Belconnen	5	3	Y
Yerrabi	8	4	
New			
B14			
B28	49	7	
T2	19	3	Y
T3	40	7	
T4	48	7	
W19	35	3	Y
W27	19	3	Y
WC14-15	50	9	
WC19	38	5	
WC4	60	8	
G23	45	14	
NC14	15	3	Y
NC18	26	4	
NC9-11	27	4	
W0	12	3	Y
W2		49	
WC0	25	4	

Table 43: Average return intervals (ARI) for 100- and 50-day dry periods and risk potential during summer harvesting assuming a 20 cm drawdown and an edge gradient of 1 in 10. Where the ARI is <3 years for either the 50- or 100-day dry periods this represents a risk to the viability of a 2 m strip of shoreline vegetation.

Pond name	**ARI 100-day (years)**	**ARI 50-day (years)**	**Risk (Y/N)**
Existing			
David St	35	4	
Dunlop Pond 1	3	1	Y
Dunlop Pond 2	5	3	Y
Ginninderra	4	2	Y
Gungahlin	5	2	Y
Isabella Pond	47	29	
Lake Tuggeranong	6	2	Y
Nichols Pond	2	1	Y
Point Hut Pond	6	2	Y
Upper Stranger Pond	19	3	Y
West Belconnen	2	1	Y
Yerrabi	3	2	Y
New			
B14		16	
B28	35	4	
T2	8	2	Y
T3	24	4	
T4	35	4	
W19	10	2	Y
W27	8	2	Y
WC14-15	37	4	
WC19	24	3	Y
WC4	47	6	
G23	26	7	
NC14	7	2	Y
NC18	16	2	Y
NC9-11	17	3	Y
W0	6	2	Y
W2	57	9	
WC0	14	2	Y

11.6.2 Water quality affects ecosystem

Water quality can still present an environmental risk even if it doesn't compromise the end-use of the water. The proximity of ponds and lakes to roads, farmland, pollutants, fertilisers and other urban run-off affects the local ecosystem of the pond and the quality of water entering environmental flows to the Murrumbidgee River. We have focused on the latter.

One of the performance indicators in *Canberra's Urban Lakes and Ponds Plan of Management* (Canberra Urban Parks and Places 2001) is that there should be a total phosphorous (TP) retention >70%. The ecological analysis has enabled us to calculate the theoretical TP retention efficiency for all new and existing ponds. For this to be >70% the hydraulic loading (equal to the inflow/area) generally has to be *less* than approximately 8.5 m/yr (Duncan, 1998). However, the size of the pond is also a factor (Wong et al. 1998). If the hydraulic loading is *greater* than 8.5 m/yr, the volume of the pond might still be large enough to process the nutrients. Processing capacity is important for detaining phosphates and nitrates from heading downstream to the Murrumbidgee. For new ponds TP retention efficiency is either neutral or positive with respect to current stormwater flows. Information on specific ponds is given in Table 44.

The calculations in Table 44 are an underestimate of TP removal efficiency as they do not account for harvesting. The harvested water will contain TP, thus removing greater volumes of TP from the waterway. Harvesting will also reduce the hydraulic loading by freeing up storage volume in the pond, thus further improving the TP removal efficiency.

Table 44: Hydraulic and nutrient processing capacities of ponds and lakes

	Volume (ML)	Surface area (ha)	Hydraulic loading (m/yr)	TP retention efficiency (%)[b]	Nutrient processing conditions[a]	Effect on nutrient flows
Existing						
David St.	3.0	0.3	76	22	Wetland	Positive
Dunlop Pond 1	14.0	0.7	16	61	High vol.	Positive
Dunlop Pond 2	13.9	0.7	8	72	High vol.	Positive
Ginninderra	3555.2	105.6	9	69	High vol.	Positive
Gungahlin	554.2	23.8	19	58	High vol.	Positive
Isabella Pond	72.0	5.8	60	29	High vol.	Positive
Lake Tuggeranong	2551.5	56.7	11	67	High vol.	Positive
Nichols Pond	48.0	4.0	3	80	High vol.	Positive
Point Hut	336.0	16.8	7	72	High vol.	Positive
Upper Stranger	45.1	4.5	16	61		Positive
West Belconnen	100.0	10.0	2	83	High vol.	Positive
Yerrabi	444.2	26.7	5	76	High vol.	Positive
New						
B14	1.7	0.1	1430	0	High turn.	Neutral
B28	8.2	0.4	117	5	High turn.	Positive
T2	35.7	1.8	31	47	High turn.	Positive
T3	28.0	1.4	69	25	High turn.	Positive
T4	9.3	0.5	292	0	High turn.	Neutral
W19	61.7	3.1	36	44	High turn.	Positive
W27	49.2	2.5	31	47	High turn.	Positive
WC15	6.0	0.3	149	0	High turn.	Neutral
WC19	8.2	0.4	51	34	High turn.	Positive
WC4	16.4	0.8	212	0	High turn.	Neutral
G23	10.5	0.5	180	0	High turn.	Neutral
NC14	37.9	1.9	24	53	High turn.	Positive
NC18	67.0	3.4	50	35	High turn.	Positive
NC911	13.6	0.7	110	8	High turn.	Positive
W0	240.0	12.0	30	48	High turn.	Positive
W2	6.9	0.3	1066	0	High turn.	Neutral
WC0	65.7	3.3	72	24	High turn.	Positive

[a] Assessed as volume >10 ML

[b] Theoretical calculation TP % = 11.68 × $(\text{hydraulic loading})^{0.44}$ using the results of Duncan (1998)

11.6.3 Environmental Flows

Here the question is how the changes to urban run-off will affect the quantity of water flows to the Murrumbidgee River and any associated impacts. The environmental flow is important for a number of reasons and urban run-off is a particular consideration:

> *The maintenance of river flow regimes and water quality are fundamental to good river health. Ecological processes which sustain native fish and frog populations, vegetation, wetlands and birdlife depend on it. Programs need to be developed that control inappropriate water flows and urban run-off which can result in increased erosion and sedimentation and reductions in water quality*. (NSW Department of Environment and Conservation 2005)

The quantity of water leaving the ACT per year in the Murrumbidgee River is regularly 100 times more than annual urban run-off flows. However, urban stormwater capture can influence at least two aspects of flows in the catchment:

- the non-permeable nature of land use in urban catchments imposes an artificially ‘flash flow’ regime, which stormwater ponds help reduce
- in times of water scarcity, when irrigation demands are at their peak and run-off is at its lowest, there is a small risk of urban stormwater capture exacerbating stressed environmental flows.

The hydrological analysis assumed a 25% loss to groundwater which was treated as truly ‘lost’ whereas in reality it will still contribute to base flow. However, given the complex dynamics of groundwater, this is difficult to gauge.

11.7 'What If?' Scenarios

Each demand and supply option has a volumetric reliability ≥95%. Behind this calculation is the assumption of a worst-case climate-change scenario for annual average temperature and rainfall for the year 2030. The hydrological calculations retain the historically observed variability in rainfall and temperatures and assume a stable yearly demand cycle. However, in previous research for the ACT it was suggested that a change in climate variability is likely:

Expert advice to ACTEW indicated that the ACT should be prepared for more frequent drought periods that are likely to be longer and drier than those experienced since 2001. Updated analysis of the medium to long-term outlook for the region showed a significant further reduction in long-term average inflows from 30% to almost 50% (ACTEW, 2007).

In this report it has been fruitful to look at inter- and intra-annual rainfall variation on top of the average changes already considered. The reports (Hughes 2003; Karl et al. 1995) that forecast an increase in variation due to climate change suggest that it is worthwhile to think about extreme weather events and their consequences happening with greater frequency.

For each risk identified in Chapter 11.1, we consider a standard set of scenarios:

1. What if the pond and lake options are implemented as they are and the historically observed variation in rainfall continues?

2. What would be the impact of the driest year happening again? This would mean about 100 days of continuous dry weather for all areas.

3. What if there was a rain event equivalent to a downpour of >100 mm in one day. Such an event has occurred in Canberra approximately once in every ten years (according to climate series outlined in Chapter 2.1).

Each of the above scenarios is likely to occur. While Scenarios 2 and 3 represent 'extreme' situations, it is probable that with climate change these scenarios will occur with increasing frequency.

It may be anticipated that the larger the size of a given pond the greater its ability to buffer any extremes of wet or dry, and this is true. However, with larger ponds there is also a greater perceived capacity for it to supply many demand centres – this is embodied in the anticipated extension of drawdown from 20 cm to 1 m for some existing lakes. This ability to supply is justified on the *average* reliability but the risks to supply are exacerbated by the number of users and the perceived stability of the water source contrasted with the actual meteorological variability.

11.8 Risk Estimation

The following tables (Table 48 to Table 56) in Chapters 11.8.1 to 11.8.3 each represent one of the three scenarios in Chapter 11.7 for each risk category. In each table, the key variables that influence each risk are listed in Column 2. The likelihood and consequences of a risk event are listed in Columns 3 and 4 respectively. Assumptions that were made regarding the performance and control of the variables are listed in Column 5. In assessing risks relating to individual ponds, it is important to ensure that these assumptions are valid. For example, it is assumed that certain regulations are present and enforced. At present regulations are in place about the limits to extraction and some control over the *rates* of extraction when the level of the pond is near or at the legislated drawdown limit. The risks estimated in Chapters 11.8.1 to 11.8.3 are based on the following guides used to describe likelihood (Table 45), consequence (Table 46) and risk (Table 47).

Table 45: Guide to the definition of 'likelihood' with respect to the frequency of a risk event as used in the risk analysis

Likelihood	**Frequency of event**
Almost certain	10 times a year
Likely	once a year
Possible	once in 10 years
Unlikely	once in 100 years
Highly unlikely	once in >100 years

Table 46: Guide to the scale of consequences used in the risk analysis

Consequence	Description (supply and ecology)	Description (health)
Negligible	Very little change from background circumstances	No or minimal discomfort
Minor	Inconvenience but within normal operating ranges	Discomfort or sickness requiring treatment
Moderate	Localised and/or short-term impact	Injury or sickness requiring hospitalisation
Serious	Widespread and/or long-term impacts & damage	Single death
Catastrophic	Permanent widespread damage	Multiple deaths

An important caveat to mention is this process is that ‘risk estimation’ is not a final assessment. Many consequences cannot be gauged at this stage because of the need for further research and any ultimate risk assessment would need to be based on data for specific ponds (unavailable at the time of writing), and for a complete system.

Risks are assigned with reference to Table 47 using best estimates. The final risk estimation on the right hand side of each table is not purely about likelihoods and consequences but also includes the controls and other considerations listed, that represent people’s and policy makers’ responses to the inherent risks.

Table 47: Guide to the estimation of risk based on the combination of likelihood and consequence. H = high risk, M = moderate risk and L = low risk

	Negligible	Minor	Moderate	Serious	Catastrophic
Almost certain	L	H	H	H	H
Likely	L	M	M	M	H
Possible	L	L	M	M	H
Unlikely	L	L	L	M	H
Highly unlikely	L	L	L	M	H

11.8.1 Water supply security

Table 48: Water supply security, Scenario 1 – background scenario based on Stage 1 report

Issue	Cause	Consequence	Likelihood	Control considerations	Risk Estimate
Over extraction	Excessive watering, illicit extraction, failure to comply with limits, growth	Minor – lower long-term reliability, more frequent loss of availability	Likely if controls not in place	Regulated extraction rates and limits, monitoring and enforcement, potentially high demands in summer coincide with high potable water needs, urban growth may increase run-off to ponds	Low
Pump failure	Operational fatigue, gross pollutants in system	Minor – no water available	Unlikely – as per commercial pump failure rates	Pumps appropriate to operating conditions, maintenance, gross pollutant traps	Low
Inter-annual variability	Variation in annual climate patterns	Minor –reliability in a specific year lower than 75%.	Unlikely	No control available, frequency of event may be increased with climate change	Low
Monthly variability	Climate variation within the year	Minor –reliability slightly less in summer than winter	Likely	No control available, magnitude of effect may be increased with climate change	Mod
Land use around pond	Development increases non-permeable area	Minor – increased inflow, increased demand from new demand centres	Possible in some areas	Urban planning, stormwater and extraction controls, household rainwater tanks	Low
Loss of pond capacity	Silting, illegal dumping	Minor – reduced storage capacity but unlikely to affect water available for drawdown	Possible in some areas	Monitoring, gross pollutant traps, maintenance and dredging	Low
Water quality prohibits use	Run-off, pollutants, blue-green algae	Minor – water unsuitable for use	Possible	Water quality requirements for irrigation, management, monitoring, treatment and removal of pollutants, waste disposal facilities available	Low

Table 49: Water supply security, Scenario 2 – extreme rain event

Issue	Cause	Consequence	Likelihood	Control considerations	Risk Estimate
Over extraction	N/A	N/A	N/A	N/A	N/A
Pump failure	Operational fatigue, pollutants in system	Minor – increased likelihood and magnitude of flooding	Highly unlikely	Pumps appropriate to operating conditions, maintenance, gross pollutant traps	Low
Inter-annual rainfall variability	N/A	N/A	N/A	N/A	N/A
Monthly variability	N/A	N/A	N/A	N/A	N/A
Land use around pond	urban growth may increase run-off to ponds	Minor – increased inflows – quality of floodwaters prevent use	Possible	Urban planning, stormwater and design controls, by pass channels, etc.	Low
Loss of pond capacity	Silting, illegal dumping blocks spillway	Minor – pond breaks its banks, repairs and restoration of capacity	Possible in some areas	Monitoring, gross pollutant traps, design, maintenance and dredging, community attitudes	Low
Water quality prevents use	Pollutants and debris washed into pond after heavy rain	Minor – large volume of water unusable – delays until water available	Unlikely	Bypass channels, education to prevent contaminants entering stormwater	Low
Flooding	Pond overflow	Moderate – could break pond banks and reduce storage	Unlikely	Pond and buffer design, spillways, by pass channels	Low

Table 50: Water supply security, Scenario 3 – prolonged dry

Issue	Cause	Consequence	Likelihood	Control considerations	Risk Estimate
Over extraction	Illicit extraction, high evaporation and near or at maximum drawdown levels	Moderate – very low short-term reliability, more frequent loss of availability	Possible	Regulated extraction rates and limits, monitoring and enforcement, potentially high demands in summer coincide with high potable water needs	Mod
Pump failure	Operational fatigue, pollutants in system	Minor – loss of supply at a critical time	Unlikely – as per commercial pump failure rates	Pumps appropriate to operating conditions, maintenance	Low
Inter-annual rainfall variability	N/A	N/A	N/A	N/A	N/A
Monthly variability	N/A	N/A	N/A	N/A	N/A
Land use around pond	Proposed development increases area of irrigated land	Minor – marginally increased demand for irrigation	Possible in some areas	Augmented ponds, urban planning and design	Low
Water quality prevents use	Reduced turnover enables greater algal growth	Moderate – potential blue-green algal blooms	Unlikely – needs specific water balance conditions	Harvesting management, monitoring, treatment of algal blooms	Low
Loss of pond capacity	Silting, illegal dumping	Minor – could temporarily affect water quality	Highly unlikely	Policing, gross pollutant traps, maintenance and dredging	Low

11.8.2 Public health and safety

Table 51: Public health and safety risk, Scenario 1 – background scenario based on Stage 1 report

Issue	Cause	Consequence	Likelihood	Control considerations	Risk Estimate
Drowning	Easy access to deep water, unrestricted access for children, accidents associated with water activities	Moderate – sickness or hospitalisation	Unlikely – very few recorded accidents in ponds	Lake edge design – planting macrophytes, fencing, education, designated swimming areas and supervised activities	Low
Accidental ingestion	Algae, cryptosporidium, pollutants, micro-organisms, etc	Moderate – sickness or hospitalisation	Unlikely, depends on local access and activities at pond and demand centre	Water quality monitoring, separate reticulation systems, safe taps, education, warning notices, medical facilities	Low
Vector-borne disease	Mosquitoes	Moderate – increase in occurrence of malaria, Ross River fever, Dengue fever	Unlikely – could change with climate	Pond design, education, medical facilities	Low

Table 52: Public health and safety risk, Scenario 2 – extreme rain event

Issue	Cause	Consequence	Likelihood	Control considerations	Risk Estimate
Drowning	Fast moving flows in stormwater drains reduced by retention	Negligible – number of drowning reduced	N/A for ponds and lakes	Plants around the edges, protection of access to spillways and stormwater drains, fencing, education	Low – N/A
Accidental ingestion	Greater than usual volumes of algae, cryptosporidium, pollutants, micro-organisms etc	Moderate – sickness or hospitalisation	Unlikely, depends on local access and activities at pond and demand centre	Water quality monitoring, separate reticulation systems, safe taps, education, warning notices, medical facilities	Low
Vector-borne disease	Mosquitoes	Moderate – increase in occurrence of malaria, Ross River fever, Dengue fever	Unlikely – for ponds and lakes. Could change with climate	Pond design, many ponds have a high turnover, education, medical facilities	Low

Table 53: Public Health and Safety Risk, Scenario 3 – prolonged dry

Issue	Cause	Consequence	Likelihood	Control considerations	Risk Estimate
Drowning	N/A	N/A	N/A	N/A	N/A
Accidental ingestion	Concentration of pollutants in evaporating ponds	Moderate – sickness or hospitalisation	Unlikely, depends on local access and activities at pond	Water quality monitoring, separate reticulation systems, safe taps, education, warning notices, medical facilities	Low
Vector-borne disease	Mosquitoes	Moderate – increase in occurrence of Malaria, Ross River Fever, Dengue Fever	Highly unlikely – mosquitoes need water to breed	Pond design, many ponds have a high turnover, education, medical facilities	Low

11.8.3 Environmental impact

According to the ACT *Water Report 2006-07* (ACT Territory and Municipal Services, 2007), the ACT is a net exporter of water to the Murrumbidgee. There is little chance that this could be compromised even with a full complement of new ponds. Urban flows are small compared with other run-off from the ACT (4 GL relative to a total of about 400 GL). However, on the rare occasions of extreme water stress it is possible that stormwater withheld by urban ponds could influence whether or not environmental thresholds are met. Further research is needed to better understand hydrological and topological connectivity of ponds and drainage patterns. Clusters of ponds that occur on the same streamline have been identified and this has been taken into account in the Stage 1 report reliability measures. Additional concerns are about the seasonal availability of water, the exposure of mud flats and the downstream water quality effects to the Murrumbidgee River.

Table 54: Environmental risk, Scenario 1 – background scenario based on Stage 1 report

Issue	**Cause**	**Consequence**	**Likelihood**	**Control considerations**	**Risk Estimate**
Local habitat change	Construction of pond, altered stream flow, increased drawdown, flooding, tourism and human activity	Moderate – loss or reduction of local biodiversity	Possible, depends on climate conditions	Planning, design of pond, construction methods, monitoring and enforcement of drawdown regulations, controlled access to sensitive areas. Particular risk due to extended drawdown on existing ponds	Moderate
Water quality affects ecosystem	Proximity to roads and farmland, run-off, pollutants, blue-green algaefertilisers, silt, etc.	Negligible – loss or reduction of local biodiversity	Unlikely new ponds generally improve environmental flows and conditions	Planning, pond location, farming practice, education, monitoring and enforcing existing pond controls	Low
Environmental Flows	Altered stream flow, increased drawdown	Negligible – exacerbates effect of critical periods for Murrumbidgee flow	Possible – urban flows are relatively small	Planning, design of pond, construction methods, monitoring and enforcement of drawdown regulations particularly in summer months	Low

Table 55: Environmental risk, Scenario 2 – extreme rain event

Issue	Cause	Consequence	Likelihood	Control considerations	Risk Estimate
Local habitat change	Altered stream flow, flooding, erosion	Minor loss or reduction of local biodiversity	Unlikely	Planning, design of pond, construction methods, spillways and weirs that mitigates fast moving flows	Low
Water quality affects ecosystem	Proximity to roads and farmland, run-off, fertilisers, flood water quality	Minor effects for existing lakes. Negligible for new ponds	Possible	Planning, pond location, farming practice, education, monitoring and enforcing, New ponds improve environmental flows and existing ponds have controls	Low
Environmental flows	Altered stream flow, flooding	Negligible effect on critical periods in Murrumbidgee flow, new ponds generally improve environmental flows and conditions	N/A – Urban run-off relatively small	Planning, design of pond, construction methods, urban run-off flows are relatively small, controlled access to sensitive areas	N/A

Table 56: Environmental risk, Scenario 3 – prolonged dry

Issue	Cause	Consequence	Likelihood	Control considerations	Risk Estimate
Local habitat change	Occasional dry is a positive; repeated dry periods of >50 days can be a negative	Moderate – long-term loss or reduction of local biodiversity	Possible depends on climate conditions	Design of pond gradient, construction methods, monitoring and enforcement of drawdown regulations	Moderate
Water quality affects ecosystem	Proximity to roads, farmland, pollutants, blue-green algae	Moderate – loss or reduction of local biodiversity	Unlikely	Planning, pond location, farming practice, education, monitoring and enforcing regulations, new ponds improve quality of environmental flows and existing ponds have existing controls	Low
Environmental flows	Altered stream flow, increased drawdown for irrigation	Moderate – exacerbates effect of critical periods in Murrumbidgee flow	Unlikely – urban run-off relatively small	Planning, monitoring and enforcement of drawdown regulations	Low

11.9 System Considerations

The risk assessment presented here fundamentally assumes that all the options in the master plan will be constructed and put into operation *as one system*. While there are some data pertaining to particular risks for particular option, most information supplied in this report is to be used for estimating risk for the portfolio of options in the master plan.

Table 57: Ponds clusters and their impact on local networks and the Murrumbidgee River[1]

Supply Name	**Type**	**Cluster**	**Consequence**
B14	Stormwater	M	New impact on Murrumbidgee
Ginninderra	Existing	G, M	Lower inflow
Gungahlin Pond	Existing	G	Affects Lake Ginninderra inflow
Nichols Pond	Existing	G	Affects Lake Ginninderra inflow
Yerrabi Pond	Existing	G	Affects Lake Ginninderra inflow
B28	Stormwater	M	New impact on Murrumbidgee
Dunlop Pond 1	Existing	M	
Dunlop Pond 2	Existing	M	
Point Hut Pond	Existing	M	
Upper Stranger Pond	Existing	M	
WC14-15	Stormwater	M	New impact on Murrumbidgee
West Belconnen Pond	Existing	M	
David St Wetland	Existing	N	Lower flow to Murrumbidgee and Molonglo Rivers
G23	Pond-ASTR	N	New impact on Murrumbidgee and Molonglo Rivers
NC18	Pond-ASTR	N	New impact on Murrumbidgee and Molonglo Rivers
NC9-11	Pond-ASTR	N	New impact on Murrumbidgee and Molonglo Rivers
Isabella Pond	Existing	T, M	
T2	Stormwater	T, M	New impact on Murrumbidgee and Tuggeranong
T3	Stormwater	T, M	New impact on Murrumbidgee and Tuggeranong
T4	Stormwater	T, M	New impact on Murrumbidgee and Tuggeranong
Tuggeranong	Existing	T, M	Lower inflow
W0	Pond-ASTR	W,M	New impact on Murrumbidgee
W19	Stormwater	W,M	New impact on Murrumbidgee
W2	Pond-ASTR	W,M	New impact on Murrumbidgee
W27	Stormwater	W,M	New impact on Murrumbidgee
WC0	Pond-ASTR	WC,M	New impact on Murrumbidgee
WC19	Stormwater	WC,M	New impact on Murrumbidgee
WC4	Stormwater	WC,M	New impact on Murrumbidgee

Note: 'M' indicates that the pond interrupts a flow to the Murrumbidgee; W = Woden, WC = Weston Creek, T = Tuggeranong, N = North Canberra, G = Ginninderra; 1: We have not considered the effects of new ponds on Lake Burley Griffin.

If all ponds are not constructed or harvesting regimes implemented then this can change risks in subtle but important ways. For example, where several ponds are planned to connect on one streamline (refer to Figure 14 and Table 57 below), downstream ponds may be more vulnerable to flooding if upstream ponds have not been constructed. Conversely some ponds may be able to supply more water more reliably for the very same reasons. The changes to the anticipated stream flow due to absent ponds may also jeopardise the beneficial effects for local ecology.

One of the messages from the focus groups was that stormwater ponds alone are not enough: how one pond fits into a bigger system needs to be considered (Chapter 9.3) and this is lightly coupled to a high level systemic risk associated with relieving water scarcity by augmenting water supplies.

If more water is made available, users may see this availability and not practice demand management. This can place pressure on existing ponds and accelerate the development of new supply options. Following the next generation of ponds, consumers may again become complacent about water security and drive another repeating and escalating cycle of supply augmentation. To mitigate this high level systemic risk, demand management and education of irrigators *must* coincide with the construction of stormwater capture options.

The impact of demand management on supply security was not measured in this study .We need to understand the growth, variation and uncertainties in demand. Controlling and monitoring demand is likely to be a critical component of the system to reduce risks of failure.

There is a possibility that, given rising costs of water, longer droughts, less rainfall and higher temperatures, additional users might seek to extract water from the ponds – either legally or illegally. With several ponds and lakes having multiple demand centres there is the possibility of a 'tragedy of the commons' dynamic. If there is only a weak regulation on extraction individuals may act to their own best advantage and irrigate even when the supply option is stressed and cannot support this action if taken by all demand centres. Preventative measures (e.g. monitoring, fines) can be used to reduce this risk and are in place for existing ponds used for irrigation. As yet, the EPA has had no cause to 'lock the pumps' for any property but more stressful drought conditions may bring about more illicit extractions.

11.10 Discussion

The risks that have been considered in this report are the risks of supply failure, the risk of adverse ecological impact and risk to public health. Detailed evaluation of these risks requires knowledge of:

1. site-specific data for the individual ponds that make up the scheme, including details of pond design, hydrogeological data and location and access and
2. the interrelationships between ponds, infrastructure and the environment for a complete scheme.

This information is not available at present, and the risk assessment undertaken in this section is, of necessity, generic.

This risk assessment studies the impact of extreme events, in the form of prolonged drought and intense storms, and provides guidance on risk issues that should be considered before introducing new ponds or lakes; or extending existing ponds and lakes. Table 48 to Table 56 outline the potential magnitude of risks that might be expected, and provide details on controls that are important to keeping those risks within acceptable levels.

Nearly all the risks that were assessed have been evaluated as low. A 'low' risk may be one that has a small impact but a high likelihood of happening, for example, mosquito pests might happen every year but with only minimal consequences. Low risk may also be ascribed to events that have a greater consequence but which are rare (e.g. prolonged dry periods that happen once or twice in every 100 years). Results should be treated with caution. Data were available for some analyses, but in several instances we have just used our best judgement.

Most risks were evaluated as low. However the following are the risks that were rated as moderate:

1. The risk to water supply security of harvesting options due to the combination of inter-annual and seasonal variation and over extraction, particularly for irrigation in the summer months when monthly reliability may be less than 95%. This risk is mitigated by controls (used by the EPA) on extraction limits and rates.

2. The ecological risk for existing lakes due to extended drawdown in combination with prolonged dry periods. Continuous dry periods of, for example, 50 or 100 days can be a positive for shoreline biota unless they recur with a frequency of three years or more. This is a risk for several existing ponds and lakes and it may be exacerbated by climate change.

The hydrological model assumed a certain shape to the lakes and ponds being used in this scheme. Where this differs from reality it may be expected that different outcomes may ensue. For example the allowed draw down of 1 m in Lake Ginninderra may expose shallow areas in the south-eastern part of the lake with localised ecological and economic consequences. Dredging and responsible management of harvesting alleviates the impact of this risk though they may represent a separate economic cost.

The ecological environment of urban areas in the ACT is already in a disturbed state and the addition of artificial ponds poses the least risk and, in fact, is likely to be beneficial to the variability and quality of environmental flows.

The quantity of water affected by new ponds and extra drawdown is also unlikely to have a significant impact on the flows to the Murrumbidgee River. Nevertheless, even 4.1 GL may be important at times of extreme water stress when there are few or no environmental flows.

Of lesser concern was the risk that the ponds pose to public health and safety. This is not because of the consequences but the likelihood of occurrence given preventative measures and policies already in place. With appropriate warning signs, separate infrastructure to potable water supply, and education, the risk of drowning or accidental ingestion is low. With pond designs that have a high throughput and appropriate design the small risk of vector borne disease is also reduced. Beyond the timescale of this study, the effects of climate change present a general increase in the risk of mosquito-borne disease throughout the ACT. It is unclear whether ponds will exacerbate this situation.

This report provides guidance on risk issues that should be considered. Before any new ponds are introduced, or existing lakes or ponds are extended, a detailed engineering, social and economic risk assessment should be conducted that takes account of local, site-specific data as well as a complete systemic view.

12 CONCLUSIONS

The prime objective of this study was to assess the feasibility of saving 3 GL/yr of potable water by 2015, mainly by using stormwater as a potential source of water. The study has investigated a large number of possible options and developed three portfolios of stormwater harvesting with least infrastructure costs to achieve this target. They were named as Master Plans A, B and C (see Chapter 7).

Master Plan A was developed first. Since it was considered as the preferred portfolio of stormwater harvesting, TBL performance assessment was undertaken for this plan (results are presented in Chapters 8 to 11).

However, on completion of the TBL performance assessment, new information on potential end users was emerged. This included significant changes to some potential end users. For example, many end users considered in developing Master Plan A, were found to be met by non-potable water supplies such as Lake Burley Griffin, groundwater or the proposed effluent re-use schemes. Emergence of changes to the potential end users had meant that Master Plan A was no longer valid. Hence, Master Plans B and C were developed using the new information on end users.

Master Plan B supersedes Master Plan A. Both Master Plans A and B include stormwater harvesting schemes with at least 95% volumetric supply reliability. Like Master Plan B, Master Plan C uses new information on end users, but includes stormwater harvesting schemes with at least 85% volumetric supply reliability. Due to limitations in availability of time and resources, further analysis of TBL performance assessment of Master Plans B and C could not be undertaken. Chapters 8 to 11 can be used to gauge these impacts related to the new master plans, however caution should be used because factors that will influence these impacts such as drawdown levels, pond volumes and demands placed upon the ponds have changed (particularly ecological impacts).

The study informs decision makers of the impacts and benefits of stormwater harvesting in terms of likely financial costs, ecological impacts, social attitudes, stakeholder views and risks. Comparing stormwater with other forms of supply is considered to be beyond the scope of this study. Hence this report **does not compare** stormwater harvesting to other forms of supply such as recycling, or surface water and groundwater sources. In addition, this report **does not rank potential stormwater harvesting schemes included in an individual master plan**. This is simply due to hydrological and ecological interactions of schemes (i.e. one scheme can influence the viability of another) included in a master plan.

12.1 Financial Cost

Total present value cost of Master Plan B (or the portfolio with at least 95% supply reliability) is \$177M – comprising \$141M capital, \$33M operation and maintenance, and \$3M replacement costs. The collective average annual supply of harvesting options included in this master plan is 3.3 GL/yr, which equates to a levelised cost of \$3.67 per kL.

Total present value cost of Master Plan C (or the portfolio with at least 85% supply reliability) is \$150M – comprising \$120M capital, \$27M operation and maintenance, and \$3M replacement costs.

The collective average annual supply of harvesting options included in this master plan is 3.5 GL/yr, which equates to a levelised cost of $2.94 per kL. The 85% reliability master plan (i.e. Master Plan C) was cheaper because the required pond volume is much less compared to pond volumes of the 95% reliability master plan (i.e. Master Plan B).

These financial cost figures include construction costs for new ponds and add-on costs for contingency, administration, procurement, insurance, site investigations, and consultant design and supervision. The levelised cost of harvesting without pond construction costs, for 95% and 85% reliability cases (i.e. Master Plans B and C) are $1.70 /kL and $1.61 /kL respectively.

12.2 Ecological Impact

The ecological analysis flagged potential risks and benefits from stormwater harvesting including:

- changed flow patterns (particularly reduced low flows during summer)
- changed flow volumes to downstream waterways
- changed nutrient loads
- altered phytoplankton and macro invertebrate levels and
- impact on species diversity upon the shore line of ponds due to the changing water levels.

Each of these risks and benefits were quantified using available hydrological data; however, a meaningful single measure of ecological impact was not possible due to aquatic vegetation diversity and health being influenced by complex interactions between each of the indices. It was also difficult to measure relative ecological impact between the indices (e.g. the relative impact of increased phytoplankton risk versus reduced nutrient load).

The ecological analysis demonstrated that new ponds are likely to reduce nutrient load and have generally low phytoplankton levels, but have limited impact on peak flows and be damaging to macroinvertebrate communities immediately downstream. Phytoplankton levels are likely to be low because turnover times are likely to be high for new ponds as they are designed for minimal volume (to reduce cost) where there are proportionally high inflows (for reliable supply). Nutrient loads would also be reduced; however this is largely due to harvesting rather than treatment by the pond (as the pond has a low turnover time). Peak flows would be minimally impacted in significant storms (roughly >1 in 3 month ARI), because the volume of the pond is small comparative to the catchment size. The new ponds would be detrimental for macroinvertebrate communities immediately downstream because low flows would be significantly reduced, especially during summer.

Introducing harvesting to existing ponds has less potential for adverse ecological impact as summer low flows are already retarded and prevented from flowing downstream. In fact, harvesting is likely to increase aquatic vegetation diversity on the pond shore, as current water levels tend to be constant, preventing some species establishing. Introducing harvesting causes increased water level variation, and provided this does not become too extreme, leads to increased aquatic vegetation diversity.

Implementation of harvesting options identified in Master Plan A would reduce discharges to the Murrumbidgee River by up to 5.0 GL/yr. This is a worst case scenario which represents the 4.4 GL/yr harvested volume plus additional losses due to evaporation from the pond surfaces. It is likely that reductions in flow will be much less or neutral as stormwater harvesting will reduce demand on the Cotter, Bendora, Corin and Googong dams, which would most likely result in increases in environmental flows. Regardless, analysis of a 5.0 GL/yr reduction in flows has shown minimal changes in flows patterns in the Murrumbidgee and Molonglo Rivers.

12.3 Social Attitudes

Social analysis indicated the value of stormwater harvesting needs to be considered beyond its instrumental resource value. Aesthetic appearance and potential for recreation are regarded as prominent amenity values of stormwater harvesting. A stormwater collection pond is seen as an attractive landscape and a place to walk and relax if designed well or an offensive eye-sore if designed badly. There is a strong preference for ‘natural’ looking stormwater collection measures. For example, a wetland with reeds and other vegetation along with rocks is preferable to a simple pond made out of concrete. Moreover, a natural looking pond is also regarded as a feature that has high potential to enhance aesthetic and recreational values and ecological benefits.

Another important discovery from the social analysis is that there is a strong preference for considering school grounds and sports grounds as high priority users of harvested stormwater, especially during time of water shortages. Golf courses, residential gardens and public parks have not been considered as high priority users of harvested stormwater, during time of water shortages, but are considered as appropriate users of harvested stormwater in all other times.

Multi-criteria assessment explored decision criteria to be used for assessing the impact of stormwater harvesting in social, environmental and economic dimensions and stakeholder preferences on each criterion. Outcomes of the MCA revealed 38% weight to economic impacts, 47% weight to social impacts and 15% weight to environmental impacts, indicating that in the ACT, there is a strong preference for considering impacts of stormwater harvesting in social and economic dimensions than the impacts upon the environmental dimension.

12.4 Risk Assessment

The study included a preliminary assessment of risks associated with stormwater harvesting. Key areas of risk considered in the study were:

- supply security risk associated with 95% volumetric reliability
- public health and safety risks associated with drowning and other immediate hazards such as drinking of stormwater and mosquito breeding and
- environmental risks such as possibility of algal blooms and changes to flow habitats.

Nearly all risks that were assessed have been evaluated as low, with the exception of the following risks rated as moderate:

- The risk to reliability of stormwater supply due to the combination of inter-annual and seasonal variation and over extraction, particularly for irrigation in the summer months when monthly reliability may be less than 95%. This risk can be mitigated by controls (used by the EPA) on extraction limits and rates.

- The ecological risk for existing lakes due to extended drawdown in combination with prolonged dry periods. Continuous dry periods of, for example, 50 or 100 days can be a positive for shoreline biota unless they recur with a frequency of three years or more. This is a risk for several existing ponds and lakes and it may be exacerbated by climate change.

13 RECOMMENDATIONS

A decision maker using this report is only presented with the option of building the entire master plan (either 85% or 95% reliability) or not proceeding with stormwater harvesting at all. Developing a range of portfolios will provide decision makers with choice and will most likely lead to improved outcomes. This report does not provide guidance on ranking of the individual options that comprise the master plan. Availability of time and resources has been the key factor in this study for not following the TBL performance assessment of multiple portfolio approach.

The master plans presented in this report is a least-cost stormwater harvesting plan. The plan is 'optimal' in terms of financial cost, but does not consider any other factors such as social acceptance, nutrient load reduction and habitat creation. Such factors are used to measure performance of the master plan (see the TBL analysis in Chapter 10) however they are not used to develop the master plan.

13.1 Alternative Approaches

In order to incorporate factors other than cost into developing a stormwater harvesting plan, it is suggested alternative approaches are taken to develop new 'master plans' or alternative portfolios of stormwater harvesting. These portfolios could then be compared to the portfolios developed in this study, perhaps using the TBL approach as per this study (Chapter 10) or cost–benefit analysis.

Possible approaches for developing alternative portfolios include:

- using the rate of nutrient removal as the criterion for identifying stormwater supply–demand options – instead of using least cost as in this study, best options could be identified based on the rate of nutrient removal

- least-cost and 95% reliability with revised harvesting target (say 1 GL/yr) – the same approach as this study, however a revised annual target could be adopted

- catchment-by-catchment comparison of options containing multiple ponds – This would involve comparing options that contain multiple ponds rather than individual ponds. Each catchment would be assessed and a series of options developed for that catchment. For example, in Sullivans Creek catchment, a series of options involving various combinations of supplies and demands would be developed (e.g. Option A: NC18, G23, NC9-11; Option B: David St Wetland, NC18 . . . . Option F: G23, NC14, NC9-11 etc.). Such an approach would remove the problem of interactions between options which occurs when individual ponds are compared. Each option could be compared by TBL/CBA using appropriate criteria (cost, nutrient removal, social acceptance, etc.). The best performing option would be selected for each catchment until a master plan covering all of Canberra is developed.

These approaches are merely suggestions and there are many more possibilities for developing alternative portfolios. The catchment-by-catchment approach has the benefit of accounting for hydrologic and ecological connectivity. Developing a range of portfolios allows comparison of performance (by using a suitable assessment method such as TBL or CBA), which will assist decision makers to reduce subjectivity of decisions.

13.2 Future Analyses

To further improve knowledge of water harvesting opportunities, further optimise stormwater harvesting planning and reduce objectivity in decision making, the following analyses are suggested:

i. Develop alternative portfolios as discussed above and assess performance of them using TBL or CBA.

ii. Trial projects for MAR including:

    - sportsground aquifers
    - local aquifers using fractured rock.

    If these trials prove successful, a further trial of local aquifers in alluvial soils could be conducted, as could an investigation into the science / risks of storing reclaimed water in aquifers.

    Such work is necessary to improve knowledge in this area. This project has been constrained by high uncertainty surrounding aquifer calculations (such as recovery efficiency, cost, extraction and injection rates).

iii. Engage hydrogeological experts to further investigate regional aquifer storage, transfer and recovery.

iv. Coordinate the recycled water strategy (as per ActewAGL 2008) with the stormwater harvesting strategy.

v. Discuss the possibility of using mains water to back-up stormwater harvesting schemes with ActewAGL-supplied water. Such discussions will need to consider the benefit of significantly reducing the required stormwater pond volume (and hence cost) with the cost of reducing the reliability of the mains system.

vi. Investigate retro-fitting catchments with WSUD measures (e.g. rainwater tanks, swales). Is this necessary if stormwater harvesting is implemented? Would such measures reduce flows into stormwater ponds?

Completing any or all of these recommendations allows for more informed decisions regarding stormwater harvesting (and wastewater recycling) in Canberra.

13.3 HydroPlanner Development

Further analysis of the system-wide impact of stormwater harvesting (i.e. on the reservoir supply system, environmental flows and flows in downstream waterways) would also be valuable. To this end:

- A CSIRO report will follow this study regarding application and development of the HydroPlanner software for the ACT. HydroPlanner is a whole-of-urban water system water quantity and quality model, initiated as part Water for a Healthy Country National Research Flagship Program. The CSIRO report will outline preliminary results on system-wide flow implications; however the report will serve more as an assessment of feasibility for total water cycle modelling for the ACT rather than presentation of outcomes. The report will illustrate importance of undertaking total water cycle modelling to assess system-wide implications of stormwater harvesting.

- Full scale development of HydroPlanner is in progress in collaboration with the eWater CRC. Application of the full scale HydroPlanner has just begun as part of eWater CRC's ACT Focus Catchment study, which builds on the HydroPlanner application initiated as part of this study. A full application of Hydro Planner requires substantial contributions from a number of agencies in the ACT (e.g. ACTEW, ActewAGL, ACT EPA and ACTPLA).

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APPENDIX A DEMANDS USED FOR DEVELOPING MASTER PLAN A

Designation	Individual End uses	Section	Block	Individual Demand (ha)	Combined Demand (ha)	Combined Demand (ML/y)	Suggested Supply Source	Possible Supply Source
		BELCONNEN						
Fraser	Fraser Neighbourhood Oval	40	1	1.3	1.9	12.1	West Belconnen Pond	Dunlop Pond 1, Dunlop Pond 2
	Fraser Primary School	40	2	0.6				
Charnwood 1	Charnwood Neighbourhood Oval	118	2	1.1	2.8	17.9	West Belconnen Pond	Dunlop Pond 1, Dunlop Pond 2
	Charnwood Primary School	93	1	1.7				
Charnwood 2	Charnwood District Playing Fields	112	14	8.5	10.5	66.8	Dunlop Pond 1, Dunlop Pond 2, West Belconnen Pond	
	St Thomas Aquinas Primary School	97	14	2				
Macgregor	Macgregor Neighbourhood Oval	58	11	1.7	3.1	19.7	B28	Lake Ginninderra
	Macgregor Primary School	81	3	1.4				
Magpies Belconnen	Magpies Belconnen Golf Club	99	11-Dec	52.2	52.2	331.5	-	Lake Ginninderra; possible sewer mining scheme?
Holt	Holt Neighbourhood Oval	13	1	1.5	1.5	9.5	B28	Lake Ginninderra
Kippax	Kippax District Playing Fields	50/51	51-53/47	14.1	17.4	110.5	Lake Ginninderra	B24
	West Belconnen Regional School	48	1	2				
	Cranleigh School	49	1	1.3				
Higgins	Higgins Neighbourhood Oval	10	19	2.4	2.4	15.2	Lake Ginninderra	B24
Latham	Latham Neighbourhood Oval	29	5	3.1	4	25.4	Lake Ginninderra	B14
	Latham Primary School	30	2	0.9				
Florey 1	St John the Apostle Primary School	12	1	0.7	1.9	12.3	B14	Lake Ginninderra
	St Francis Xavier College	1	1	1.2				
Florey 2	Florey Neighbourhood Oval	143	32	1.7	2	12.8	Lake Ginninderra	B14; B37
	Florey Primary School	143	31	0.3				
Page	Page Neighbourhood Oval	1	5	1.9	1.9	12.1	Lake Ginninderra	B14
Scullin	Scullin Neighbourhood Oval	15	5	3.2	5.1	32.4	Lake Ginninderra	B14
	Southern Cross Primary School	13	1	1.9				
Flynn	George Simpson Park	18	6	2.2	2.2	14	Lake Ginninderra	B14; B37
Spence	Spence Neighbourhood Oval	21	1	3.1	3.1	19.7	Lake Ginninderra	
Melba 1	Copland College	25	1	0.1	5.5	34.9	Lake Ginninderra	B37
	Melba Neighbourhood Oval	61	1	2				
	Mt Rogers Community School	44	1	3.4				
Melba 2	Melba District Playing Fields	26	5	4.6	9.2	58.4	Lake Ginninderra	B37
	Melba High School	27	1	4.6				
Evatt 1	Evatt Neighbourhood Oval	12	1	2.1	3.6	22.9	Lake Ginninderra	B2
	Evatt Primary School	11	1	1.5				
Evatt 2	Miles Franklin Primary School	82	1	1.5	3	18.9	Lake Ginninderra	B37
	St Monicas Primary School	86	5	0.4				
	South West Evatt Oval	89	3	1.1				
McKellar	Belconnen Soccer Club	71	14	0.9	3	19	Lake Ginninderra	B2
	McKellar Neighbourhood Oval	53	2	2.1				
Giralang	Giralang District Playing Fields	85	19	6.8	7.9	50.2	Lake Ginninderra	B2
	Giralang Primary School	80	4	1.1				
Hawker	Belconnen Bowling Club	3	1	0.4	13.8	87.3	Lake Ginninderra	
	Belconnen High School	5	1	3.3				
	Hawker College	2	1	0.3				
	Hawker District Playing Fields	3	11-Dec	8.7				
	Hawker Enclosed Oval	38	20	1				
Weetangera	Weetangera Neighbourhood Oval	20	3	2.6	4.5	28.6	Lake Ginninderra	
	Weetangera Primary School	20	5	1.9				
Macquarie	Macquarie Neighbourhood Oval	19	24	2.6	4.1	26	Lake Ginninderra	B3
	Macquarie Primary School	18	2	1.5				
Macquarie/Belconnen	Benjamin Way	-	-	2.6	8.9	56.8	Lake Ginninderra	B3
	Canberra High School	52	5	2.7				
	Eastern Valley Oval	150	2	1.6				
	Jamison Enclosed Oval	54	1	2				
Belconnen 1	Emu Bank Park	149	14	1.4	2.8	17.8	Lake Ginninderra	
	Margaret Timpson Park	54	42	1.4				
Belconnen 2	John Knight Memorial Park	65	33	3.5	3.5	22.2	Lake Ginninderra	
Belconnen 3	Diddams Close Park	159	1	1.6	1.6	10.2	Lake Ginninderra	
Cook	Cook Neighbourhood Oval	13	12	2.1	2.1	13.3	Lake Ginninderra	B3
Aranda	Aranda District Playing Fields	1	24	8.4	9.1	57.6	Lake Ginninderra	B3
	Aranda Primary School	1	2	0.7				
AIS	AIS Multi-Purpose Playing Fields	8	37	1.7	5.6	35.2	Lake Ginninderra	B1
	AIS Soccer Fields	8	37	1.8				
	AIS Track and Field Facility	8	26	1				
	Canberra Stadium	8	26	1.1				
Bruce	ActewAGL Park	9	4	1.4	5.6	35.6	Lake Ginninderra	B3; B1
	Radford College	4	9	4.2				
University of Canberra	University of Canberra	3	1	4.5	4.5	28.6	Lake Ginninderra	B3; B1
Kaleen 1	Kaleen South Oval	149	9	3	3.8	24.1	Lake Ginninderra	B1
	Maribyrnong Primary School	120	1	0.8				
Kaleen 2	Kaleen District Playing Fields	117	26	7.4	12.4	78.7	Lake Ginninderra	B1
	Kaleen Enclosed Oval	117	25	3.2				
	Kaleen High School	101	1	1.8				

Designation	Individual End uses	Section	Block	Individual Demand (ha)	Combined Demand (ha)	Combined Demand (ML/y)	Suggested Supply Source	Possible Supply Source
Kaleen 3	Kaleen North Oval	76	4	3.2	5	31.8	Lake Ginninderra	B1; B2
	Kaleen Primary School	45	1	0.9				
	St Michaels Primary School	60	1	0.9				
TOTAL				***229***	***229***	***1474.3***		
GUNGAHLIN								
*Crace	*Crace Miscellaneous	0	588	5	5	31.8	Gungahlin Pond	Lake Ginniderra; B2
Gold Creek	Gold Creek Country Club	85/86/88/89	2/14/11/21-22	45	45	285.8	Nichols Pond; Gungahlin Pond	
Nicholls	Gold Creek School (Senior)	78	11	0.6	6.6	41.9	Gungahlin Pond	Nichols Pond; Yerrabi Pond
	Nicholls Neighbourhood Oval	73	3	2				
	The Perce Douglas Memorial Playing Fields	78	8	4				
Ngunnawal	Ngunnawal Neighbourhood Oval	134	75	2	2.2	14	Gungahlin Pond	Yerrabi Pond
	Ngunnawal Primary School	134	74	0.2				
Amaroo	Amaroo District Playing Fields	109	1	7	9.1	57.8	Yerrabi Pond	Gungahlin Pond
	Amaroo School	93	3	2.1				
Gungahlin Lakes	Gungahlin Lakes Golf Club	177/84	1/02/2001	45	45	285.8	Yerrabi Pond; Gungahlin Pond	Nichols Pond
Gungahlin	Burgmann Anglican School	20	1-Feb	2.5	2.5	15.6	Gungahlin Pond	Yerrabi Pond
Palmerston	Palmerston District Primary School	154	12	0.1	2.5	15.9	Gungahlin Pond	Yerrabi Pond
	Palmerston Neighbourhood Oval	154	7	2.4				
*Throsby	*Throsby Sportsgrounds	0	718	8	8	50.8	Yerrabi Pond	G25; G23
*Harrison	*Harrison Sportsgrounds	2	Nov-13	7	7	44.5	G23	G25
Gungahlin Cemetery	Gungahlin Cemetery	39	5	15	15	95.3	NC18	G23
Mitchell	Belconnen Dog Obedience Club	0	601	0.9	38.7	245.5	NC18 (partial)	G23
	Canberra Harness Racing Club Training Track	0	765	1.3				
	Capital Linen Service	16	1	36.5				
TOTAL				***186.5***	***186.5***	***1184.4***		
NORTH CANBERRA								
Lyneham 1	Thoroughbred Park - Canberra Racing Club	69	9	6.4	6.4	40.6	NC18	
EPIC	Canberra Harness Racing Club Racing Track	72	5	1.4	6.1	38.5	NC18	G23
	Exhibition Park in Canberra (EPIC)	72	5	4.4				
	ACT Canine Association	0	466	0.3				
Lyneham 2	Yowani Country Club	67	4	50	50	317.5	-	NC18
Lyneham 3	National Hockey Centre	59	42	1.8	11.5	72.9	-	NC18; NC12a
	Tennis ACT	64	6	0.7				
	Southwell Park Sportsgrounds	59	38	9				
Lyneham 4	Lyneham High School	47	2	2.7	4.1	26	NC9-11	NC13; NC12
	Lyneham Neighbourhood Oval	41	19	1.2				
	Lyneham Primary School	41	18	0.2				
Dickson	Daramalan College	34	1	1.4	2.1	13.6	-	NC9-11; NC14
	Majura Tennis Centre	72	17	0.7				
Dickson/Ainslie	Emmaus Christian School	17	4	1	2.3	14.3		NC14; NC9-11
	North Ainslie Primary School	43	1	1.3				
Downer	Downer Neighbourhood Oval	73	2	3.4	3.4	21.6		NC14
Watson/Dickson	Dickson College	76	1	0.2	10.1	63.9		NC14
	Dickson District Playing Fields	76	4	8.8				
	Rosary Primary School	49	3	1.1				
Hackett	Hackett Neighbourhood Oval	12	15	2.3	2.3	14.6		NC14
Watson	Majura Primary School	31	15	0.7	1.8	11.4		NC18; NC14
	Watson Neighbourhood Oval	21	8	1.1				
Ainslie	Ainslie Football Park	26	19	1.9	6.5	41.3		NC9-11; Lake Burley Griffin
	Majura Enclosed Oval	38	5	1.6				
	Majura Oval	38	2	2.5				
	Northbourne Avenue	26	4	0.5				
O'Connor/Turner	O'Connor Co-operative School	89	4	0.3	9.4	59.4	David St Wetland; NC9-11	NC7A; Lake Burley Griffin
	O'Connor Enclosed Oval	39	4	1.7				
	O'Connor District Playing Fields	39	4	4.3				
	St Joseph's Primary School	78	1	0.8				
	Turner Primary School	67	16	2.3				
O'Connor	Black Mountain School	84	55	0.1	0.1	0.6		NC4; NC8; Lake Ginninderra; Lake Burley Griffin
Ainslie/Braddon	Corroboree Park	79	3	2.7	3.7	23.4		NC6; Lake Burley Griffin
	Merici College	11	1	1				
Braddon	Ainslie Primary School	31	1	3	5.3	33.4		NC6; Lake Burley Griffin
	Braddon Tennis Club	24	15	0.3				
	Canberra City Bowling Club	25	16	0.4				
	Northbourne Oval	30	6	1.6				
Turner/ANU	ANU North Oval	25	1	2	2.5	16		NC2; NC3: NC4; NC5; Lake Burley Griffin
	ANU Willows Oval	63	1	0.1				
	Canberra North Bowling Club	66	2	0.4				
ANBG	Australian National Botanic Gardens	0	861	40	40	254		Lake Burley Griffin
ANU	ANU Fellows Oval	39	1	0.1	2.1	13.3		Lake Burley Griffin
	ANU South Oval	39	1	2				
Acton	Acton Park (Ferry Terminal)	33	22	0.2	0.2	1.3		Lake Burley Griffin
City	Glebe Park	65	2	0.1	0.1	0.6		Lake Burley Griffin
Campbell/Reid	Australian War Memorial	39	1	4.2	10.3	65.4		Lake Burley Griffin

Designation	Individual End uses	Section	Block	Individual Demand (ha)	Combined Demand (ha)	Combined Demand (ML/y)	Suggested Supply Source	Possible Supply Source
	Campbell High School	38	2	2.2				
	Reid Oval	39	5	3.9				
Campbell	Campbell Neighbourhood Oval	29	4	1	3.9	24.8		Lake Burley Griffin
	Campbell Primary School	29	3	2.9				
ADFA	ADFA Ovals Nos. 1 & 2	64	1	4.7	21.7	137.8		Lake Burley Griffin
	ADFA Ovals Nos. 3-6	0	550	14.8				
	ADFA Parade Ground	64	1	2.2				
RMC 1	RMC Golf Club	120	3	23.7	42.3	268.6		Lake Burley Griffin
	RMC Playing Fields	120	3	18.6				
TOTAL				***248***	***248***	***1574.9***		
MAJURA								
RMC 2	RMC No. 1 Sports Oval	6	2	1.9	1.9	12.1		Lake Burley Griffin
Pialligo	Pialligo Nurseries	2	4-31	?	?	?		Lake Burley Griffin
TUGGERANONG								
Kambah 1	Tuggeranong Vikings BMX Club	199	5	0.02	0.02	0.2	-	Lake Tuggeranong; T1
Kambah 2	Kambah District Playing Fields (1)	115	12	8.5	8.5	54	Lake Tuggeranong	T1
Kambah 3	Kambah District Playing Fields (3)	353	10	7.4	8.1	51.4	Lake Tuggeranong	T1
	Taylor Primary School	353	1	0.7			Lake Tuggeranong	T1
Murrumbidgee	Murrumbidgee Country Club	7	16	45	45	285.8	Lake Tuggeranong	
Kambah 4	Kambah District Playing Fields (2)	286	30	12	14	88.9	Lake Tuggeranong	T1
	Kambah Park Fitness Track	286	26	1.2				
	Urambi Primary School	239	1	0.8				
Wanniassa 1	Wanniassa District Playing Fields	140	1	2.9	10.2	64.8	Lake Tuggeranong	
	Wanniassa North Playing Fields	202	5	3.8				
	Wanniassa School Junior Campus	142	1	0.8				
	Wanniassa School Senior Campus	141	1	2.7				
Wanniassa 2	Wanniassa Hills Primary School	253	1	1.7	1.7	10.8	Lake Tuggeranong	
Wanniassa 3	Erindale College	180	8	0.9	6.8	43.4	Lake Tuggeranong	Isabella Pond
	Mackillop Catholic College - Wanniassa	125	8	2.3				
	Vikings Park	126	16	3.6				
Wanniassa 4	Trinity Christian School	117	5	1	1	6.4	Isabella Pond	Lake Tuggeranong
Monash	Monash Neighbourhood Oval	171	1	1.4	1.9	11.7	Isabella Pond	Tuggeranong Weir; Lake Tuggeranong
	Monash Primary School	171	1	0.5				
Fadden	Fadden Neighbourhood Oval/Primary School	335	1	2.3	2.3	14.6	-	T2; Lake Tuggeranong
Gowrie	Gowrie District Playing Fields	228	12	5.5	8.1	51.4	T2	Isabella Pond
	Gowrie Primary School	229	3	1.1				
	Holy Family Primary School	226	15	1.5				
Fadden/Chisholm	Chisholm District Playing Fields	575	15	6	8.1	51.4	-	T2; Isabella Pond
	Fadden Pines District Park	353	11	2.1				
Chisholm	Caroline Chisholm High School	567	2	0.9	2.8	17.5	-	T2; T4; Isabella Pond
	Chisholm Neighbourhood Oval	549	1	1.3				
	Chisholm Primary School	550	1	0.6				
Gilmore	Gilmore Neighbourhood Oval	58	6	1.6	1.9	11.7	-	T2; T4; T3
	Gilmore Primary School	58	7	0.3				
Greenway 1	Tuggeranong Town Park	62	4	8	8.5	53.8	Lake Tuggeranong	Tuggeranong Weir
	Tuggeranong Valley Lawn Bowls	46	5	0.5				
Greenway 2	Tuggeranong Dog Training Club	46	9	0.3	2.4	15.4	Lake Tuggeranong	Tuggeranong Weir
	Tuggeranong Enclosed Oval	46	12	2.1				
Isabella Plains	Isabella Plains Neighbourhood Oval	856	40	2.8	5.8	36.6	Upper Stranger Pond	Isabella Pond; T4
	Isabella Plains Primary School	856	41	0.8				
	Mackillop Catholic College - Isabella Plains	877	16	2.2				
Bonython	Bonython Neighbourhood Oval	21	3	2.1	2.6	16.5	Upper Stranger Pond	Lower Stranger Pond; T4
	Bonython Primary School	21	4	0.5				
Richardson	Richardson Oval	494	1	1.3	1.4	8.9	T4	T3
	Richardson Primary School	452	2	0.1				
Calwell 1	Calwell Oval	701	2	2	3.2	20.3	Point Hut Pond	Gordon Pond; T4; Upper Stranger Pond; Lower Stranger Pond
	Covenant College	476	1	1.2				
Calwell 2	Calwell Primary School	751	21	1.6	1.7	10.8	T4	T3
	Were St Parkland	787	28	0.1				
Calwell 3	Calwell District Playing Fields	798	17	11	12.4	78.7	T3; T4	
	Calwell High School	795	11	0.7				
	St Francis of Assisi Primary School	796	16	0.7				
Theodore	Theodore Oval	666	1	1.3	2.9	18.4	-	T3
	Theodore Primary School	668	3	1.6				
Gordon	Gordon Neighbourhood Oval	410	12	0.9	4.3	27.3	Point Hut Pond	
	Gordon Primary School	410	15	1				
	Point Hut Pond District Park	563	2	2.4				
Conder	Charles Conder Primary School	286	2	0.8	9.2	58.3	Point Hut Pond	
	Conder Neighbourhood Oval	286	3	2.1				

Designation	Individual End uses	Section	Block	Individual Demand (ha)	Combined Demand (ha)	Combined Demand (ML/y)	Suggested Supply Source	Possible Supply Source
	Gordon District Playing Fields	410/211	14/13	5.6				
	Lanyon High School	212	10	0.6				
	St Clare of Assisi Primary School	212	12	0.1				
Banks	Banks Oval	12	20	2.8	2.8	17.8	Point Hut Pond	
TOTAL				***177.5***	***177.5***	***1126.9***		
JERRABOMBERRA								
Symonston	Canberra Greyhound Racing Club	107	2	11	11	69.7	-	Lake Burley Griffin
SOUTH CANBERRA								
Vikings Capital	Vikings Capital Golf Club	100	23	30	30	190.5		Lake Burley Griffin
Narrabundah 1	Narrabundah Neighbourhood Oval	124	7	1.5	1.9	12.1	-	Lake Burley Griffin
	Narrabundah Primary School	124	6	0.4				
Narrabundah 2	Mill Creek Oval	34	38	2.2	2.2	14	-	Lake Burley Griffin
Narrabundah 3	Jerrabomberra Sports Ground	64	4	3.6	6	38.4	-	Lake Burley Griffin
	Narrabundah College	87	1	1.8				
	St Benedicts Primary School	88	21	0.7				
Narrabundah 4	Boomanulla Oval	34	22	2	17	107.9	-	Lake Burley Griffin
	Errol Kavanagh Memorial Oval	34	26	5.5				
	Narrabundah Ball Park	34	32	1				
	Narrabundah Pitch n Putt	34	34	8.5				
Red Hill	Red Hill Primary School	27	11	0.4	0.6	3.9	-	Lake Burley Griffin
	Red Hill Tennis Club	27	20	0.2				
Red Hill/Griffith	Canberra Grammar	6	1	5	6.8	42.9	-	Lake Burley Griffin
	Flinders Park	88	29	1.8				
Federal	Federal Golf Club	56	1	11.5	11.5	73	-	W19; Lake Burley Griffin
Griffith 1	Kingston Oval	22	9	2	3.9	24.8	-	Lake Burley Griffin
	St Clares College	29	1	1.9				
Griffith 2	Canberra South Bowling Club	42	15	0.4	2.4	15.2	-	Lake Burley Griffin
	Flinders Tennis Club	42	10	0.5				
	Griffith Oval	42	17	0.8				
	Griffith Oval No. 2	42	17	0.7				
Barton/Griffith	Manuka Oval	15	15	2	11.9	12.7	-	Lake Burley Griffin
	Telopea Park	30	1	7.2				
	Telopea Park Primary School	29	1	2.7				
Barton	Bowen Park	31	4	3.7	3.7	23.5	-	Lake Burley Griffin
Forrest	Canberra Bowling Club	12	3	0.3	0.9	5.8	-	Lake Burley Griffin
	Forrest Primary School	13	1	0.6				
Capital Hill	Parliament House	1	2	32	32	203.2	-	Lake Burley Griffin
Parkes	Parliamentary Triangle	58	1	120	120	762	-	Lake Burley Griffin
Deakin 1	Canberra Girls Grammar Junior Campus	49	15	0.5	0.5	3.2	-	W0; W2; Lake Burley Griffin
Deakin 2	Canberra Girls Grammar Senior Campus	9	Jan-19	0.6	0.7	4.1	-	W0; W2; Lake Burley Griffin
	Latrobe Park	45	14	0.1				
Deakin 3	Deakin West District Playing Fields	68	13/23	10.8	14	88.9	-	W0; W2; Lake Burley Griffin
	Mint Oval	65	4	3.2				
Deakin 4	Alfred Deakin High School	35	76	1.5	2.3	14.6	-	W0; W2; Lake Burley Griffin
	The Woden School	35	21	0.5				
	West Deakin Hellenic Bowling Club	35	28	0.3				
Yarralumla 1	Canberra Croquet Club	40	7	0.3	6	38.1	-	Lake Burley Griffin
	Flynn Place	-	-	0.5				
	Lennox Gardens	42	10	5.2				
Yarralumla 2	Canberra Southern Cross Club - Yacht Club	42	10	0.2	0.2	1.4	-	Lake Burley Griffin
Yarralumla 3	Weston Park	124	5	4.4	14.6	92.7	-	W0; W2; Lake Burley Griffin
	Yarralumla Nursery	123	2	10.2				
Yarralumla 4	Yarralumla Neighbourhood Oval	82	13	2.5	2.8	18	-	W0; W2; Lake Burley Griffin
	Yarralumla Primary School	82	12	0.1				
	Yarralumla Tennis Club	53	1	0.2				
Yarralumla 5	Forestry Oval	4	4	1.5	46.5	295.3	W0	W2; Lake Burley Griffin
	Royal Canberra Golf Club	119/121	2-Jan	45				
Government House	Government House	122	1	20	20	127	W0	Lake Burley Griffin
TOTAL				*358.4*	*358.4*	*2213.3*		
WODEN VALLEY								
Curtin 1	North Curtin District Playing Fields	106	13	6.6	6.6	41.7	W2	W0; Lake Burley Griffin
Curtin 2	Curtin Primary School	60	1	0.7	2.5	15.6	W2	W0; WC4; W19 Lake Burley Griffin
	South Curtin Neighbourhood Oval	60	4	1.8				
Hughes	Clarrie Hermes Park	28	7	3.6	4.2	26.7	-	W19; W2; W0; Lake Burley Griffin
	Hughes Primary School	35	34	0.6				
Garran	Malkara School	8	45	0.8	1.5	9.4	-	W19; W2; W0; Lake Burley Griffin
	Sts Peter & Paul Primary School	8	40	0.7				
Phillip 1	Canberra College Woden Campus	79	7	1	8.3	52.4	-	W19; W2; W0; Lake Burley Griffin
	Canberra Southern Cross Club - Bowling Greens	24	4	1.4				
	Phillip Oval Football Park	23	9	2.5				
	Pitch & Putt Golf Course	79	4	3.4				
Lyons	Lyons Neighbourhood Oval	55	9	2.7	3.5	22.2	-	W19; W2; W0; WC4; WC19; WC13; WC17; WC9; Lake Burley Griffin

Designation	Individual End uses	Section	Block	Individual Demand (ha)	Combined Demand (ha)	Combined Demand (ML/y)	Suggested Supply Source	Possible Supply Source
	Lyons Primary School	41	5	0.8				
Phillip 2	Arabanoo Park	80	36	1.1	8.8	55.9	W19	W27; W0; W2; Lake Burley Griffin
	Eddison Park	131	7	1.7				
	Woden Athletic Field	131	5	1.8				
	Woden Cemetery	109	1	4				
	Woden Town Park	80	24	0.2				
Phillip/Garran	Garran Neighbourhood Oval	33	9	2.4	7.3	46.4	W19	W27; W0; W2; Lake Burley Griffin
	Garran Primary School	33	1	0.7				
	Phillip Enclosed Oval	1	13	2.6				
	Phillip Playing Fields	1	6	1.7				
Mawson	Canberra Christian School	17	2	0.4	4.6	28.9	W27	W19; W26
	Mawson Neighbourhood Oval	17	5	3				
	Mawson Primary School	17	5	1.2				
Pearce 1	Marist College	49	16	6	10.6	67.3	W27	W19; W26
	Melrose High	49	1	2				
	Pearce Neighbourhood Oval	27	16	2.6				
Pearce 2	Sacred Heart Primary School	43	2	0.4	0.4	2.4	-	W27; W26
Torrens/Mawson	Mawson District Playing Fields	47	25	10.5	14.4	91.4		W27; W26
	Torrens Neighbourhood Oval	20	15	2.5				
	Torrens Primary School	22	13	1.4				
Farrer	Farrer Neighbourhood Oval	25	3	2.9	3.8	23.9	-	W27; W26
	Farrer Primary School	33	2	0.9				
TOTAL				***76.3***	***76.3***	***484.2***		
WESTON CREEK								
Chapman	Chapman Neighbourhood Oval	13	1	2.9	4.7	29.6	-	WC20-1; WC20-2; WC20-3; WC23; WC19; WC4
	Chapman Primary School	12	4	1.8				
Waramanga	Arawang Primary School	39	1	1.4	9.3	59	WC19 (partial)	WC20-1; WC20-2; WC20-3; WC23; WC4; WC17; WC13; WC9
	St John Vianneys Primary School	44	4	0.3				
	Stromlo High School	45	1	1.8				
	Waramanga District Playing Fields	46	7	5.8				
Stirling	Canberra College Weston Campus	24	2	0.4	10.3	65.3	-	WC20-1; WC20-2; WC20-3; WC4; WC17; WC13; WC9; WC3; WC2; WC0
	Stirling District Playing Fields	24	88	9.6				
	Weston Creek Bowling Club	24	5	0.3				
Rivett	Rivett Neighbourhood Oval	27	4	3.3	3.3	21	WC4	WC20-1; WC20-2; WC20-3; WC4; WC17; WC14; WC15; WC3; WC2; WC0
Holder	Holder Neighbourhood Oval	23	1	2.5	2.5	15.9	WC4	WC4; WC17; WC14; WC15; WC13; WC9; WC3; WC2; WC0
Duffy	Duffy Neighbourhood Oval	54	1	2.5	3.7	23.5	WC14-15	WC0; WC2; WC3; WC4
	Duffy Primary School	23	2	1.2				
Holder/Weston	Weston Oval	22	3	2	2	12.7	WC4	WC9; WC0; WC2; WC3; WC14-15
Weston	Canberra Institute of Technology & Horticultural School Weston Campus	96	6	2.7	2.7	17.1	WC4	WC3; WC2; WC0
*North Weston	Australian Defence College	0	1212	1	5.4	34.3		
	*Weston Pond Surrounds	0	1204	4.4				
*Molonglo	*Molonglo 1 Neighbourhood Oval	0	1171	2.3	2.3	14.6		
National Zoo	National Zoo and Aquarium	0	1496	50	50	317.5	WC0	W0; Lake Burley Griffin
Arboretum	Canberra International Arboretum and Gardens	0	1544	180	180	1143	-	WC0; W0; Lake Burley Griffin
TOTAL				***276.1***	***276.1***	***1753.5***		
GRAND TOTAL				**1564.7**	**1564.7**	**9893.1**		

APPENDIX B MAP OF DEMAND CLUSTERS

Please see next page for a map of demand clusters. Table 58 identifies the clusters in the map. Refer to Appendix A for the properties of each cluster.

Table 58: Demand Cluster IDs for Map

ID	Name	ID	Name	ID	Name
1	ACTON	52	FLOREY 2	103	MONASH
2	ADFA	53	FLYNN	104	MURRUMBIDGEE
3	AINSLIE	54	FORREST	105	NARRABUNDAH 1
4	AINSLIE/BRADDON	55	FRASER	106	NARRABUNDAH 2
5	AIS	56	GARRAN	107	NARRABUNDAH 3
6	AMAROO	57	GILMORE	108	NARRABUNDAH 4
7	ANBG	58	GIRALANG	109	NATIONAL ZOO
8	ANU	59	GOLD CREEK	110	NGUNNAWAL
9	ARANDA	60	GORDON	111	NICHOLLS
10	ARBORETUM	61	GOVERNMENT HOUSE	112	NORTH WESTON
11	BANKS	62	GOWRIE	113	O'CONNOR
12	BARTON	63	GREENWAY 1	114	O'CONNOR/TURNER
13	BARTON/GRIFFITH	64	GREENWAY 2	115	PAGE
14	BELCONNEN 1	65	GRIFFITH 1	116	PALMERSTON
15	BELCONNEN 2	66	GRIFFITH 2	117	PARKES
16	BELCONNEN 3	67	GUNGAHLIN	118	PEARCE 1
17	BONYTHON	68	GUNGAHLIN CEMETERY	119	PEARCE 2
18	BRADDON	69	GUNGAHLIN LAKES	120	PHILLIP 1
19	BRUCE	70	HACKETT	121	PHILLIP 2
20	CALWELL 1	71	HARRISON	122	PHILLIP/GARRAN
21	CALWELL 2	72	HAWKER	123	PIALLIGO
22	CALWELL 3	73	HIGGINS	124	RED HILL
23	CAMPBELL	74	HOLDER	125	RED HILL/GRIFFITH
24	CAMPBELL/REID	75	HOLDER/WESTON	126	RICHARDSON
25	CAPITAL HILL	76	HOLT	127	RIVETT
26	CHAPMAN	77	HUGHES	128	RMC 1
27	CHARNWOOD 1	78	ISABELLA PLAINS	129	RMC 2
28	CHARNWOOD 2	79	KALEEN 1	130	SCULLIN
29	CHISHOLM	80	KALEEN 2	131	SPENCE
30	CITY	81	KALEEN 3	132	STIRLING
31	CONDER	82	KAMBAH 1	133	SYMONSTON
32	COOK	83	KAMBAH 2	134	THEODORE
33	CRACE	84	KAMBAH 3	135	THROSBY
34	CURTIN 1	85	KAMBAH 4	136	TORRENS/MAWSON
35	CURTIN 2	86	KIPPAX	137	TURNER/ANU
36	DEAKIN 1	87	LATHAM	138	UNIVERSITY OF CANBERRA
37	DEAKIN 2	88	LYNEHAM 1	139	VIKINGS CAPITAL
38	DEAKIN 3	89	LYNEHAM 2	140	WANNIASSA 1
39	DEAKIN 4	90	LYNEHAM 3	141	WANNIASSA 2
40	DICKSON	91	LYNEHAM 4	142	WANNIASSA 3
41	DICKSON/ANSLIE	92	LYONS	143	WANNIASSA 4
42	DOWNER	93	MACGREGOR	144	WARAMANGA
43	DUFFY	94	MACQUARIE	145	WATSON
44	EPIC	95	MACQUARIE/BELCONNEN	146	WATSON/DICKSON
45	EVATT 1	96	MAGPIES BELCONNEN	147	WEETANGERA
46	EVATT 2	97	MAWSON	148	WESTON
47	FADDEN	98	MCKELLAR	149	YARRALUMLA 1
48	FADDEN/CHISHOLM	99	MELBA 1	150	YARRALUMLA 2
49	FARRER	100	MELBA 2	151	YARRALUMLA 3
50	FEDERAL	101	MITCHELL	152	YARRALUMLA 4
51	FLOREY 1	102	MOLONGLO	153	YARRALUMLA 5

APPENDIX C RAINFALL RUN-OFF MODELS

A rainfall run-off modelling approach was developed for urban Canberra based on the calibration and validation of three rainfall-run-off models for which stream gauge data were available: Sullivan's Creek upstream of Barry Drive; Yarralumla Creek upstream of Curtin; and Yarralumla Creek upstream of Mawson. The fitted parameters for each of these catchments were used to develop run-off time series for all urban catchments based on impervious area, the most influential characteristic for run-off in urban areas.

Pervious fraction was the only parameter able to be measured for each catchment and was done so by investigating land use categories in the 'ACT Territory Plan land use' GIS layer. Each land use was assigned effective impervious fractions based on a review of the literature and investigation of satellite imagery (see Table 2 in Chapter 4.1). (Land uses of the type ‘federal land’, ‘municipal services’, ‘entertainment, accommodation and leisure’ and ‘broadacre’ were inspected separately using aerial photography if they constituted a significant proportion of the catchment, as they varied case by case; the fraction impervious values shown for these land uses in Table 2 is only a guide).

Climate files for the three catchments were obtained from Ecowise Environmental (gauge data) and the SILO Data Drill (interpolated datasets) (QNR&M, 1998). Table 59 details the source and length of record of data used and Figure 49 shows the location of these catchments within the urban area of Canberra.

Table 59: Climate data sources for fitting rainfall run-off models

Catchment	**Catchment Area (km^2)**	**Data type**	**Data Source**	**Gauge Number/ Coordinates**	**Time period**	**Data Gaps?**
Sullivans Creek	48.7	Rainfall	Ecowise Environmental	570813	03/01/1987 10/04/2007	19%
		Evaporation	SILO Data Drill	35°15’S 14°09’E	24/04/1986 10/04/2007	No
		Streamflow	Ecowise Environmental	410775	24/04/1986 10/04/2007	0.04%
Mawson	5.9	Rainfall	SILO Data Drill	35°21’S 149°06’E	01/01/1971 31/03/2003	No
		Evaporation	SILO Data Drill	35°21’S 149°06’E	01/01/1971 31/03/2003	No
		Streamflow	Ecowise Environmental	410753	15/09/1971 12/03/2007	0.8%
Curtin	27.5	Rainfall	SILO Data Drill	35°21’S 149°06’E	01/01/1971 31/03/2003	No
		Evaporation	SILO Data Drill	35°21’S 149°06’E	01/01/1971 31/03/2003	No
		Streamflow	Ecowise Environmental	410745	31/01/1970 11/12/2006	2.4%

Figure 49: Gauged catchments within urban Canberra

The models were developed, calibrated and validated using the SimHyd rainfall-run-off model in the Rainfall Run-off Library (eWater, 2007). SimHyd is a daily conceptual rainfall-run-off model with 7 parameters. This version has two additional parameters for impervious areas. Figure 50 outlines the structure of the model: the model parameters are highlighted in red.

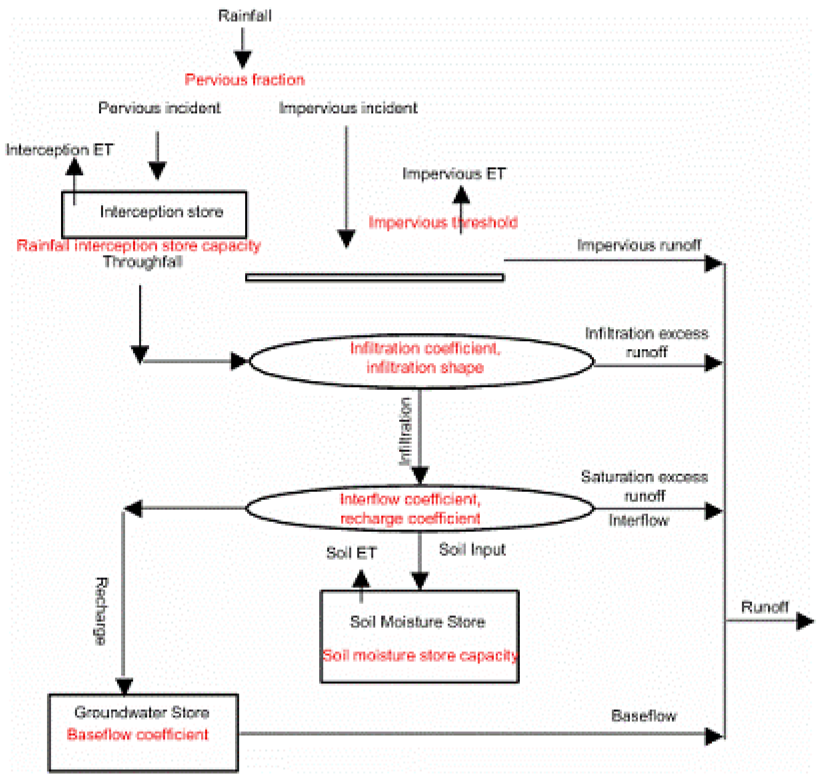

Figure 50: Structure of the SIMHYD model (Podger, 2004)

The record length (without gaps in rainfall or evaporation) was split in two for calibration and validation periods. The longest or driest period was chosen for calibration to attempt to gain the best fit for possible future conditions. The calibration and validation periods are outlined in Table 60; this includes model warm-up for equilibration of initial stores.

Table 60: Calibration and validation periods of rainfall run-off models

Catchment	**Calibration**			**Validation**		
	Start	*Warm-up*	*End*	*Start*	*Warm-up*	*End*
Sullivans Creek	02/06/1990	01/12/1990	08/05/1997	18/03/2002	01/09/2002	10/04/2007
Mawson	01/01/1987	05/03/1987	31/03/2003	15/09/1971	04/12/1971	31/12/1986
Curtin	01/01/1987	05/03/1987	31/03/2003	01/01/1971	18/02/1971	31/12/1986

The calibration was optimised for *daily* run-off using optimisation tools (Genetic Algorithm or Shuffled Complex Evolution, followed by Pattern Search) to two objective functions. The primary objective function was to maximise the coefficient of efficiency or Nash-Sutcliffe criterion (E), which expresses the proportion of variance of flows accounted for directly by the model. This value is always less than 1 as illustrated in the equation below where m = measured and o = observed flow.

$$1-\frac{\sum (m(i)^{\lambda}-o(i)^{\lambda})^{2}}{\sum (o(i)^{\lambda}-mean\_obs^{\lambda})^{2}}$$

The secondary objective was to have total run-off within 5%, imposed as a penalty on the Nash-Sutcliffe criterion.

First the model was calibrated for each catchment separately to identify the range of local parameter sets and the best achievable fits to the data. Optimisation of infiltration coefficient and infiltration shape is not required in most catchments (Chiew and Siriwardena, 2005). Indeed these showed little variation/sensitivity here and so were set to default values of 200 and 1.5 respectively to improve chances of optimisation of the remaining 7 parameters. Table 61 shows the parameters corresponding to the best fit in each catchment. The *E* value and run-off difference obtained is considered 'good to very good'.

Table 61: Optimal SimHyd parameters for each catchment

	Sullivans Creek	Mawson	Curtin
Baseflow coefficient.	0.527	0.475	0.502
Impervious Threshold	1.3	0	0
Infiltration Coefficient.	200	200	200
Infiltration Shape	1.5	1.5	1.5
Interflow Coefficient.	0.067	0	0.011
Perv. Fraction	0.89	0.91	0.9
RISC	5	0	0.5
Recharge coefficient	0.318	0.784	0.805
SMSC	130	75	70
E (calibration)	0.870	0.687	0.695
E (validation)	0.778	0.605	0.571
Run-off difference (calibration)	-5.0%	3.5%	-3.0%
Run-off difference (validation)	-4.5%	0.5%	-8.0%

The optimal parameters for the Sullivans Creek, Mawson and Curtin catchments (Table 61) were then used to develop a single parameter set for generic application to all catchments across Canberra. This was achieved by fixing the parameters one by one starting with measured pervious fraction and then proceeding in order of least to most sensitive parameter across subsequent calibrations. Pervious fraction was set according to the measured value, estimated as previously outlined in Chapter 4.1. This was 0.82, 0.73 and 0.75 for Sullivans Creek, Mawson and Curtin catchments respectively. These settings were below the calibrated pervious fraction values (Table 61), however to translate the run-off model from one catchment to another, use of measured fraction impervious values is critical. Fixing of the pervious fraction in this manner altered the remaining parameter set significantly.

Remaining parameters were set by considering: general consensus of average calibrated values; typical literature values; and minimising reduction in efficiency of fit across the catchments. This was difficult in some cases as divergence in parameter values increased as more parameters were fixed. The RISC (rainfall interception store capacity) parameter was particularly difficult to reconcile between Mawson/Curtin and Sullivans Creek. In this case, an average and physically plausible value was chosen which minimised the reduction in fit in each catchment.

Once fixed, the final parameter set was tested for any additional possible optimisation. Table 62 shows the final parameter set obtained and Table 63 shows the fit of this parameter set to each catchment.

Table 62: Generic SimHyd parameter set for Canberra

Parameter	Value
Baseflow Coefficient	0.3
Impervious Threshold	5
Infiltration Coefficient	200
Infiltration Shape	1.5
Interflow Coefficient	0.01
Pervious Fraction	Varies
Rainfall Interception Store Capacity	1.9
Recharge Coefficient	0.56
Soil Moisture Store Capacity	125

Table 63: Performance of test catchments against generic parameter set

	Coefficient of Efficiency (daily time-step)		**Correlation (daily time-step)**		**Difference in total run-off**	
	Calibration	*Validation*	*Calibration*	*Validation*	*Calibration*	*Validation*
Sullivan's Creek	0.816	0.645	0.918	0.859	13.97%	13.33%
Mawson	0.561	0.467	0.766	0.726	-15.53%	-17.23%
Curtin	0.593	0.462	0.773	0.695	-23.58%	-26.63%

This parameter set evidently did not fit the data as well as the individual optimised parameter sets. Whilst the coefficients of efficiency obtained could still be considered reasonable, representing the pattern of flow fairly well, the run-off difference was significantly greater. The run-off was significantly overestimated for Sullivan's Creek and underestimated for Curtin and Mawson, with a maximum difference of 26.63%. This under or overestimation of the run-off, particularly for higher fraction impervious values, would not be expected to adequately represent the influence of impervious fraction or allow for realistic comparison of yield of potential supply options.

To overcome this underestimation problem, an alternative approach was developed. As the optimisation of the individual catchments yielded significantly better results, a method was developed to relate these parameters to the ungauged catchments. Indeed the parameterisation process and difficulty in fitting a generic parameter set indicated that different processes were dominant in the two areas, potentially relating to the degree of rural/undeveloped area present. To translate these optimised sets of parameters it was assumed that:

- Fraction impervious is proportional to volumetric run-off coefficient and they can be related mathematically.

- The Sullivan's Creek model (Table 61), with an impervious fraction of 0.18 is appropriate for predicting catchments with low fraction impervious values (≤0.2), whilst the Curtin Model (Table 61) is better at predicting higher fraction impervious values (>0.2).

A relationship between volumetric run-off coefficient (V_{rc}) and fraction impervious (F_i) was developed using the Sullivan's Creek, Mawson and Curtin models with the assumption that the V_{rc} will be around 0.05 for a F_i of 0 (Figure 51). This relationship was developed using the 2030 climate sequence. A run-off series for each catchment was developed by using the mathematical relationship to determine run-off coefficient. This was then used to scale run-off outputs (uniformly adjusted to the trend line) of the model corresponding to the fraction impervious of the catchment in question. This would be Sullivan's Creek where F_i ≤0.2 or Curtin Model where F_i >0.2. For example, for a catchment with F_i of 0.1, run-off on day *t* is calculated by the following process:

1. On day *t*, according to the Sullivan's Creek model, flow is equal to Q_t

2. The trend line, as shown in Figure 51, is:

   $$V_{rc} = -0.3888F_i^3 + 0.856F_i^2 + 0.3817F_i + 0.05$$

3. The V_{rc} of the Sullivan's Creek model, when run using the 2030 climate sequence is 0.11, and the measured F_i for Sullivan's Ck is 0.18

4. To fit with the trend line in equation stated above, Q_t is adjusted to Q_t' by:

   $$Q_t' = Q_t * (V_{rc}\ trend\ line/V_{rc}\ original)$$

   $$= Q_t * [-0.3888F_i^3 + 0.856F_i^2 + 0.3817F_i + 0.05]/ V_{rc}\ original$$

   $$= Q_t * [-0.3888*(-0.18)^3 + 0.856*(-0.18)^2 + 0.3817*(-0.18) + 0.05]/0.11$$

   $$= Q_t * 0.14/0.11$$

   Q_t' being the flow as per the trend line in Figure 51 for a F_i of 0.18 (Sullivan's Creek) on day *t*.

5. Flow on day *t*, for a catchment with F_i of 0.1, $Q_t^{0.1}$, can then be calculated as:

   $$Q_t^{0.1} = Q_t' *\mathbf{V_{rc}} \text{ (for } F_i \text{ of 0.1) / } \mathbf{V_{rc}} \text{ (for } F_i \text{ of 0.18)}$$

   $$= Q_t' * 0.1 / 0.14$$

This method is far from ideal; however given that rainfall run-off models could only be calibrated for three catchments, this is the best result possible. A rainfall run-off model with an appropriate volumetric coefficient and hydrograph shape is required for accurate stormwater harvesting models. Unfortunately, these two parameters could not be reconciled to develop an appropriate generic SimHyd model for urban Canberra. The relationship between V_{rc} and F_i adopted for this study (Figure 51) is more realistic than that of the generic parameter set, and the shape of the hydrographs used in the modelling will be akin to those fitted to Sullivan's Creek and Curtin.

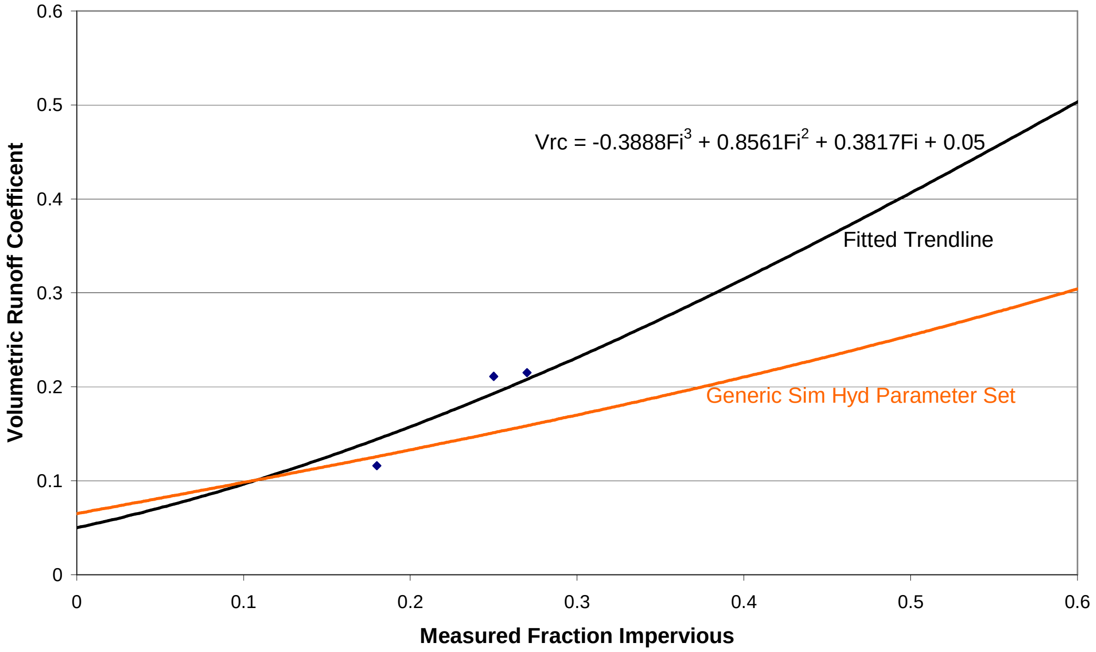

Figure 51: Comparison of fraction impervious and volumetric run-off coefficient values

APPENDIX D POTENTIAL AND EXISTING LAKE AND POND SITES

See next page for a map of potential and existing lake and pond sites, with catchment area.

APPENDIX E HYDROGEOLOGICAL PROVINCES

See next page for a map of the hydrogeological provinces of the ACT region.

APPENDIX F MAR DESIGN AND COSTING

Detailed below are the equations and assumptions used to cost the MAR examples in this report. The proposed 'W2' pond on Yarralumla Creek and its associated demands are used as an example.

Bore Design

Each MAR scheme was modelled in accordance with Figure 52 below. Figure 52 is a simplified design of an MAR scheme and contains many generalities. It is very much a conceptual design suited for the screening purposes of this report only.

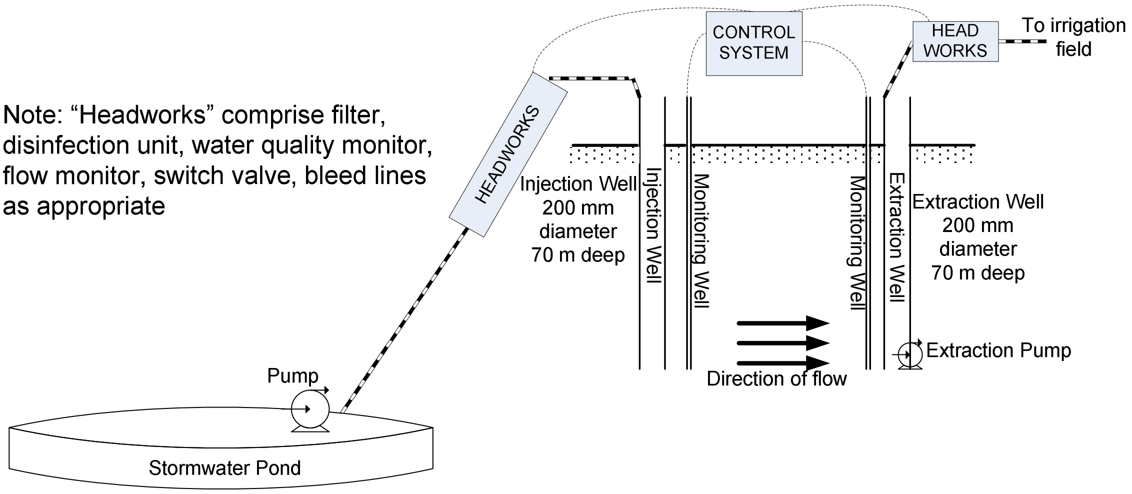

Figure 52: Conceptual generic ASTR design

As discussed in Chapter 4.2, the headworks required for each scheme will vary depending on the hydrogeological province. For example, wells in the Mt Painter Volcanics hydrogeological province will require minimal water quality treatment (e.g. filter screen) due to the high injection rates, which means clogging is less likely to be an issue. This is not the case for wells in the Alluvium province (which have not been analysed in detail for this study) which will require further treatment, such as from a sand filter.

For this study, headwork costs other than pipes and pumps from the pond (i.e. filters, disinfection units, water quality monitors, switch valves etc.) were derived from Evans (2008) who estimated $25,000 per injection bore in fractured rock aquifers. MAR was not considered for any other province due to excessive treatment costs (approximately $3.50/kL, per comm. Taylor 2008).

It is noted that water table levels have not been explicitly calculated or modelled (Figure 52). This is because starting water table levels for each scheme are as yet unknown and it is assumed the scheme will be located over an appropriately large area, so that drawdown and injection limits will not be an issue. This design and costing exercise is to test the potential of aquifer storage; it is not a process of recommending specific locations or undergoing detailed design.

In the case of the 'W2' pond in the Yarralumla Creek catchment (Table 3) supplying the 'Curtin 1' demand cluster, the total demand of the irrigators is 41.7 ML/yr (Appendix A). Following the equations from Chapter 6.2 and assuming there is a 25% loss from the aquifer, the minimum amount water flowing from an aquifer annually, $Q_{aquifer}$,, is:

$Q_{aquifer}$ = Amount of water extracted from aquifer on annual basis

$Q_{aquifer} = D_{end\ point} / (1-0.25) = 41.7/0.75 = 55.6$ ML/y

In this case, the volumetric reliability between the pond and aquifer is 95%. Therefore, the average annual volume of water to be delivered from the pond to the aquifer needs to be:

$Q_{pond\text{-}aquifer}$ = Average volume of water to be extracted from pond and injected to aquifer

$Q_{pond\text{-}aquifer} = Q_{aquifer} / (0.95) = 55.6/0.95 = 58.5$ ML/y

The injection rate of each bore, $Q_{injection}$ is assumed to be 3 litres per second in this area (Mt Painter Volcanics, Table 4). The number of injection bores required, $N_{injection\ bore}$, is therefore:

$N_{injection\ bore} = Q_{pond\text{-}aquifer} / Q_{injection}$ = 58.5 ML per year / 3 L per second = 58.5 / 94.7 = 0.62

Obviously, the number of bores needs to be an integer, so $N_{injection\ bore}$ is rounded up to 1.

The number of extraction bores required was calculated by first estimating the maximum demand. As is discussed in Chapter 3.2, annual demand is estimated to be 635 mm (6.35 ML/ha) and is the equivalent of the difference between evaporation and rainfall in the 2030 climate series used in this study. It is assumed that irrigation of each field occurs once every 3 days and is alternated between ovals / parks so that irrigation is occurring somewhere each day during the irrigation season. For a well designed irrigation regime, the maximum daily irrigation for the Curtin 1 demand cluster would be 0.3 ML.

Assuming that the maximum extraction rate is equal to 4 l/s (Table 4), the number of extraction bores required, $N_{extraction\ bore}$, is equal to:

$N_{extraction\ bore}$ = Maximum daily irrigation / $Q_{max\ extraction}$ = (0.3 ML/day) / (4 l/s) = 0.81

Once again, the number of bores needs to be an integer, so $N_{extraction\ bore}$ is rounded up to 1.

In this case, there is only 1 demand cluster (Curtin 1, see Appendix A), so it is assumed all of the demand can be supplied from a single bore field. If there were multiple demand clusters, the number of bores required would need to be revised.

It is noted the above is a simple conceptual example. For detail design, greater care needs to be taken in ensuring injection / extraction rate accuracy. The design could also allow for the end user to extract water directly from the pond (as well as the aquifer) which would improve operational efficiency during summer. There is also potential to inject into both bores during wet periods and extract from both bores during dry periods.

Pond Design

In order to determine the pond size required to supply the demands of the ASR schemes, a 65 year daily model simulation using a 2030 climate series was run (see Chapter 2.1 for details of the climate sequence, Appendix K for details of the harvesting model and Appendix C for details of the rainfall run-off model). Depending on the scenario being analysed, the volumetric reliability was fixed at either 85% or 95%. Demand was determined from the $Q_{pond\text{-}aquifer}$ equation above. The pond size was then iteratively adjusted until the required volumetric reliability was achieved.

Costing

The present value (PV) cost was estimated by summing the capital, replacement and maintenance costs, i.e.

Cost_{PV} (\$2008) = Capital Cost + PV Operation-Maintenance Cost + PV Replacement Cost

Evans (2008) suggested capital cost for each bore to be $94,000 comprising headworks of $25,000, telemetry of $5,000, monitoring well (including monitoring equipment) of $50,000 and drilling of $14,000 (200 mm diameter pipe at 70 metres depth). A further $10,000 was added to this value for the extraction pump, to obtain an estimated cost per bore of $94,000.

'Add on' costs were allowed for in the form of contingency, consultant design and supervision, special investigations, insurance and administration-procurement. Values were chosen by CSIRO based on typical values used by ACTPLA (per. comm. Garside, 2008) of 30% for contingency, 20% for Consultant Design and Supervision, 20% for Special Investigations, 0.6% for Insurance and 4% of the total for Administration-Procurement. In this case, a greater contingency (30%) was adopted than for other items such as pipes, pumps and ponds given the comparative greater uncertainty of aquifer projects. A greater special investigations value was also used (20%) given there needs to be gathering of geotechnical data and a degree of searching to find an appropriate site. Administration-procurement was calculated as simply 4% of the construction cost plus contingency, design and supervision and special investigations in order to simplify the costing process.

A total cost of $270,000 was estimated for a single bore (Table 64). This includes a construction cost of $104,000 which equates to a total capital cost of $185,000 with 'add-ons' included. Replacement costs, which include provision of 30% for contingency, are estimated as $48,000 in PV ($2008) terms. Limited information was available for operation and maintenance costs, so annual operating costs of between 1.5% and 2.0% of capital cost were assumed. This equated to an estimated operation and maintenance PV cost of $38,000. All PV calculations were undertaken in accordance with the formulae described in Appendix L.

In the case of 'W2' in Yarralumla Creek, where there is 1 injection and 1 extraction bore,

W2 Bore Cost_{PV} (\$2008) = \$270,000 * 2 = \$540,000

It should be noted that this cost does not include the pond, pipes from pond to aquifer or pumping from pond to aquifer. These costs, in most cases, are substantially greater than the aquifer costs. See Appendix L and Appendix P for example pond, pipe and pump design, modelling and costing.

Table 64: Present value (PV) cost of a single bore

CAPITAL CONSTRUCTION COST		
Headworks		$ 25,000
Telemetry		$ 5,000
Monitoring		$ 50,000
Bore		$ 14,000
Extraction Pump		$ 10,000
Sub-total		**$ 104,000**
Including allowances	**Allowance (%)**	
Contingency	30%	$ 31,200
Consultant Design & Supervision	20%	$ 20,800
Special Investigations	20%	$ 20,800
Sub Total		**$ 176,800**
Insurance	0.6%	$ 1,061
Administration-Procurement Solutions	4%	$ 7,072
TOTAL		$ 184,933
Total Capital Cost (rounded) ($)		**$ 185,000**
REPLACEMENT COSTS (PV)		
Headworks		$ 9,721
Telemetry		$ 1,944
Extraction pump		$ 5,988
Monitoring Well		$ 19,441
Sub Total		**$ 37,094**
Contingency	30%	**$ 11,128**
Total Replacement Cost		**$ 48,222**
Total Replacement Cost (rounded)		**$ 48,000**
OPERATION & MAINTENANCE COST	**Beta**	
Annual headworks cost (assumed 2% of capital)	0.02	$ 500
Annual telemetry cost (assumed 1.5% of capital)	0.015	$ 75
Annual bore cost (assumed 2% of capital)	0.02	$ 280
Annual pump cost (assumed 1.5% of capital)	0.015	$ 150
Annual monitoring cost	0.02	$ 1,000
Sub Total		$ 2,005
Contingency	30%	$ 602
Total Annual Cost		$ 2,607
PV Total annual cost (incl. contingency)		$ 38,379
Total PV O+M Cost (rounded)		**$ 38,000**
TOTAL PV PROJECT COST		**$ 271,000**
ROUNDED TOTAL ($PV)		**$ 270,000**

APPENDIX G REGIONAL AQUIFER REPORT

Canberra Integrated Urban Waterways Project
Draft Regional shallow aquifer Report 18th December 2007

Ian Lawrence, Senior Research Fellow CRC eWater
Ray Evans, Director, Salient Solutions

Summary

This Report outlines the scope of large (regional) shallow aquifers across Canberra, and assesses their storage capacity, leakage rates, recharge and abstraction trench length requirements.

Table 65: Summary of aquifer values

Aquifer medium classification	Storage capacity (GL)	Length of trench required per KL of recharge (m)	Annual leakage rate (%)	Max abstraction rate (KL/hr/m of trench)
Sandy gravel	400 to 500	0.07	29	2.76
Clayey sandy gravel		0.27	3.0	0.28
Silty clayey gravel		0.33	1.4	0.14

Summary of costs:

Inlet structure	$15,000 - $30,000
Inlet pump & rising main	$10,000 - $15,000
Infiltration swale, bio-filter & gravel trench	$200/metre
Aquifer water recovery pump	$5000
Annual maintenance	$15,000

Background

The CSIRO assessment of stormwater detention, storage and supply options has identified groundwater storage as a key element in respect to storing stormwater during rainfall events (low water demand), and abstracting water from the storage for water supply during dry or peak irrigation demand periods.

Two categories of groundwater aquifer systems have been adopted for the purpose of the assessment:

- Local aquifer storage & retrieval (ASR) or aquifer storage, transfer & retrieval (ASTR) systems;
- Regional aquifer storage, transfer & retrieval (ASTR) systems.

Within each system category there are two geological categories of aquifer:

- shallow alluvial aquifers; and
- deep fractured rock aquifers.

This note develops a generic model for the regional ASTR shallow aquifer systems, identifying:

- storage capacity of typical regional shallow aquifers;
- their typical input (recharge) hydraulic rates and recharge arrangements;
- their efficiency in respect to leakage of stored water; and

- ‘engineering’ of the aquifers required to improve their storage capacity and hydraulic conductivity and to reduce their leakage;
- typical development and operations costs associated with establishing the aquifers as active stormwater storage systems.

Further development is required on the natural water cycle function of the aquifers in the landscape, including their role in sustaining environmental flows in local waterways.

Description & Distribution of Shallow Aquifers across Canberra

A major feature of the Silurian sedimentary landscapes across Canberra is the deposition of alluvial material across valley floors, forming layers of silt, sand and gravel (pedoderms). Water 'mounds' are maintained within these zones by interflow drainage down the adjacent slopes, with springs across the valley floors often a feature of the areas.

In many cases, clearing during the 1870s to 90s resulted in gully erosion, with drainage of the pedoderms to the floors of the gullies. Where erosion gullies have not occurred, discharge of the pedoderms is either via springs, or exfiltration through the lower 'face' of the pedoderm (alluvial fan), as occurs in the Horse Park Wetland.

Where urban development has occurred over the pedoderm area (Isabella Plains Tuggeranong, Conder & Banks in southern Tuggeranong), the past practice has been installation of groundwater interception drains. Residential development has been excluded from some major pedoderms in Gungahlin (Ginninderra Ck at Gungahlin Drive, Gungaderra Ck at Gungahlin Dr/Grasslands Nature Park), while Water Sensitive Urban Design based urban development is proposed in the case of the Horse Park pedoderm.

Geotechnical surveys of the pedoderms indicate typically layers of sandy gravels to silty clayey gravels, to depths of generally 3 to 4 m across the valley floors. Typically, the gravel layers are overlain by sandy loams to clay loams of 1.0 to 1.5 m depth. The heterogeneity of the layers effectively limits the hydraulic conductivity, thereby limiting the leakage from the pedoderms. Even after 3 years of severe drought, the Horsepark pedoderm retained a significant depth of water (ACT Geotechnical Engineers Report 2005).

Recharge of the pedoderms under natural conditions is predominantly via interflow through the lithosol soil layer down the slopes, into the pedoderm layer in the valley floor.

Table 66: Hydraulic conductivity & porosity of aquifer materials

Aquifer Classification	Aquifer medium	Hydraulic conductivity (m/s)	Porosity
Pedoderm	Sandy gravel	10^{-3}	0.35
	Clayey sandy gravel	10^{-4}	0.25
	Silty clayey gravel	5×10^{-5}	0.20

Where gravel layers occur to the surface, springs are frequently observed, particularly during wet periods. A number of farmers have excavated material from the springs, to provide a permanent pool for watering of stock.

Table 67: Schedule of regional pedoderms

Catchment	Location	Area ha	Storage Volume m^3
Ginninderra Ck (Gungahlin)	Horsepark	100	400,000
	Nichols/Ngunnawal	40	160,000
Gungaderra Ck	Crace	130	500,000
Ginninderra Ck (Belconnen)	Kippax?		
Sullivans Ck	Mitchell/Kenny	120	480,000
	Lyneham?	90?	360,000
Jerrabomberra Ck	Hume	??	
Yarralumla Ck	Curtin/Weston Ck?	??	
	Mawson/Pearce?	??	
Tuggeranong Ck	Isabella Plains	170	700,000
Point Hut Ck	Conder & Banks	100	400,000
Lanyon Ck	Lanyon	110	440,000

Notes: Estimates of Storage Volume based either on geotechnical surveys or assumption of average depth of 2 m and porosity of 20%.
The Gungaderra/Crace system is already fully established, with discharge from the Franklin Water Pollution Control Pond into the head of the Crace pedoderm.

- their typical input (recharge) hydraulic rates and recharge arrangements;
- their efficiency in respect to leakage of stored water; and
- ‘engineering’ of the aquifers required to improve their storage capacity and hydraulic conductivity and to reduce their leakage;
- typical development and operations costs associated with establishing the aquifers as active stormwater storage systems.

Recharge Systems and Rates

For the regional shallow alluvial aquifers, there are two types of recharge systems:

- bio-retention swales with underlying gravel infiltration trench;
- window ponds intersecting the aquifer alluvial layer, with recharge through the bed of the pond (pre-treatment via ‘contained’ wetland).

The calculation of the trench length is based on the required recharge rate, the depth of the aquifer, the hydraulic conductivity of the aquifer porous material, and the connectivity coefficient for the aquifer (heterogeneity of material).

Length of trench = $V/[e_s\, bH + 60\, k_h\, \tau(b + H/2)U]$ (Formula 5.4a)

where L = length of trench (m)

V = inflow volume from storm m^3
e_s = trench material porosity = 0.35
b = width of trench = 2.0 m
H = depth of trench = 2.0 – 3.0 m
k_h = site soil hydraulic conductivity m/s
U = moderating (adjustment) factor translating test pit conductivity to field
τ = duration of recharge or the storm event (minutes)
(assumes infiltration into the aquifer along 1 side of the trench only)

Trench emptying time:

$$T = -4.6Lbe_s/(2k_h(L+b)) \log_{10}[Lb/(Lb+2H(L+b))] \text{ secs} \quad \text{(Formula 3.31)}$$

$$T \approx -4.6be_s/(2k_h) \log_{10}[b/(b+2H)] \text{ secs}$$

Source: Argue, John R. (Editor) 2004. WSUD: Basic Procedures for Source Control of Stormwater. A Handbook of Australian practice. (Gravel filled trench infiltration device)

Table 68: Length of recharge trench (3 m depth) required per KL of recharge volume

Aquifer medium classification	Hydraulic conductivity m/s	Length of trench required per KL of recharge	Time required to drain trench hours
Sandy Gravel	10^{-3}	0.07	0.2
Clayey Sandy Gravel	10^{-4}	0.27	1.5
Silty Clayey Gravel	5×10^{-5}	0.33	3.1

Notes: Computation File ‘RegAquifer ASR.xls’

Where the recharge and abstraction rate hydraulic performance is limited as a result of high heterogeneity of material in the aquifer, the construction of lateral gravel filled trenches across the aquifer can significantly improve the connectivity of gravel lenses, without seriously impairing the longitudinal leakage rate.

Table 69: Aquifer leakage rate estimates

Aquifer medium classification	Hydraulic conductivity m/s	Assumed hydraulic gradient %	Leakage rate % of annual recharge
Sandy Gravel	10^{-3}	5.0	2.8
Clayey Sandy Gravel	10^{-4}	5.0	0.3
Silty Clayey Gravel	5×10^{-5}	5.0	0.1

Notes: Computation File ‘RegAquifer ASR.xls’

Where significant leakage spots exist as a result of the gradient of the aquifer, or loss of edge containment as a result of falling terrain, bentonite filled trenches can be constructed to plug the leakage pathway.

Abstraction System and Rates

Note that in the case of the shallow aquifers, the recharge system is gravity based, with use of a pump drawing water from the infiltration/abstraction gravel trench to abstract water from the aquifer for water supply purpose. via: an ASTR based system.

The analysis assumes the use of the same trench as used in the recharge of the sportsground aquifer, for abstraction of water for irrigation purposes, and the installation of a perforated pipe within the lower gravel zone to balance inflow along the length of the trench, and to deliver infiltrated water to the abstraction pump pit at one end or in the centre of the trench.

For 2 dimensional flow to a trench (infiltration both sides) (Dupuit Equation)

$y_2^2 - y_1^2 = q/k_D\,(x_2 - x_1)$ (Jaeger, C. (1961) Engineering Fluid Mechanics)

$q = k_D\,(y_2^2 - y_1^2)/(x_2 - x_1) = k_D\,(H_h^2 - h_0^2)/X$

where k_D is the permeability coefficient (m/s)

H_h is the height of the water table above the base of the trench

X is the horizontal distance from the side of the trench to the point of zero drawdown influence on the phreatic line.

The upper 'free water' limit for pasture is 0.6m. i.e. the maximum permissible height of the recharge water mound beneath the sports ground relative to the base of the trench is $(H_{trench} - 0.6)$

The critical depth for the trench (drawdown level yielding the maximum rate of inflow to the trench)
$h_c = 0.636\,q_{max}/k_D$
Assume a 'y' value = 3 x $(H_{trench} - 0.6)$

Incorporating these values into the discharge equation yields:

$$q_{max} = k_D\,(H_h^2 - h_0^2)/Y = k_D\,[(H_{trench} - 0.6)^2 - (0.636\,q_{max}/k_D)^2]/Y$$

$$q_{max}^2 + 5k_DYq_{max} - 2.5\,k_D^2(H_{trench} - 0.6)^2 = 0$$

$$q_{max} = -\,1.25k_DY \pm 0.5\,[6.25k_D^2Y^2 + 10k_D^2(H_{trench}-0.6)^2]^{0.5}$$

and

$$L/V = 1/[e_s\,b\,H + t(hrs)\,q_{max}]$$

Table 70: Storage abstraction capacity of 3m deep trench

Aquifer medium classification	**Assumed length of drawdown path (m)**	**Max abstraction rate (KL/hr/m of trench)**
Sandy Gravel	7.2	2.76
Clayey sandy Gravel	7.2	0.28
Silty Clayey Gravel	7.2	0.14

Notes: Computation File 'RegAquifer ASR.xls'

Restoration of Aquifers Having Agricultural Drains and/or Urban Stormwater Pipe Reticulation

Where there is extensive residential development and stormwater reticulation across the surface of the aquifer, opportunities for the restoration of the aquifer are limited. The extensive reticulation of leaky stormwater pipes across the aquifer, generally at a depth close to the base of the aquifer (2.5 – 3.5 m), effectively drains the aquifer. In these cases, residents should be encouraged to uncouple their stormwater connections, and distribute discharges to infiltration systems within their gardens.

Where infrastructure across the aquifer is limited to main drains (concrete pipe), there is an opportunity to restore the aquifer, by placing drainage cutoff collars around the pipes.

In the case of channels (Karl Cloos speaks of major flows under channels such as Sullivans Ck channel), there is a risk of 'floating-off' the concrete channel slabs in the event of the aquifer filling with water. While the slabs have gravel bedding and weep holes to reduce this pressure, this is never the less the most common cause of channel failure during wet periods. In these cases, the most practical restoration mechanism is the removal of the concrete channel and creation of a series of ponds, using lateral bentonite trenches across the floodplain, and concrete weirs within the main flow channel.

Clearly, restoration of aquifers will require site specific studies.

Development and Operations Costs

Infrastructure associated with establishing the aquifers as active stormwater storage systems:

- A litter screen and coarse sediment trap on the pump well for diversion of stormwater drain flow to the aquifer. Cost $15,000 - $30,000 each.
- Installation of a pump and rising main to divert stormwater from the stormwater drain to the infiltration swale. Cost $10,000 - $15,000
- A 2 metre wide swales & bio-filters (trench filled with loam soil and plants to promote biological breakdown of organic material), over the main gravel storage, infiltration & abstraction trench zone. Cost $200/metre.
- An aquifer water recovery pump within the infiltration trench. Cost $5000
- Pipe work for delivery of recovered aquifer water to supply nodes.

Note that a pond for treatment and balancing storage is not required in the case of the regional shallow aquifers.

Operation & maintenance costs relate primarily to periodic cleaning of the sediment trap and pump maintenance. Cost $10,000/yr.

Life of bio-filters – 30 years.

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APPENDIX H SPORTSGROUND AQUIFER REPORT

Canberra Integrated Urban Waterways Project
Draft Local sportsground shallow aquifer Report 18th December 2007

Ian Lawrence, Senior Research Fellow CRC eWater
Ray Evans, Director Salient Solutions

Summary

This Report outlines the scope of small (local) shallow aquifers across Canberra, and assesses their storage capacity, leakage rates, recharge and abstraction trench length requirements.

Table 71: Summary of aquifer values

Aquifer medium classification	Storage capacity (KL/m^2)	Length of trench required per KL or recharge (m)	Leakage rate (%)	Max abstraction rate (KL/hr/m of trench)
Sandy Loam	0.5 – 0.7	0.25	1.4	0.28
Loam		0.30	0.7	0.14
Clay Loam		0.35	0.1	0.03

Summary of costs:

Inlet structure	$5,000 - $8,000
Inlet pump & rising main	$2,000 - $3,000
Infiltration swale, bio-filter & gravel trench	$200/metre
Aquifer water recovery pump	$2000
Annual maintenance	$5,000

Background

The CSIRO assessment of stormwater detention, storage and supply options has identified groundwater storage as a key element in respect to storing stormwater during rainfall events (low water demand), and abstracting water from the storage for water supply during dry or peak irrigation demand periods.

Two categories of groundwater aquifer systems have been adopted for the purpose of the assessment:
- Local aquifer storage & retrieval (ASR) or aquifer storage, transfer & retrieval (ASTR) systems;
- Regional aquifer storage, transfer & retrieval (ASTR) systems.

Within each system category there are two geological categories of aquifer:
- shallow alluvial aquifers; and
- deep fractured rock aquifers.

This note develops a generic model for the Local shallow aquifer systems, identifying:
- storage capacity of typical local shallow aquifers;
- their typical input (recharge) hydraulic rates and recharge arrangements;
- their efficiency in respect to leakage of stored water; and

- ‘engineering’ of the aquifers required to improve their storage capacity and hydraulic conductivity and to reduce their leakage;
- typical development and operations costs associated with establishing the aquifers as active stormwater storage systems.

Description & Distribution of Local Shallow Aquifers across Canberra

Sportsgrounds across Canberra have been located, in the main, adjacent to major stormwater drainage corridors. The sportsgrounds have generally been constructed to an elevation between the 1 in 5 yr and 1 in 10 yr ARI flood level.

Their location takes advantage of:
- location within the 1 in 100 yr ARI floodplain (area excludes residential development);
- the availability of fill from the stormwater channel excavation to build-up the level bench required to accommodate the sports fields (economy of cut & fill earthworks).

As a result, many of the sportsgrounds have sand & gravel zones within their sub-base (a medium having a significant water storage capacity), and are immediately adjacent to a significant source of stormwater.

A ‘water use inventory’ of Canberra University’s use of water, undertaken by Button and Usback in 1997, identified serious over- watering of the sportsfield, and the development of a major water mound beneath the sportsgrounds.

From the perspective of the ‘Canberra Integrated Urban Waterways Project’, the finding highlights the potential for storage of sportsground irrigation water requirements, within the sub-base of the sportsgrounds themselves. Where sportsgrounds are over – watered (as a result of over-irrigation water application or high rainfall conditions), water is stored within the sub-base and is available for re-use. In addition, the storage can be supplemented by recharging the aquifer using stormwater from adjacent drains, for subsequent recovery for irrigation water supply.

What are the physical characteristics of these local aquifers in respect to:
- their water storage capacity;
- their typical input (recharge) hydraulic rates and recharge arrangements;
- their efficiency in respect to leakage of stored water;
- ‘engineering’ of the aquifers required to improve their storage capacity and hydraulic conductivity and to reduce their leakage; and
- typical development and operations costs associated with establishing the aquifers as active stormwater storage systems.

Table 72: Hydraulic conductivity & porosity of aquifer materials

Aquifer classification	Aquifer medium	Hydraulic conductivity (m/s)	Porosity
Pedoderm	Sandy gravel	10^{-3}	0.35
	Clayey sandy gravel	10^{-4}	0.25
	Silty clayey gravel	5×10^{-5}	0.20
Soils	Sand loam	10^{-4}	0.40
	Loam	5×10^{-5}	0.35
	Clay loam	10^{-5}	0.30

Assessment of Annual Irrigation Water Requirement

Depth of irrigation requirement = 500 mm year (TAMS End User Guideline)

On the basis of:
- 90% of this demand occurring during the October to April period;
- a maximum water supply deficit of 70% over this period; and
- a 10% leakage of water from the storage during this period,

the net water storage requirement at the start of October is 350 mm.

Table 73: Sports ground storage requirement by sport codes

Code	Area ground m^2	Storage req. m^3
Rugby	9000	3100
Soccer	9000	3100
AFL	25000	8800
Cricket	5000	1800

Assessment of Biofilter/Infiltration Trench Length Requirement

The most practical and low cost means of recharging the sportsground aquifer is the transfer of stormwater directly to a swale/bio-filter trench, connecting into an infiltration trench. A bio-retention swale/trench comprises a shallow swale having a 1 to 2% gradient with shrubs or grasses planted within the top loam layer of the bio-filter. The bio-filter comprises 1 m depth of surface sandy loam, underlain by 1 m depth of gravel and an agricultural drain collector pipe.

In the case of the sportsgrounds, the most efficient location for the infiltration trench is parallel to the creek or stormwater drain line, and between the middle and the 2/3rds width of the sportsground, away from the creek or stormwater drain line.

The infiltration trench performs four functions:
- improves the hydraulic connectivity through the aquifer;
- infiltration of recharge stormwater into the aquifer during storm events;
- exfiltration/abstraction trench during water recovery from the aquifer for water supply purposes; and
- provides a detention storage in situations where the infiltration or exfiltration rate of the aquifer is less than the stormwater recharge or irrigation recovery rates.

The gravel trench would normally be covered by 0.6 m of sand and loam, as necessary to maintain the quality of the turf playing surface, and to prevent capillary rise – salinisation of the surface vegetation.

The calculation of the infiltration trench length is based on the required recharge rate, the depth of the aquifer, the hydraulic conductivity of the aquifer porous material, and the connectivity coefficient for the aquifer (heterogeneity of material).

Length of infiltration trench = $V/[e_s bH + 60 k_h \tau(b + H/2)U]$ (Formula 5.4a)

where L = length of trench
V = inflow volume from storm m^3
e_s = trench material porosity = 0.35
b = width of trench = 2.0 m
H = depth of trench = 2.0 - 3.0 m
k_h = site soil hydraulic conductivity m/s
U = moderating (adjustment) factor translating test pit conductivity to field
τ = time of trench filling or duration of the storm event (minutes)

Trench emptying time:

$$T = -4.6Lbe_s/(2k_h(L+b)) \log_{10}[Lb/(Lb+2H(L+b))] \text{ secs} \quad \text{(Formula 3.31)}$$
$$T \approx -4.6be_s/(2k_h) \log_{10}[b/(b+2H)] \text{ secs}$$

Source: Argue, John R. (Editor) 2004. WSUD: Basic Procedures for Source Control of Stormwater. A Handbook of Australian practice. (Gravel filled trench infiltration device)

Table 74: Length of infiltration trench (m) per KL of stormwater diverted to the trench for a stormwater transfer duration of τ minutes.

Site soil composition	**Direct stormwater transfer**			**Stormwater transfer via pond**		
	Storm duration (min)	**Trench length m, per m^3 recharge**	**Trench drainage time (hr)**	**Transfer duration (hr)**	**Trench length m, per m^3 recharge**	**Trench drainage time (hr)**
Sandy Loam	360	0.10	3.5	12	0.07	2.7
Loam	360	0.15	6.9	12	0.12	5.5
Clay Loam	360	0.29	34.6	12	0.27	27.4

Note: Width of trench for direct stormwater transfer 3m; for pond transfer 2 – 2.5 m.
Refer to computation file ‘Sportsground ASR.xls’

Where the recharge and abstraction rate hydraulic performance is limited as a result of high heterogeneity of material in the aquifer, the construction of lateral gravel filled trenches across the aquifer can significantly improve the connectivity of gravel lenses, without seriously impairing the longitudinal leakage rate.

Table 75: Aquifer leakage rate estimates

Aquifer medium classification	**Hydraulic conductivity m/s**	**Assumed hydraulic gradient %**	**Leakage rate % of annual recharge**
Sandy Loam	10^{-4}	5.0	1.4
Loam	5×10^{-5}	5.0	0.7
Clay Loam	10^{-5}	5.0	0.2

Notes: Computation File ‘RegAquifer ASR.xls’

Where significant leakage spots exist as a result of the gradient of the aquifer, or loss of edge containment as a result of falling terrain, bentonite filled trenches can be constructed to plug the leakage pathway.

Assessment of Retrieval/Abstraction Trench Length Requirement

The analysis assumes the use of the same trench as used in the recharge of the sportsground aquifer, for abstraction of water for irrigation purposes, and the installation of a perforated pipe within the lower gravel zone to balance inflow along the length of the trench, and to deliver infiltrated water to the abstraction pump pit at one end or in the centre of the trench.

For 2 dimensional flow to a trench (infiltration one side only)

$y_2^2 - y_1^2 = 2q/k_D\,(x_2 - x_1)$ (Jaeger, C. (1961) Engineering Fluid Mechanics)

$q = ½\, k_D\,(y_2^2 - y_1^2)/(x_2 - x_1) = ½\, k_D\,(H_h^2 - h_0^2)/Y$

where k_D is the permeability coefficient (m/s)

H_h is the height of the water table above the base of the trench

Y is the horizontal distance from the side of the trench to the point of zero drawdown influence on the phreatic line.

The upper ‘free water’ limit for pasture is 0.6m; i.e. the maximum permissible height of the recharge water mound beneath the sports ground relative to the base of the trench is $(H_{trench} - 0.6)$

The critical depth for the trench (drawdown level yielding the maximum rate of inflow to the trench) $h_c = 0.636\, q_{max}/k_D$

Incorporating these values into the discharge equation yields:

$$q_{max} = ½\, k_D\,(H_h^2 - h_0^2)/Y = ½\, k_D\,[(H_{trench} - 0.6)^2 - (0.636\, q_{max}/k_D)^2]/Y$$

$$q_{max}^2 + 5k_D Y q_{max} - 2.5\, k_D^2 (H_{trench} - 0.6)^2 = 0$$

$$q_{max} = - 2.5k_D Y \pm 0.5\,[25k_D^2 Y^2 + 10k_D^2 (H_{trench} - 0.6)^2]^{0.5}$$

Table 76: Storage abstraction rate capacity of trench

Aquifer medium	**Depth of trench (m)**	**Assumed length of drawdown path (m)**	**Max abstract rate (KL/hr/m of trench)**	**Length of trench per KL of abstraction (m)**
Sandy Loam	3	7.2	0.28	0.12
Loam	3	7.2	0.14	0.13
Clay Loam	3	7.2	0.03	0.15

Notes: Trench depth of 3 m
Refer to computation file ‘Sportsground ASR.xls’

Water Quality Treatment

The major concern in operating Aquifer Storage & Retrieval systems, is the protection of infiltration & abstraction zones from clogging by suspended solids. The devices outlined above include the routing of stormwater diverted directly from drains, to a bio-filter, providing a high level of treatment efficiency with respect to suspended solids, nutrients and toxicants.

Review of Option

For a sportsground of 9000 m^2, the annual storage requirement for irrigation is 3100 m^3.
Depth of storage for this volume of water for Clayey sandy gravel (porosity of 0.25) is 1.0 m, plus a 0.6 m water free zone to protect the turf – well within the 3 m depth trench assumed in this analysis.

On the basis of diversion of the 3100 KL of water over 10 storm events, the diversion/event = 310 KL. For a 60 minute stormwater flow duration, this represents a trench length requirement of 93 m for the Loam site condition. Subject to availability of sufficient flow locally, this storage requirement could easily be met, even with the most conservative assumption regarding site soil conditions.

Based on a peak weekly irrigation requirement of 30 mm, 3 irrigation cycles/week and irrigation over an 8 hr period for each cycle:

peak demand/hr = 9000 m^2 x 10 mm/1000/8 = 11.3 KL/hr

Length of trench required to meet abstraction rate for the Loam site condition = 11.3/0.14 = 80 m vs 93 m for recharge. Subject to sufficient stormwater flow available locally, technically, this technique appears very do-able.

Development and Operation Costs

Infrastructure associated with establishing the aquifers as active stormwater storage systems:

- A litter screen and coarse sediment trap on the pump well for diversion of stormwater drain flow to the aquifer. Cost $5,000 - $8,000 each (precast).
- Installation of a pump and rising main to divert stormwater from the stormwater drain to the infiltration swale. Cost $2,000 - $3,000
- A 2 metre wide swales & bio-filters (trench filled with loam soil and plants to promote biological breakdown of organic material), over the main gravel storage, infiltration & abstraction trench zone. Cost $200/metre x 90 m = $18,000.
- An aquifer water recovery pump within the infiltration trench. Cost $2000
- Pipe work for delivery of recovered aquifer water to supply nodes.

Note that a pond for treatment and balancing storage is not required in the case of the regional shallow aquifers.

Operation & maintenance costs relate primarily to periodic cleaning of the sediment trap and pump maintenance. Cost $5,000/yr.

Life of bio-filters – 30 years.

Actions Required to Further Assessing this Option

A significant number of sportsgrounds are located on alluvial stream deposits. In these cases, site soil conditions should easily meet the Clayey sandy gravel conditions. In other cases, sportsgrounds along the drainage lines have been built-up using fill excavated from the channel construction. Geophysical transects of these sites would provide sufficient information to fully assess the viability of the sportsground sub-base as an aquifer storage device, at minimal cost.

Comprehensive geotechnical information is available for the northern end of Sullivans Ck, and Ginnindera and Gungaderra Creeks, as part of the Gungahlin Geotechnical Studies 1983. (records with ACTPLA).

References

Argue, John R. (Editor) 2004. WSUD: Basic Procedures for Source Control of Stormwater. A Handbook of Australian Practice. (Gravel filled trench infiltration device)

Button, B & Usback, R. (1996). University of Canberra model water user Project. CRC for Freshwater Ecology Technical Report.

Coffeys Pty Ltd. (1983). Geotechnical Investigation for the New Town of Gungahlin, ACT. Report & Drawing C.2879/2/1. Report for NCDC

Computation File ‘Sportsground ASR.xls’

Engineers Australia (2006). Australian Run-off Quality: A guide to Water Sensitive Urban Design.

Jaeger, C. (1961) Engineering Fluid Mechanics.

APPENDIX I SPORTSGROUND AQUIFER DESIGN AND COSTING

A sportsground aquifer was designed and costed in accordance with Figure 11 in Chapter 6.6.

Detailed below are the calculations and costs used to develop Table 10 in Chapter 6.6.

- Weir and litter trap / pumping well ~ assumed cost $5000

- Pump from weir to infiltration swale / trench.

  As flows are assumed to be sufficient (i.e. are not required to capture storm events), a maximum pumping rate of 2 L/s was assumed sufficient.

  Using the formula provided by Kirilly Dickson of ACTEW, cost was calculated as $8000.

  Pumping Cost ($) = 4000*Flow rate (L/s)

  Pumping Cost ($) = 4000*2 = $8000

  Note: this could potentially be a gravity fed system. Inclusion of this pump cost is a conservative approach.

- Cost of pipe from weir to infiltration swale / trench

  The Darcy-Weisbach equation was used to estimate the nominal diameter.

$$h_f = \frac{8fLQ^2}{\pi^2 gD^5}$$

  Where: h_f = head loss factor = assumed value of 2.5 m; f = Darcy-Weisbach friction factor = assumed value of 0.02; Q = flow; L = length, g = gravity and D = diameter.

  The equation was solved for D to obtain a nominal diameter of 23 mm. This was upsized to 50 mm, which is the smallest pipe size considered in this study.

  Using the ACTEW formula for capital cost estimation and an estimated required pipe length of 150 m. (Under gravity fed conditions, if sportsground is 2 m above creek bed, creeks run at ~3% grade and 1% grade is required for pipe, a 100 m pipe length is required. The value of 100 m was increased to 150 m to allow for obstructions such as going around ovals or avoiding road crossings. It is noted that a value of less than 100 m is probably adequate if a pump is employed at the weir).

  Pipe Cost ($) = 1.45*Pipe Diameter (mm)*Pipe Length (m) = 1.45*50*150 = $10,875

- Infiltration swale / trench

Case A: Pumping from Creek to Trench/Swale

If pumping is required, it is assumed water will be transferred from the creek to the swale intermittently, depending upon the capacity of the trench to cope with additional flows. A typical transfer duration is assumed to be 6 hours.

Volume transferred = 6 hours * 2 L/s *60*60 = 43200 L = 43.2 kL

Using formula 5.4a from Appendix H (Argue, 2004), and conservatively assuming a loam soil type

$$L/V = 1/[e_s\, bH + 60\, k_h\, \tau(b + H/2)U] = 1/[0.45*2*3+60*0.00005*360(2+3/2)*1]$$

$L/V = 0.15$ m/kL (where b and H have been assumed)

The required length for transferring 43.2 kL is therefore:

$L = 0.15*43.2 = 6.5$ metres

This value of L is well below what is required for retrieving the water for irrigation (see equation below).

To ensure the trench will not spill during transfer, the trench drainage time needs to be estimated. Using formula 3.31 from Appendix H (Argue, 2004):

$$T = -4.6Lbe_s/(2k_h(L+b))\, \log_{10}[Lb/(Lb+2H(L+b))] \text{ secs}$$

For this case, we know L>>b, as a long trench as per Figure 11 is required for extraction and storage. Therefore, the equation for T can be simplified to:

$$T \approx -4.6be_s/(2k_h)\, \log_{10}[b/(b+2H)] = -4.6*2*0.45/(2*0.00005)*\, \log_{10}[2/(2+2*3)]$$

$T \approx 24925$ secs = 6.9 hours

For this case, drainage time (6.9 hours) is only marginally greater than transfer time (6 hours). Considering storage in the trench, V_s, (or in other words the volume of trench void space) is far greater than the inflow; the trench will not spill during transfer unless antecedent conditions have the trench close to capacity. Provided the operator properly monitors the system, this circumstance will not occur. There is therefore no need for continuous modelling, and we can be confident that in the case of pumping from the creek to the infiltration trench, adequate storage and hydraulic conductivity conditions exist.

$V_s = e_s.LbH = 0.35*90*2*3 = 189$ kL

Where L is estimated from the equation for abstraction below.

Case B: Gravity Feed from Trench to Swale

A gravity feed system will need to be carefully designed taking into account the hydrological regime of the catchment. If there is consistent, reasonably reliable flow in the creek, the diversion system will need to be designed with either:

- A diversion pipe that only diverts low flows which will not overload the swale;
- A switch valve to ensure excessive flows do not enter the swale; or,
- An overflow pipe/drain running from the swale back to the creek.

If there are intermittent flows, then detailed hydrological and hydraulic modelling will need to be undertaken to ensure the system is designed properly. For this simplified conceptual example, the following calculations demonstrate that for flow lasting 12 hours following a significant storm event, the system is able to cope.

For a 75 mm diameter pipe running full, using Manning's equation and assuming n=0.013, S=0.01

$$Q = (1/n)*AR^{2/3}S^{1/2} = 2.4 \text{ litres per second}$$

The total volume transferred over 12 hours is therefore equal to:

$$Q = 2.4*12*60*60 = 104 \text{ kL}$$

Considering the storage volume of the trench is 189 kL and that it takes 6.9 hours to drain the trench, a 12 hour flow of 2.4 litres per second should be able to be catered for by the swale / infiltration trench.

The above calculations demonstrate a gravity-fed swale/infiltration system is feasible for charging 'sportsground aquifers'. Obviously, more detailed design (and perhaps continuous modelling) is required prior to proceeding with a real case study.

Abstraction

Assuming a peak weekly irrigation of 30 mm, 3 irrigation cycles/week, intermittent watering of the ovals, where each cycle lasts 8 hours:

$$\text{Peak demand/hr} = 9000 \text{ m}^2 * 10 \text{ mm} / 1000 / 8 = 11.3 \text{ kL/hr}$$

The length of trench required to meet the abstraction rate, using Table 76 from Appendix H, is therefore 80 metres for loam type soil (i.e. 11.3/0.14).

Costing

As described above, the trench has been sized as 80 m length by 2 m width by 3 m depth. Boubli & Kassim (2003) estimated gravel trenches cost $150/m^3. For this study, this figure was indexed from 2002 at an inflation rate of 2.5% to yield the value of $174/m^3.

A value of \$5.50/m^2 (Bill Guy & Partners, 2004) was adopted for planting costs. This was indexed from 2004 to yield a value of \$6/m^2.

- Recovery Pump

  The peak pumping rate for the recovery trench has been estimated as 11.3 kL over an 8 hour period as per calculations above. This equates to 3.1 L/s. Based on the ACTEW formula as previously described, the cost for this pump is \$12,500.

- Pipe from well to sportsground irrigation system

  Using the Darcy-Weisbach equation once again, nominal diameter = 28 mm, so a 50 mm diameter pipe was adopted. With an assumed length of 50 m from the well to the sportsground irrigation system, total capital cost is estimated to be \$3,625.

- Replacement costs

  Replacement costs were estimated using the formula:

  $$Cost_{PV} = F(1+r)^{-T_L}$$

  Where, F = Future Cost, r = discount rate = 0.065, T_L= Life time of asset

  So, total replacement cost for an analysis period, n is

  $$Cost_{PV} = P + P(1+\pi)^{-T_L} + P(1+\pi)^{-2T_L} + ... + P(1+\pi)^{-iT_L}$$
  $$Where: iT_L \leq n$$

  Pumps were assumed to have a life of 15 years and swales 30 years. A discount rate of 6.5% was adopted.

- Operation and maintenance costs

  Pumps and weir structures were assumed to have an annual cost equal to 1.5% of capital cost.

  Swales were assumed to have annual cost of \$2.15/m^2 based on Fletcher et al. (2005) who estimated \$1.50 for vegetated swales and \$2.50 for grassed swales. An average value of \$2 was adopted and indexed from 2005.

- Allowances / ‘add-on’ costs

  Allowances of 30% of capital cost for contingency, 20% for design and supervision and 20% for special investigations have been made. This is significantly higher than allowances for pipes, pumps and ponds (see Table 78) due to the greater investigations required and novel technology / approach. Allowances of 4% for administration / procurement and 0.6% for insurance of the total of capital plus contingency, design, supervision and investigations have also been included.

APPENDIX J LAKE HYPSOMETRIC CURVES

The following information on lake hypsometric curves has been provided by Ian Lawrence of the eWater CRC.

Schedule of ACT Lakes & Ponds

There is very little survey information available for existing lakes ponds. Surface areas, volumes and depths have been estimated using approximate shapes (i.e. hypsometric curves) as per Table 77.

Table 77: Schedule of ACT lakes & ponds

Feature	**Surface Area (ha)**	**Volume (GL)**	**Av. Depth (m)**	**Max. Depth (m)**	**Length (m)**	**Av Width** **Effective width @ dam** **Transverse shape type**
Lake Burley Griffin	704.2	33.17	4.71	17.4	9800	720/720 Flat rectangular
Lake Ginninderra	105	3.7	3.5	10.1	3300	320/640 Vee
Lake Tuggeranong	57.1	2.6	4.6	9.0	2100	270/540 Flat rectangular
Gungahlin Pond	23.8	0.6	2.5	7.0	950	250/500 Vee
Yerrabi Pond	26.4	0.6	2.0	5.0	1300	200/410 Vee
Point Hut Pond	16.7	0.35	2.0	4.0	400	420/420 Flat rectangular
W Belconnen Pond	9.9	0.15	1.0	1.5	1000	100/100 Flat rectangular
Tuggeranong Weir	7.5	0.11	1.5	2.5	800	120/120 Flat
Isabella Pond	5.7	0.07	1.2	2.5	480	120/120 Flat rectangular
Lower Stranger Pd	4.1	0.08	2.0	3.0	513	80/80 Vee
Upper Stranger Pd	4.4	0.043	1.0	2.0	410	110/110 Flat rectangular
Jarramlee (Dunlop 1)	0.7	0.011	1.5	2.0	110	60/127 Flat triangular
Fassifern (Dunlop 2)	0.7	0.011	1.5	2.0	130	50/107 Flat triangular
Gordon Pond	0.6	0.009	1.5	2.0	70	100/170 Flat triangular
David St Wetland	0.3	0.003	1.0	1.5	55	Flat triangular
Banksia St Wetland	3.6	0.04	1.2	2.4	200	Flat triangular
Nichols Pond	0.2	0.002	1	2	45	Flat triangular

Computation of Hypsometric Curves

For Vee shaped pondage cross-sections:

$A_{\text{surface}} = W_{\text{Pond @ dam}}/2 \text{ x } \text{Length}_{\text{Pd}}$, or $W_{\text{Pond @ dam (effective)}} = 2 \text{ x } A_{\text{Pond @ FSL}}/\text{Length}_{\text{Pd @ FSL}}$
$W_{\text{Pond @ dam}} = 2 \text{ x } \text{Depth}/\tan\theta$
$\tan\theta = 2 \text{ x } \text{Depth}_{\text{max}}/W_{\text{Pond @ dam (effective)}}$
where θ is the transverse slope of the Pond sides
$\text{Length}_{\text{Pond}} = \text{Depth}/\tan\varphi$
$\tan\varphi = \text{Depth}_{\text{max}}/\text{Length}_{\text{Pond @ FSL}}$
where φ is the longitudinal slope of the Pond bed.
$V_{\text{Pond}} = {}^{1}/_{3} \text{ x } W/2 \text{ x } D \text{ x } L = WDL/6$

For flat shaped pondage cross-sections:

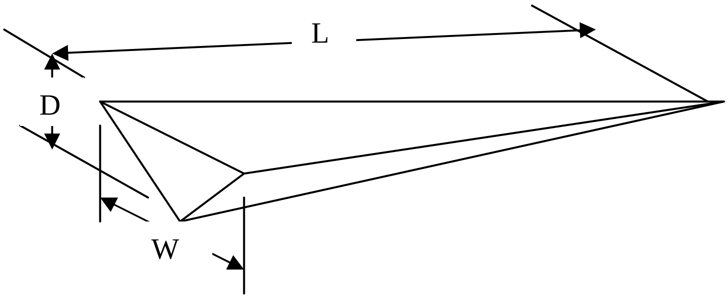
$A_{\text{surface}} = W_{\text{Pond @ dam}} \text{ x } \text{Length}_{\text{Pd}}$, or $W_{\text{Pond @ dam (effective)}} = A_{\text{Pond @ FSL}}/\text{Length}_{\text{Pd @ FSL}}$
W_{Pond} is constant, $\text{Length}_{\text{Pond}} = \text{Depth}/\tan\varphi$
$\tan\varphi = \text{Depth}_{\text{max}}/\text{Length}_{\text{Pond @ FSL}}$

where φ is the longitudinal slope of the Pond bed.
$V_{Pond} = {}^{1}/_{2} \text{ x W x D x L} = WDL/2$

Approximate Volume for Vee Shaped Lakes & Ponds

$V \approx W_{dam} D_{max} L/6$

Figure 1 Outline of Vee shaped lakes & ponds

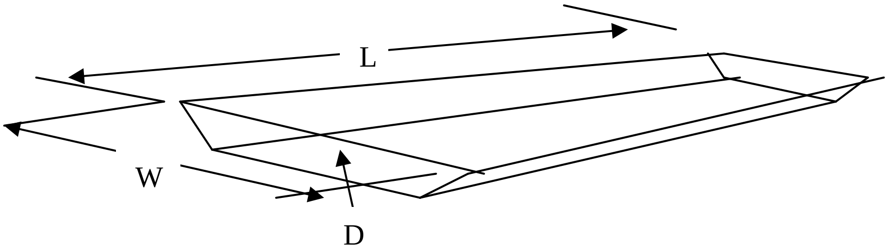


e.g.: $V_{Lake\ Ginninderra} = 640 \text{ x } 3300 \text{ x } 10.1/6 = 3.55$ GL

Approximate Volume for Flat Shaped Lakes & Ponds

$V \approx W_{av} \text{ x L x } D_{av}$

Figure 2. Outline of Flat shaped lakes & ponds



eg: $V_{Point\ Hut\ Pond} \approx 420 \text{ x } 400 \text{ x } 4 = 0.35$ GL

APPENDIX K HARVESTING MODELS

Harvesting models were developed for:

- Ponds
- Ponds with Aquifer Storage (ASR & ASTR)
- Lakes

These models included inflows from stormwater and reclaimed water (depending upon the scenario).

The harvesting models used for lake, pond and pond-aquifer models (Figure 53 and Figure 54) are very similar. Each uses the same simple algorithm for the pond, which is a spill-before-yield algorithm that produces conservative results (as opposed to spill-after-yield). In other words, on each time step within the model, the spill is calculated prior to the demand being met. Perhaps this is best described by the algorithms shown following.

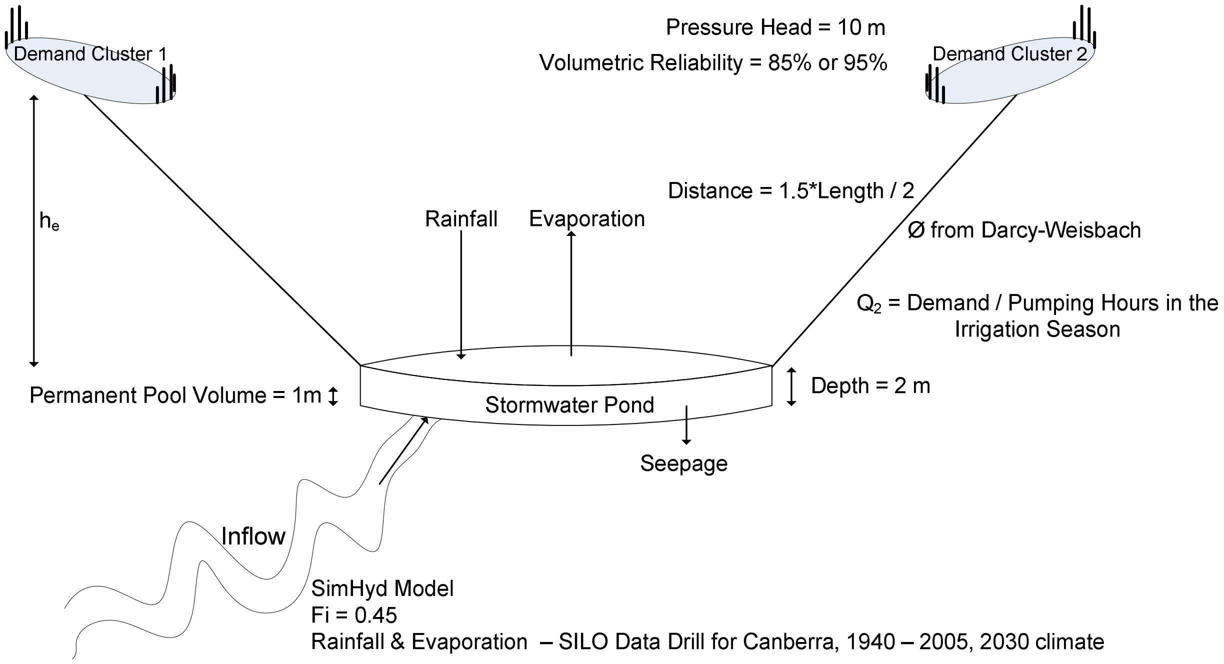


Figure 53: Conceptual pond harvesting model (for 85% volumetric reliability)

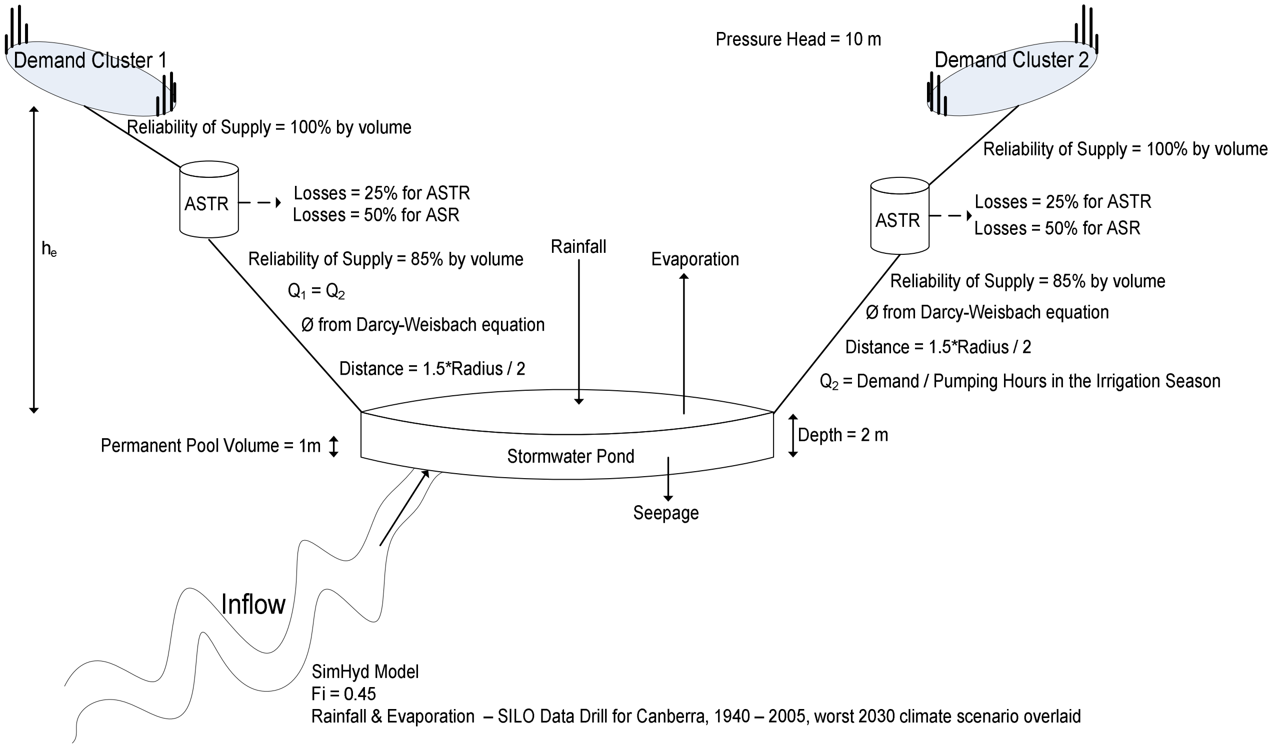


Figure 54: Conceptual pond-aquifer harvesting model (for 85% volumetric reliability)

Model inputs for new ponds: detention depth (assumed 2 m); permanent pool depth (assumed 1 m); initial depth (assumed 1.5 m); surface area; demand time series (unique to each month and calculated by finding the average monthly deficit between rainfall and evaporation = 6.35 ML/yr as per Chapter 3.2).

It should be noted that existing lakes had an assumed stage-depth relationship which was incorporated into the model, whilst the pond models had an assumed uniform depth of 2 metres. The allowable drawdown in the lake models was 1 metre.

Pond model algorithm:

$$S'_t = \text{Maximum}\,(S_{t-1} + I + R - E - G,\ 0)$$

Where, S'_t = First storage calculation; S_{t-1} = Final storage level from previous time-step; I = inflow; R = rainfall, E = evaporation, G = seepage

$$Q_{spill} = \text{Maximum}\,(S'_t - D_{detention}{*}A)$$

Where Q_{spill} = Spill; $D_{detention}$ = Detention depth; A = surface area

$$S''_t = S'_t - Q$$

Where S''_t = Second storage calculation

$$S_t = S''_t - Q_{supply}$$

Where Q_{supply} = Supply

These calculations are repeated for each time-step (daily) for the entire model, which in this case is a 65 year sequence.

The lake model is the same as the pond model with the exception that the lake model uses a stage-volume relationship developed from the hypsometric curves in Appendix J.

The only difference between the pond-aquifer and pond models is aquifer storage. The pond-aquifer model was required to calculate the number of bores required. This was done based on the injection rates as per Table 4 in Chapter 4.2. For the ASR models (i.e. one well systems) it was assumed the irrigation period was 7 months of the year (October to April). For the ASTR models (i.e. two well systems), there is a separate well for injection which is used year round.

It should also be noted that the pond-aquifer models are designed with two distinct volumetric reliabilities. There is a volumetric reliability between the pond and the aquifer and a separate volumetric reliability between the aquifer and the demand (which is equal to 100% for all models). ‘Natural’ (i.e. ‘ambient’) groundwater is therefore sometimes used to supply the demand, however over the entire modelling period there is no net loss of ‘natural’ groundwater.

APPENDIX L LEVELISED COSTING METHOD AND COST DATA

Present Value (PV) and Levelised Cost Method

The total cost of each water supply option is made up of the following three components:

Capital Costs + Operation & Maintenance Costs + Replacement Costs

Total cost is reported in present value (PV), a commonly used method found in many textbooks and literature. PV is calculated by the formula:

$$PV(\$) = \sum_{T:0\rightarrow 50} \frac{C_t}{(1+r)^T}$$

Where C_t is equal to the annual cost, all capital costs are assumed to occur in the year $T = 0$ and r is the discount rate which is equal to 0.065.

Residual value costs, i.e. the salvageable value of the asset at the end of the life of the project, has not been included in this analysis, however it would have minimal impact on the overall PV cost given a lengthy project life (50 years) has been used.

The PV cost was converted to a 'levelised cost' to enable ranking of options and selection of ponds for inclusion in the master plan (as per Chapter 7). 'Levelised cost' is the unit cost of an item (in this case \$/kL) and is defined as the present value of costs (capital, operational, maintenance and replacement) divided by the present value of units supplied. The denominator is discounted in the same manner as the numerator to reflect the present value of revenue flows. 'Levelised cost' therefore represents an estimation of the price required, in present day terms, to recoup costs over the analysis period. It is defined by the equation:

$$LevelisedCost(\$) = \frac{\sum_{n=1}^{t} C_n (1+r)^{\frac{1}{n}}}{\sum_{n=1}^{t} V_n (1+r)^{\frac{1}{n}}}$$

Where t = analysis period (50 years for this example), n = year (1 through 50 for this example), C = cost, r = discount rate (6.5% for this example), V = volume of the demand met over the analysis period.

The present value of the capital cost is assumed to be simply equal to the capital cost as the analysis period starts in the year t=0.

The present value of the operation and maintenance cost ($PV_{O\&M}$) is calculated by the formula:

$$PV_{O\&M} = A\left[\frac{(1+r)^T - 1}{r(1+r)^T}\right]$$

Where, A = Annual Cost, r = discount rate = 0.065, T = analysis period = 50 years. The formula stated above is commonly found in many textbooks.

With an analysis period of 50 years, some infrastructure will need replacement. The present value of replacing infrastructure (PV_R) is calculated by the formula:

$$PV_R = F(1+r)^{-T_L}$$

Where, F = Future Cost, r = discount rate = 0.065, T_L= Life time of asset

So, total replacement cost for an analysis period, T, including the initial capital cost is

$$Cost_{NPV} = P + P(1+r)^{-T_L} + P(1+r)^{-2T_L} + ... + P(1+r)^{-iT_L}$$
$$Where: iT_L \le T$$

Once again, this is a commonly used formula found in many textbooks. P refers to price in 2008 dollars.

Add-On Costs/Allowances

‘Add-on’ costs (i.e. ‘allowances’) have been made for contingency, special investigations, consultant design, consultant supervision, insurance, administration and procurement. Contingency, special investigations, consultant design and consultant supervision are calculated as a fixed percentage of the capital cost. Insurance, administration and procurement are a fixed percentage of the capital cost plus allowances for contingency, special investigations, consultant design and consultant supervision. All ‘add-on’ values used (Table 78) were chosen by CSIRO following advice from Jack Garside of ACTPLA and Ray Evans of Salient Solutions.

The value of add-on costs were altered depending on the infrastructure being delivered. For example contingency, special investigations, consultant design and consultant supervision is greater for aquifers compared to other items because of the high uncertainty in costs, greater need for investigations and unique nature. Government agencies and consultants generally do not have as much practice in delivering MAR schemes as ponds, pumps, pipes and sewer mining.

Table 78: Summary of ‘add-on’ costs

Item	Contingency	Special Investigations	Consultant Design & Supervision	Insurance	Administration & Procurement
CAPITAL					
Ponds	20%	12%	8%	0.6%	4%
Pumps	20%	12%	4%	0.6%	4%
Pipes	20%	12%	4%	0.6%	4%
Aquifers	30%	20%	20%	0.6%	4%
Sewer mining	20%	12%	8%	0.6%	4%
OPERATION, MAINTENANCE & REPLACEMENT					
Ponds	0%	0%	12%	0%	8%
Pumps	0%	0%	12%	0%	8%
Pipes	0%	0%	12%	0%	8%
Aquifers	10%	0%	12%	0%	8%
Sewer mining	0%	0%	12%	0%	8%

Pipes

Design

Nominal pipe sizes were estimated using the Darcy-Weisbach equation, i.e.:

$$D = \frac{fLV^2}{2h_f g}$$

Where D = diameter, f = Darcy-Weisbach friction factor = 0.02 (assumed), L = length of pipe (as calculated below), V = velocity, h_f = head loss due to friction = 2.5 (assumed), g = 9.81 m/s/s. Substituting $V=Q/A=4Q/\pi D^2$, the following equation is obtained:

$$h_f = \frac{8fLQ^2}{\pi^2 g D^5}$$

This equation was solved for D to obtain the nominal diameter.

Pipe sizes of 50, 75, 100, 150, 225, 300, 375, 450 and 525 mm were used. Calculated velocities were in the order of 0.3 – 0.4 m/s.

L was assumed to be the distance between the supply and demand, multiplied by a factor (1.25) to account for the fact the pipe distance will be longer than the shortest possible distance between the supply and demand (due to obstacles such as roads, houses, other infrastructure etc.).

It was assumed water was pumped directly from the pond storage to the demand on an 'as-needs' basis rather than pumping to an on-site storage. Adopting the latter approach has the advantage of reducing the size of pumps and pipes as water is transported over longer time periods (rather than simply the irrigation period), but this is counter-balanced by the cost of the on-site storage.

A preliminary analysis discovered there is potential to reduce life cycle cost by using on-site storages; however this finding was dependant on the values adopted for costing. Using ACTEW's estimation for on-site storage generally resulted in an increase in project costs, however using estimates based on the retail cost of rainwater tanks resulted in a decrease. The ACTEW estimation is probably an over-design for the purposes of this project as it is for a reticulated mains system, whilst the estimation using rainwater tank costs is probably an under-design. It was concluded that pumping to an on-site storage was not a necessary design feature at this conceptual stage as any influence it has on cost is well within the uncertainties of the modelling and costing. More detail on this analysis is given in Appendix M.

Capital costs

Capital costs for pipes are based on email correspondence with Kirilly Dickson of ACTEW and are based on the following formula:

Cost (\$/m) = 1.45*Pipe Diameter (mm)

It is noted that the value of 1.45 is indicative only and can vary between 1.1 and as much as 5.0 if boring is required. It is suitable for the conceptual design purposes of this report but is not suitable for detailed design.

Operation & maintenance

Annual cost (\$/y) = β*Capital Cost(\$)

Where $\beta = 0.005$ and capital cost does not include 'add-ons'/ allowances.

Ponds

Capital costs

Excavation costs were based on excavation costs (provided by Jack Garside of ACTPLA) for 'Flemington Road Pond 1 & 2', Bonner Floodway's 'Upper Pond' and 'Lower Pond', 'Amaroo North Pond 1 & 2', 'Gungaderra Creek Pond A' and 'Weston Creek Pond'. Based on these costs, ACTPLA suggest using the following method for estimating pond costs:

1. Small ponds up to 20 ML allow \$100/m^3 + abnormal items
2. Larger ponds over 20 ML allow \$50/m^3 + abnormal items

This procedure was adjusted slightly to ensure excavation costs increased with excavation volume in all cases so that:

1. For first 20 ML of excavation, allow \$100/m^3
2. For all excavation greater than 20 ML, allow \$50/m^3

Note that abnormal items and land acquisition costs were not included in the conceptual costing.

Figure 55 below shows a comparison of excavation costs calculated using the formula suggested in the MUSIC manual for capital cost of ponds (Wong et al., 2005) and those using the procedure for excavation costs outlined above. It is noted there is a significant difference in the estimated costs. This may be partly due to recent increases in excavation costs.

The cost of the pond is the most sensitive parameter for estimating total harvesting cost.

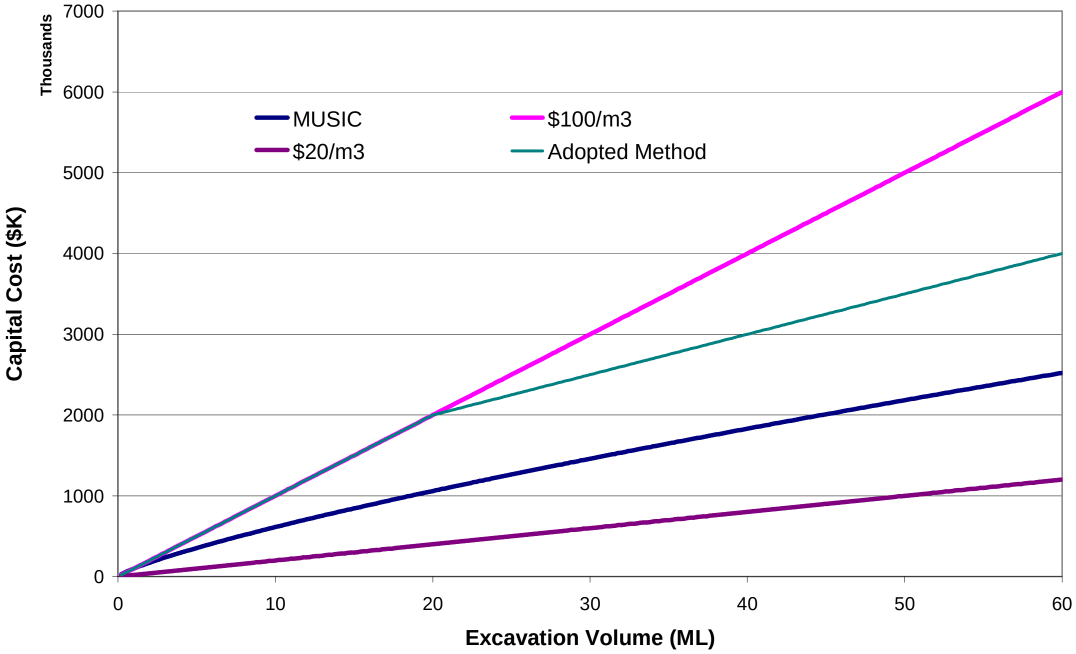


Figure 55: Comparison of excavation cost estimates for ponds.

Ponds (planting)

Planting costs were estimated using the 'average' value as reported in Bill Guy & Partner's Detail Design Estimating Guide for Civil Engineering Works (2004). The values of \$4.50/m^2 for planting and \$1/m^2 for topsoiling were adopted. These values were indexed from 2003 to 2008 using an inflation rate of 2.5%.

Operation & maintenance

Total annual maintenance (TAM) was calculated by the formula in the MUSIC User Guide (Wong et al., 2005)

TAM (\$2005) = $185.4*A^{0.478}$ where A = area (m^2)

Renewal and adaptation cost (RAC) is also calculated by a formula in the MUSIC User Guide (Wong et al., 2005)

RAC (\$) = 0.014*Capital Cost

Pumps

The total pumping requirement to transport water from the supply source to the demand centre, h_t, was calculated using the following formula:

$$h_t = h_d + h_e + h_f$$

Where h_d = required terminal pressure at demand point = 10 m (assumed), h_e = elevation differential between demand and supply, h_f = friction loss in pipe (calculated by Darcy-Weisbach equation)

Email correspondence with William Bencke of ACTEW suggested the following formula for pump station costs:

Pump Station Cost (\$) = $80{,}000*(0.71*Q)^{0.38}$

(where Q is pump flow rate in litres per second).

Email correspondence with Kirilly Dickson of ACTEW suggested the following formula for pumping costs:

Pumping Cost (\$) = 4,000*Q   (where Q is pump flow rate in litres per second).

The formula adopted for pump costing was a combination of the above two formulas. The first formula was considered to overestimate pumping costs for small flows whilst the second formula was considered to underestimate pumping costs for large flows. The following formula was therefore adopted:

Pumping Cost (\$) = IF($Q<102$,4000*Q), IF($Q\geq102$, $80000*(0.71*Q)^{0.38}$)

This formula was adopted for estimating the cost of pumping water from a supply source (e.g. pond) to a demand centre or secondary storage (i.e. aquifer storage).

A comparison of different methods for estimating pumping costs is shown in Figure 56. The broken black line represents the cost estimation formula adopted for this project.

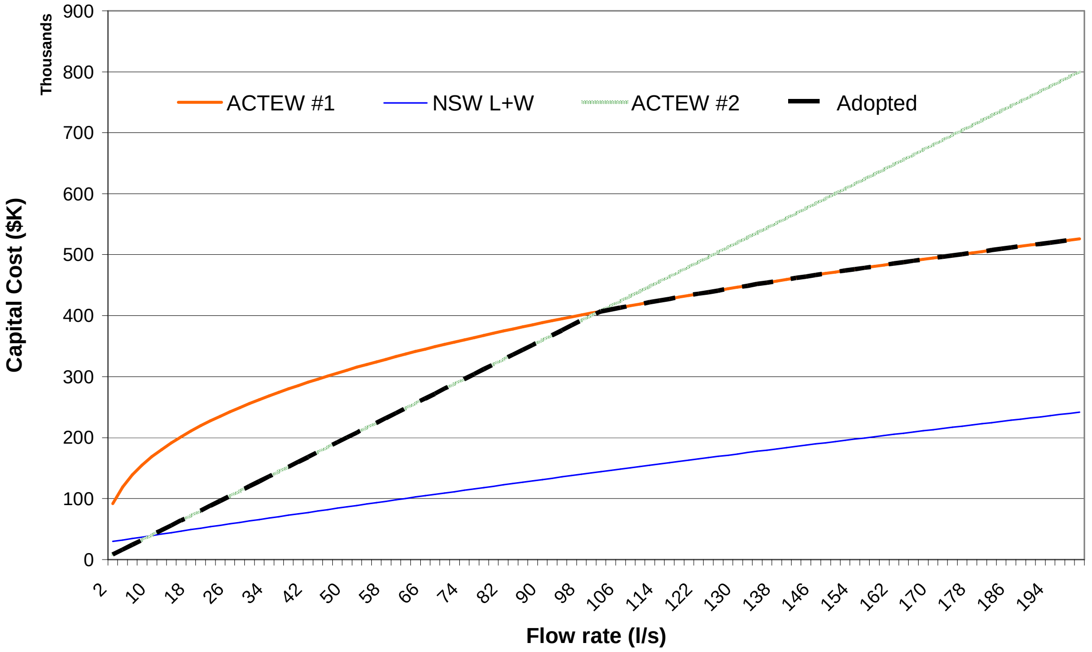


Figure 56: Comparison of pumping cost estimates

Operation & maintenance

Annual cost ($/y) = β*Capital Cost($)

Where β = 0.015 for pumps and capital cost does not include 'add-ons'/ allowances.

Energy

Annual energy cost, C_e, is calculated by the formula:

$$C_e = \frac{8.76 \rho g Q_{av} h_t R}{\eta}$$

Where ρ is specific gravity, g is acceleration due to gravity, Q_{av} is the average flow (m^3/s), h_t is the pumping head (m), R is the energy cost = 15c per kWh (based on email correspondence with Jack Garside and Chris Deschamps of ACTPLA), and N is the pumping efficiency which is assumed to equal 0.75.

Bores

See Appendix F for an example cost of a fractured rock bore.

Capital costs

The capital costs for bores were based on Evans (2008) and are as follows:

- Drilling and bore: $14,000

- Headworks: $25,000
- Telemetry: $5,000
- Monitoring well: $50,000
- Extraction pump: $10,000

Therefore, for an ASR scheme:

Total Capital Cost = 14,000 + 25,000 + 5,000 + 50,000 + 10,000 = $104,000

Operation & maintenance

Unfortunately, no quantitative values for operation and maintenance costs were available, so assumptions needed to be made. To calculate annual operation and maintenance cost, the following formula was used:

Annual cost ($/y) = β*Capital Cost($)

A β value of 0.02 was adopted for headworks, the bore and monitoring equipment. A β value of 0.015 was adopted for pumps and telemetry.

Sewer Mining

All costs for sewer mining (with the exception of 'add-on' costs) were provided by Wayne Harris (per. comm. 2007) and emanate from his discussions with Peter Norton-Baker and Aquatech Maxicon (a specialist water and wastewater treatment company with experience in building sewer mining plants). These discussions have allowed an estimation of plant sizes ranging from 100 kL/day to 4 ML/day.

A sewer mining plant is assumed to consist of the following elements

- Sewer interception / diversion structure and pump
- Raw sewage / inlet balance tank
- Recycled water treatment plant

The recycled water treatment plant has been costed using MBR technology and allowances have been made for additional secondary UV disinfection, basic solids handling facilities, site works and installation. Based on these costs, estimations of capital cost in relation to plant flow were developed (Table 79). The individual cost points shown in Table 79 define a curve which shows an economy of scale related to increasing flow.

Table 79: Capital cost of sewer mining plant (source: Wayne Harris)

Plant flow (kL/day)	Capital Cost
100	$1,300,000
300	$2,600,000
1000	$5,450,000
4000	$10,950,000

Operation and maintenance cost

In addition to energy, chemical and membrane replacement costs, allowances have also been made for operations monitoring and management, solids disposal and general operational maintenance (Table 80). Operations monitoring costs have been included on the basis there may be several sewer mining plants operating in the system under a central management provided either by ACTEW or some other similar operational agency (either private or public).

The operations monitoring and management cost has a significant fixed cost which is assumed to be $20,000 per annum regardless of plant size. This allows for the plant to be monitored remotely from a central control room and for an operator to make routine visits to the site as well as attend emergency callouts to attend alarms or other operational conditions which require a site visit.

The general plant maintenance cost has been based on a notional cost to perform routine electrical and mechanical operational maintenance and servicing on the installed equipment. This item shows some economy of scale related to the capital cost of the equipment, hence the operational and maintenance costs have a similar cost function to the capital cost function. A cost for purchasing raw sewage from the water utility has not been included.

Table 80: Operations and maintenance cost of sewer mining plant

Plant Flow kL/day	Fixed annual cost	Variable Cost per kL of recycled water produced
100	$20,000	$1.34
300	$20,000	$1.25
1,000	$20,000	$1.19
4,000	$20,000	$1.13

Replacement costs

Much of the equipment that forms a sewer mining plant will have a life span greater than the analysis period (50 years). For these equipment, there is no need to estimate replacement costs. However, many of the equipment (e.g. rotating machines, pumps, motors, electrical control equipment) will have a life span less than the analysis period. For this reason, replacement costs were estimated.

It was assumed typical electrical control equipment and switchboards need replacing every 15-20 years, and mechanical equipment every 20-25 years. However, given the equipment will be used less than a ‘typical’ treatment plant, it has been assumed a major refurbishment every 25 years will suffice.

Determining the major refurbishment cost required a number of assumptions. It was assumed 30% of the factory price of the STP is electrical and mechanical equipment, which needs replacement at 25 years. In addition, all of the secondary disinfection equipment and all of the solids handling equipment were also included. These latter two items are mainly electrical and mechanical equipment whereas the STP itself consists of many tanks, pipes and membranes that are regularly replaced and hence not subject to major refurbishment costs. On this basis, the 25 year replacement/refurbishment costs for the STP and its associated elements were estimated (Table 81).

Table 81: Major refurbishment cost of sewer mining plant (at 25 year age)

Plant Flow kL/day	Major Refurbishment Cost after 25 years ($2007)
100	$410,000
300	$825,000
1,000	$1,650,000
4,000	$3,300,000

The sewer diversion structure consists of an interception manhole and a pump station and it is assumed that one third of the capital cost relates to the electrical and mechanical equipment in the pump station. Only the electrical and mechanical equipment in the pump station needs to be replaced/refurbished after 25 years. The time period is based on the same logic as for the STP itself. On this basis, the costs for replacement/refurbishment of the sewer diversion structure were estimated (Table 82).

Table 82: Major refurbishment cost of sewer diversion structure (at 25 year age)

Plant flow (kL/day)	Major refurbishment cost after 25 years ($2007)
100	$20,000
300	$35,000
1,000	$50,000
4,000	$70,000

The inlet storage tank has been estimated based on the cost of a concrete tank with a metal 'silo' type roof. Provided the roof is designed properly, the tank adequately vented and is subject to routine inspection and painting, the whole structure will last at least the analysis period (50 years) without need for refurbishment

Painting is also a cost that needs to be included. A good paint system should last up to 15 years, but should not be left much longer. Hence, allowance has been made for painting the main structure every 15 years based on nominal assumed values (Table 83).

Table 83: Cost to repaint major structural elements (every 15 years)

Plant flow (kL/day)	Major refurbishment cost after 25 years ($2007)
100	$7,500
300	$12,000
1,000	$20,000
4,000	$30,000

Summary

A summary of all costs included for a sewer mining plant is shown in Table 84, which is an example for a 100 kL/day plant flow. 'Add-on' costs, in the form of contingency, consultant design and supervision, special investigations, insurance and administration-procurement have been included and are shown in Table 84. The same 'add-on' values were used for all plant flows (100, 300, 1000 and 4000 kL/day). Straight line interpolation was used between the points for costing sewer mining plants of alternate sizes.

Table 84: Example sewer mining cost

CAPITAL CONSTRUCTION COST		
Sub-total		**$ 1,300,000**
Including allowances	**Allowance (%)**	
Contingency	20%	$ 260,000
Consultant Design & Supervision	12%	$ 156,000
Special Investigations	8%	$ 104,000
Sub Total		**$ 1,820,000**
Insurance	0.6%	$ 10,920
Administration-Procurement Solutions	4%	$ 72,800
TOTAL		$ 1,903,720
Total Capital Cost (rounded) ($)		**$ 1,904,000**
REPLACEMENT COSTS		
Plant Replacement Cost		$ 105,081
Diversion Structure Replacement Cost		$ 5,126
Painting		$ 4,603
Sub Total		**$ 114,810**
Contingency	20%	$ 22,962
Total Replacement Cost		**$ 137,772**
OPERATION & MAINTENANCE COST		
Fixed Annual Cost		$ 20,000
Variable Production Cost ($1.34/kL) - Annual Cost		$ 48,944
Sub Total		**$ 68,944**
Design, supervision, administration & procurement	20%	$ 13,789
Total Annual O+M		**$ 82,732**
Total NPV Project Cost		**$ 1,218,192**
TOTAL NPV PROJECT COST		**$ 3,259,964**
ROUNDED TOTAL ($)		**$ 3,260,000**
LEVELISED COST ($/kL)		**$6.06 per kL**

APPENDIX M STORAGE OPTION ANALYSIS

Preliminary analysis was undertaken to assess the potential of an onsite storage tank to alter the cost of a scheme. Examples were developed following the costing method and data outlined in Appendix L, with the addition of an onsite storage component. These schemes are based on supplying one demand from a stormwater pond, with an onsite tank at the end use location designed as a temporary storage to hold maximum daily demand. With the addition of an onsite tank, supply is able to be pumped to the tank over a 24 hour period, rather than the 8 hour period coinciding with actual irrigation.

Table 85 below shows costs with and without onsite storage, for various demand volumes. The pipe distance and pumping head have been set at 625m and 20m respectively. Costs are based on Net Present Value over a 50 year timeframe, including annual operation and maintenance and add-on costs. Key values used to derive this data are shown in

Table 86. Table 87 gives examples for 100ML demand, showing the effect of changes in pipe distance and pump head. The main source of uncertainty here lies in the tank cost itself. The two sources of tank cost data included the ActewAGL costing procedure for water supply system tanks, and publicly available retail rainwater tank costs. The difference between these domestic-type rainwater tanks and water supply system tanks likely indicates the range of possible costs.

Whilst there is reasonable reduction in pipe/pump costs with onsite storage, these figures show little or no economic benefit in onsite storage compared to the chosen configuration due to possibly high cost of storage. Whilst rainwater tanks may provide cost savings, they may be under-designed, and for larger schemes numerous tanks are required. On the other hand, water supply tanks are always more costly, though may be overdesigned. From these figures, a possible mid-range design product would be unlikely to have to have costs leading towards general adoption of on-site storage at this stage.

Longer distances and higher pumping head mean greater potential for savings due to the greater proportion of the cost of piping and pumping (variable cost) as a proportion of the total cost (fixed cost). Smaller schemes, where the rainwater tank requirements are more sensible could be considered for onsite storage. This may make some of the smaller pond schemes more viable but would likely need to be considered on a case-by-case basis to assess issues such as onsite storage space, specific tank design and maintenance responsibilities.

Table 85: Costs of schemes with and without onsite storage, for various levels of demand

Chosen configuration (no onsite storage)

	Scheme 1		*Scheme 2*		*Scheme 3*		*Scheme 4*	*Scheme 5*
Demand (ML/y)	10		35		100		250	800
Pumping hours	8		8		8		8	8
Average flow (l/s)	1.6		5.7		16.3		40.7	130.1
Pipe diameter (mm)	75		150		225		300	375
Total Life Cycle Cost (NPV) Pipe and Pump ($)	136,033		319,176		630,329		1,215,320	2,953,827
Total Life Cycle Cost ($)	**136,033**		**319,176**		**630,329**		**1,215,320**	**2,953,827**

Alternative configuration (onsite storage)

	Scheme 1		*Scheme 2*		*Scheme 3*		*Scheme 4*	*Scheme 5*
Demand (ML/y)	10	10	35	35	100	100	250	800
Demand (m^2)	15748	15748	55118	55118	157480	157480	393701	1259843
Max Demand (mm/day)	4.23	4.23	4.23	4.23	4.23	4.23	4.23	4.23
Max Demand (ML/day)	0.067	0.067	0.233	0.233	0.666	0.666	1.665	5.329
Storage Safety Factor	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Storage Size (ML)	0.08	0.08	0.28	0.28	0.80	0.80	2.00	6.39
Tank Type	ActewAGL	Rainwater	ActewAGL	Rainwater	ActewAGL	Rainwater	ActewAGL	ActewAGL
Number of Tanks	1	2	1	7	1	18	1	1
Storage Cost ($)	146,730	13,980	285,020	48,930	497,330	125,820	808,263	1,497,208
Annual O+M for Storage ($)	1,467	140	2,850	489	4,973	1,258	8,083	14,972
NPV Storage O+M ($2007)	21,605	2,058	41,968	7,205	73,229	18,526	119,013	220,457
NPV Storage with add-on costs ($2007)	239,467	22,816	465,160	79,855	811,655	205,341	1,319,105	2,443,481
Pumping hours	24	24	24	24	24	24	24	24
Average flow (l/s)	0.77	0.77	1.90	1.90	5.40	5.40	13.6	43.4
Pipe diameter (mm)	50	50	75	75	150	150	150	300
Total Life Cycle Cost (NPV) Pipe and Pump ($)	79,918	79,918	141,644	141,644	313,796	313,796	481,702	1,269,934
Total Life Cycle Cost ($)	**319,385**	**102,734**	**606,804**	**221,499**	**1,125,451**	**519,137**	**1,800,807**	**3,713,415**
% Saving from no onsite storage	-135%	24%	-90%	31%	-79%	18%	-48%	-26%

Table 86: Key variables used in costing

ActewAGL Water Supply Tank Cost	$560,000*Volume (ML)^0.53
Rainwater Tank Cost (45kL) (retail) (http://www.enviro-friendly.com/tankmasta-water-tanks.shtml#45000)	$6,990
Storage Operation and Maintenance Cost (% of capital cost, annual)	1.0%
Analysis Period (yrs)	50
Discount Rate	6.5%
Add-on cost factor	1.42

Table 87: Costs of current vs alternative configuration for different pipe and pump variables

Current configuration (no onsite storage)

	Scheme 1	*Scheme 2*	*Scheme 3*
Demand (ML/y)	100	100	100
Pipe Distance (m)	625	625	1563
Lift	20	50	50
Pumping hours	8	8	8
Average flow (l/s)	16.3	16.3	16.3
Pipe diameter (mm)	225	225	225
Total Life Cycle Cost (NPV) Pipe and Pump ($)	630,329	778,498	1,249,144
Total Life Cycle Cost ($)	**630,329**	**778,498**	**1,249,144**

Alternative configuration (onsite storage)

	Scheme 1		*Scheme 2*		*Scheme 2*	
Tank Type	ActewAGL	Rainwater	ActewAGL	Rainwater	ActewAGL	Rainwater
NPV Storage with add-on costs ($2007)	811,655	205,341	811,655	205,341	811,655	205,341
Pumping hours	24	24	24	24	24	24
Average flow (l/s)	5.40	5.40	5.40	5.40	5.40	5.40
Pipe diameter (mm)	150	150	150	150	150	150
Total Life Cycle Cost (NPV) Pipe and Pump ($)	313,796	313,796	363,186	363,186	675,597	675,597
Total Life Cycle Cost ($)	**1,125,451**	**519,137**	**1,174,841**	**568,527**	**1,487,252**	**880,938**
% Saving vs no onsite storage	-79%	18%	-51%	27%	-19%	29%

APPENDIX N GENERIC SCENARIO RESULTS

See next page for spreadsheet results of generic scenario costing results.

APPENDIX O COMPARISON OF 85% AND 95% VOLUMETRIC RELIABILITY

This short note provides some context regarding the implications of design of a scheme based on 85% and 95% volumetric reliability, where the definition of ‘volumetric reliability’ is the percentage of volume of demand met over the modelling sequence (in this case, 65 years as per Chapter 2.1).

Schemes designed at 85% and 95% volumetric reliability are compared for performance on shorter timescales, especially during periods of low flow. The examples show several generic stormwater pond schemes modelled using the 2030 climate sequence and a pond drawdown limit of 1m depth (Table 88 and Table 89).

As expected, ponds with 95% volumetric reliability perform much better during drought periods, however during the most severe dry periods the difference in performance is not so great. This is because neither scheme has been designed to 100% reliability so failure is expected during the most severe dry periods.

One of the modelled examples demonstrates that a scheme with 250ML of demand on a stormwater pond with a 1000ha catchment designed for 95% average volumetric reliability has:

- Minimum volumetric reliability over 1 year of 70%
- Minimum time-based reliability over 1 year of 61% (where ‘time reliability’ is defined as the percentage of days where demand is fully satisfied)
- Time reliability of 85% and volumetric reliability of 81% over the lowest year of stream flow
- Time reliability of 92% and volumetric reliability of 90% over the lowest seven years of stream flow record
- Maximum supply failure period of 118 days

This compares to the same scheme with an 85% volumetric reliability which has:

- Minimum volumetric reliability over 1 year of 52%
- Minimum time-based reliability over 1 year of 53%
- Time reliability of 81% and volumetric reliability of 68% over the lowest year of stream flow record
- Time reliability of 85% and volumetric reliability of 77% over the lowest seven years of stream flow record
- Maximum supply failure period of 141 days

These results indicate that a scheme with 95% reliability will perform much better than a scheme with 85% reliability; however neither will be able to maintain all grass types at all times. As is partly explained by the results of modelling and costing in the main body of this report, designing stormwater pond schemes beyond 95% reliability is in the vast majority of cases inefficient because required pond volume becomes very large which causes costs to become excessive.

This short note reinforces the importance of improving the reliability of supply by:

- Discussing with the mains water provider the possibility of backing up the harvesting schemes.
- Combining stormwater harvesting schemes with MAR and / or sewer mining.

Table 88: Performance of stormwater ponds at 85% reliability

Scenario (Time period)	Demand (ML)	Catchment Area (ha)	Time Reliability	Volumetric Reliability
Minimum 1-year inflow	35	250	80.7%	66.7%
	100	500	80.3%	65.6%
	250	1000	81.3%	67.8%
Minimum 7-year inflow	35	250	89.2%	82.4%
	100	500	86.3%	79.2%
	250	1000	84.7%	77.0%
Minimum 1 -year time reliability	35	250	66.4%	51.0%
	100	500	57.9%	50.9%
	250	1000	52.6%	52.4%
Minimum 7-year time reliability	35	250	85.9%	78.8%
	100	500	85.9%	79.1%
	250	1000	84.6%	81.0%
Minimum 1 -year vol reliability	35	250	66.4%	51.0%
	100	500	57.9%	50.9%
	250	1000	52.6%	52.4%
Minimum 7-year vol reliability	35	250	86.9%	78.8%
	100	500	87.7%	78.2%
	250	1000	84.7%	77.0%

	Demand (ML)	Catchment Area (ha)	Time (days)
Longest consecutive failure period	35	250	63
	100	500	103
	250	1000	141

Table 89: Performance of stormwater ponds at 95% reliability

Scenario (Time period)	Demand (ML)	Catchment Area (ha)	Time Reliability	Volumetric Reliability
Minimum 1-year inflow	35	250	86.2%	79.1%
	100	500	87.9%	81.6%
	250	1000	84.6%	81.3%
Minimum 7-year inflow	35	250	97.2%	95.2%
	100	500	95.4%	91.8%
	250	1000	92.1%	90.3%
Minimum 1 -year time reliability	35	250	62.2%	62.7%
	100	500	59.9%	67.9%
	250	1000	61.2%	70.0%
Minimum 7-year time reliability	35	250	92.6%	91.7%
	100	500	91.6%	91.6%
	250	1000	90.3%	91.0%
Minimum 1 -year vol reliability	35	250	62.2%	62.7%
	100	500	59.9%	67.9%
	250	1000	61.2%	70.0%
Minimum 7-year vol reliability	35	250	94.2%	91.1%
	100	500	91.6%	91.6%
	250	1000	92.1%	90.3%

	Demand (ML)	Catchment Area (ha)	Time (days)
Longest consecutive failure period	35	250	115
	100	500	122
	250	1000	118

APPENDIX P STORMWATER POND DESIGN AND COSTING EXAMPLE

This short note outlines costing procedures for stormwater ponds using the B14 pond supplying the Florey 1 demand centre as an example. A detailed summation of costs for this example is given in Table 90 below.

The pond was sized to meet a volumetric reliability of 95% using the rainfall run-off model described in Appendix C and a harvesting model as per Appendix K and the demand for the Florey 1 demand cluster is 12.3 ML/yr as per Appendix A. The resultant pond size is 864 m^2.

The capital cost of the pond, pipes and pumps was calculated as per equations in Appendix L to be $178,045, $92,468 and $8,008 respectively.

Replacement costs for pumps were calculated to be $4,795 using the equation shown in Appendix L and assuming a pump life of 15 years.

Operation and maintenance costs for the pipes and pumps were assumed to be 0.5% and 1.5% of capital cost respectively on an annual basis.

The annual maintenance cost of the pond was calculated by the formula suggested in the MUSIC User Guide (Wong et al., 2005) with a 20% allowance for contingency

$$\text{TAM (\$2005)} = 185.4 * A^{0.478} \quad \text{(+20\% contingency), where A = area in } m^2$$

For this example, and including an inflation rate of 2.5%, this translates to

$$\text{TAM (\$2005)} = 185.4 * 864^{0.478} * 1.025^3 * 1.2 = \$6069$$

Renewal and adaptation cost (RAC) is also calculated by a formula suggested in the MUSIC User Guide (Wong et al., 2005). In this instance, the capital cost also includes the allowances for the pond construction cost.

$$\text{RAC (\$)} = 0.014 * \text{Capital Cost} = 0.014 * 260730 = \$3650$$

Allowances, in the form of contingency, consultant design / supervision, special investigations, insurance, administration and procurement are included as per Table 78 in Appendix L and Table 90 below.

Present value replacement and operation costs for the B14 - Florey 1 example are shown in Table 90 below and are calculated as per the formula in Appendix L.

Note that residual value (i.e. salvage value) costs have not been included in this calculation (however it would have minimal impact on the overall PV cost given a lengthy project life (50 years) has been used).

Table 90: Example stormwater pond costing (B14 pond supplying Florey 1 demand)

CAPITAL CONSTRUCTION COST		
Pipes		$ 92,468
Pumps		$ 8,008
Pond		$ 178,045
Sub-total		**$ 279,000**
Including allowances	**Allowance (%)**	
Contingency	20%	$ 55,800
Consultant Design & Supervision	12%	$ 33,480
Special Investigations (Ponds)	8%	$ 14,244
Special Investigations (Pipes & Pumps)	4%	$ 4,019
Sub Total		**$ 382,524**
Insurance	0.6%	$ 2,295
Administration-Procurement Solutions	4%	$ 15,301
TOTAL		$ 400,120
Total Capital Cost (rounded) ($)		**$ 400,000**
REPLACEMENT COSTS (NPV)		
Pumps		$ 4,795
Contingency	20%	**$ 959**
Total Replacement Cost		**$ 5,754**
Total Replacement Cost (rounded)		**$ 6,000**
OPERATION & MAINTENANCE COST	**Beta**	
Annual pipe cost (Beta = 0.005)	0.005	$ 462
Annual pump cost (Beta = 0.015)	0.015	$ 120
Energy		$ 907
Sub Total		$ 1,490
Contingency	20%	$ 447
Total Annual Cost (pipe, pump, energy)		$ 1,937
Total Annual Cost Pond (as per equation above)		$ 9,719
NPV Total annual cost (incl. contingency)		**$ 171,631**
Total NPV O+M Cost (rounded)		**$ 172,000**
TOTAL NPV PROJECT COST		**$ 578,000**
ROUNDED TOTAL ($)		**$ 580,000**
LEVELISED COST ($/kL)		**$3.37 per kL**

APPENDIX Q MASTER PLAN A MAP

See next page for a map of the Master Plan supply–demand options.

The legend shown in Appendix B identifies the clusters shown on the map.

APPENDIX R ECOLOGICAL INDICATORS FOR TBL ASSESSMENT

Aquatic Vegetation

Table 91: Base case – shore exposure at 20 cm. Aquatic vegetation scores derived from analysis of the pond drawdown time series. The average recurrence intervals for spells of 50-75 days and >75 days where the water level is drawn down more than 20cm are used to determine the scores as shown in Table 18 and Table 19. The final score for the base case takes an average between the scores for the 20cm and 50cm drawdown levels (50cm scores shown in Table 92).

Pond name	**ARI (d >75 day)**	**ARI (d>50 day)**	**ARI (50<d<75day)**	**Score >75 day**	**Score 50-75 day**	**Combined score**	**Average score (20cm and 50cm)**
David St	46	34	128	1	1	1	1
Jarramlee (Dunlop Pond 1)				1	1	1	1
Fassifern (Dunlop Pond 2)				1	1	1	1
Ginninderra	9	4	6	1	5	5	3
Gungahlin	39	33	220	1	1	1	1
Isabella Pond	41	33	172	1	1	1	1
Lake Tuggeranong	20	8	15	1	1	1	1
Lower Stranger Pond	20	9	17	1	1	1	1
Nichols Pond	7	4	8	3	3	3	2
Point Hut Pond	14	4	6	1	5	5	3
Tuggeranong Weir	39	18	34	1	1	1	1
Upper Stranger Pond	42	35	207	1	1	1	1
West Belconnen	3	2	10	5	1	5	3
Yerrabi	9	3	6	1	5	5	3

Table 92: Base case – shore exposure at 50 cm. Aquatic vegetation scores derived from analysis of the pond drawdown time series. The average recurrence intervals for spells of 50-75 days and >75 days where the water level is drawn down more than 20cm are used to determine the scores as shown in Table 18 and Table 19. The final score for the base case takes an average between the scores for the 20cm and 50cm drawdown levels (20cm scores and averages are shown in Table 91).

Pond name	**ARI (d >75 day)**	**ARI (d>50 day)**	**ARI (50<d<75day)**	**Score >75 day**	**Score 50-75 day**	**Combined score**
David St				1	1	1
Jarramlee (Dunlop Pond 1)				1	1	1
Fassifern (Dunlop Pond 2)				1	1	1
Ginninderra	45	39	306	1	1	1
Gungahlin				1	1	1
Isabella Pond				1	1	1
Lake Tuggeranong				1	1	1
Lower Stranger Pond	49	43	386	1	1	1
Nichols Pond	45	39	294	1	1	1
Point Hut Pond	44	39	301	1	1	1
Tuggeranong Weir	55	47	322	1	1	1
Upper Stranger Pond				1	1	1
West Belconnen	13	6	13	1	1	1
Yerrabi	46	40	316	1	1	1

Table 93: Harvesting Case - shore exposure at 20 cm drawdown level (see explanation in caption for Table 91). Also included is a column indicating the change in score from the Base Case score

Pond name	**ARI (d >75 day)**	**ARI (d>50 day)**	**ARI (50<d<75day)**	**Score >75 day**	**Score 50-75 day**	**Combined score**	**Average score (20cm and 50cm)**	**Change**
David St	22	4	5	1	5	5	3	2
Jarramlee (Dunlop Pond 1)	3	1	3	5	6	6	6	5
Fassifern (Dunlop Pond 2)	5	3	9	6	1	6	3.5	2.5
Ginninderra	3	2	3	5	6	6	6	3
Gungahlin	4	2	4	6	6	6	5.5	4.5
Isabella Pond	40	29	105	1	1	1	1	0
Lake Tuggeranong	4	2	4	6	6	6	5.5	4.5
Lower Stranger Pond	8	4	7	3	3	3	2	1
Nichols Pond	2	1	4	3	6	3	4.5	2.5
Point Hut Pond	5	2	5	6	5	6	3.5	0.5
Tuggeranong Weir	31	9	13	1	1	1	1	0
Upper Stranger Pond	10	3	5	1	5	5	3	2
West Belconnen	2	1	8	3	3	3	4.5	1.5
Yerrabi	3	2	5	5	5	5	4	1
B14		16		1	1	1	1	1
B28	15	4	6	1	5	5	4	4
T2	5	2	3	6	6	6	5.5	5.5
T3	13	4	5	1	5	5	3	3
T4	14	4	7	1	3	3	2	2
W19	5	2	4	6	6	6	5.5	5.5
W27	5	2	3	6	6	6	5.5	5.5
WC15	19	4	6	1	5	5	3	3
WC19	7	3	4	3	6	6	4.5	4.5
WC4	35	6	7	1	3	3	2	2
G23	22	7	10	1	1	1	1	1
NC14	4	2	4	6	6	6	5.5	5.5
NC18	5	2	4	6	6	6	5.5	5.5
NC911	6	3	4	5	6	6	5.5	5.5
W0	4	2	4	6	6	6	6	6
W2	39	9	12	1	1	1	1	1
WC0	6	2	3	5	6	6	5.5	5.5

Table 94: Harvesting Case - shore exposure at 50 cm drawdown level (see explanation in caption for Table 92)

Pond name	**ARI (d >75 day)**	**ARI (d>50 day)**	**ARI (50<d<75day)**	**Score >75 day**	**Score 50-75 day**	**Combined score**
David St	36	14	23	1	1	1
Jarramlee (Dunlop Pond 1)	5	3	11	6	1	6
Fassifern (Dunlop Pond 2)	10	5	9	1	1	1
Ginninderra	4	3	11	6	1	6
Gungahlin	6	3	5	5	5	5
Isabella Pond				1	1	1
Lake Tuggeranong	6	4	13	5	1	5
Lower Stranger Pond	45	39	286	1	1	1
Nichols Pond	4	3	11	6	1	6
Point Hut Pond	14	7	13	1	1	1
Tuggeranong Weir	50	43	313	1	1	1
Upper Stranger Pond	34	18	39	1	1	1
West Belconnen	4	3	10	6	1	6
Yerrabi	7	4	7	3	3	3
B14				1	1	1
B28	37	7	8	1	3	3
T2	9	3	5	1	5	5
T3	28	7	9	1	1	1
T4	35	7	9	1	1	1
W19	10	3	5	1	5	5
W27	9	3	5	1	5	5
WC15	38	9	12	1	1	1
WC19	25	5	7	1	3	3
WC4	41	8	10	1	1	1
G23	28	14	26	1	1	1
NC14	9	3	6	1	5	5
NC18	21	4	5	1	5	5
NC911	23	4	5	1	5	5
W0	6	3	4	5	6	6
W2		49		1	1	1
WC0	18	4	6	1	5	5

Phytoplankton Blooms

Table 95: Average recurrence intervals (ARI) for periods of critical pond turnover rates. A longer ARI indicates a lower algal risk.

Base Case		***Harvesting Case***	
Pond name	**Critical turnover ARI (years)**	**Pond name**	**Critical turnover ARI (years)**
David St	1.2	David St	1.2
Jarramlee (Dunlop Pond 1)	0.8	Jarramlee (Dunlop Pond 1)	1.1
Fassifern (Dunlop Pond 2)	0.6	Fassifern (Dunlop Pond 2)	0.8
Ginninderra	0.5	Ginninderra	0.5
Gungahlin	0.7	Gungahlin	0.7
Isabella Pond	1.2	Isabella Pond	1.4
Lake Tuggeranong	0.5	Lake Tuggeranong	0.5
Lower Stranger Pond	0.7	Lower Stranger Pond	0.7
Nichols Pond	0.6	Nichols Pond	0.7
Point Hut Pond	0.6	Point Hut Pond	0.6
Tuggeranong Weir	0.9	Tuggeranong Weir	0.8
Upper Stranger Pond	1.2	Upper Stranger Pond	1.2
West Belconnen	0.5	West Belconnen	0.5
Yerrabi	0.6	Yerrabi	0.6
		B14	5.3
		B28	2.2
		T2	1.2
		T3	1.1
		T4	1.9
		W19	1.4
		W27	1.3
		WC15	2.3
		WC19	1.6
		WC4	2.6
		G23	1.2
		NC14	1.0
		NC18	1.1
		NC911	1.8
		W0	0.8
		W2	4.5
		WC0	1.2

Water Quality

Table 96: Load reduction indicator used in the DMCE analysis and the quantities used to derive this indicator. See Chapter 8.3.2 for explanation.

	Volume (ML)	**Surface area (ha)**	**Depth (m)**	**Hydraulic loading (m/yr)**	**Nutrient retention efficiency (%)**	**Load reduction indicator**
David St	3.0	0.3	2.0	76	22	0.0
Jarramlee (Dunlop Pond 1)	14.0	0.7	2.0	16	61	0.0
Fassifern (Dunlop Pond 2)	13.9	0.7	2.0	8	72	0.0
Ginninderra	3555.2	105.6	10.1	9	69	1.4
Gungahlin	554.2	23.8	7.0	19	58	0.8
Isabella Pond	72.0	5.8	2.5	60	29	0.3
Lake Tuggeranong	2551.5	56.7	9.0	11	67	0.7
Lower Stranger Pond	61.6	4.1	3.0	21	56	0.1
Nichols Pond	48.0	4.0	2.4	3	80	0.0
Point Hut Pond	336.0	16.8	4.0	7	72	0.1
Tuggeranong Weir	144.0	9.6	3.0	37	43	0.3
Upper Stranger Pond	45.1	4.5	2.0	16	61	0.1
West Belconnen	100.0	10.0	2.0	2	83	0.0
Yerrabi	444.2	26.7	5.0	5	76	0.2
B14	1.7E-04	0.1	2	1430	0	0.0
B28	8.2E-04	0.4	2	117	5	0.2
T2	3.6E-03	1.8	2	31	47	0.8
T3	2.8E-03	1.4	2	69	25	0.8
T4	9.3E-04	0.5	2	292	0	0.2
W19	6.2E-03	3.1	2	36	44	1.6
W27	4.9E-03	2.5	2	31	47	1.2
WC15	6.0E-04	0.3	2	149	0	0.1
WC19	8.2E-04	0.4	2	51	34	0.2
WC4	1.6E-03	0.8	2	212	0	0.2
G23	1.1E-03	0.5	2	180	0	0.2
NC14	3.8E-03	1.9	2	24	53	0.8
NC18	6.7E-03	3.4	2	50	35	2.1
NC911	1.4E-03	0.7	2	110	8	0.3
W0	2.4E-02	12.0	2	30	48	7.2
W2	6.9E-04	0.3	2	1066	0	0.9
WC0	6.6E-03	3.3	2	72	24	2.3

Drawdown

Table 97: Drawdown indicator values used in the DMCE analysis: the percentage of time between November and April for which the drawdown exceeds 0.5m.

Base		***Harvesting***	
Pond name	**Drawdown score**	**Pond name**	**Drawdown score**
David St	0.2	David St	15.8
Jarramlee (Dunlop Pond 1)		Jarramlee (Dunlop Pond 1)	21.0
Fassifern (Dunlop Pond 2)		Fassifern (Dunlop Pond 2)	13.4
Ginninderra	0.9	Ginninderra	20.1
Gungahlin	0.4	Gungahlin	19.8
Isabella Pond	0.3	Isabella Pond	0.5
Lake Tuggeranong	0.4	Lake Tuggeranong	17.0
Lower Stranger Pond	0.4	Lower Stranger Pond	1.0
Nichols Pond	1.1	Nichols Pond	25.5
Point Hut Pond	1.3	Point Hut Pond	8.9
Tuggeranong Weir	0.5	Tuggeranong Weir	0.7
Upper Stranger Pond	0.3	Upper Stranger Pond	5.9
West Belconnen	7.4	West Belconnen	23.3
Yerrabi	0.8	Yerrabi	18.6
		B14	14.1
		B28	17.8
		T2	20.2
		T3	18.8
		T4	18.0
		W19	20.0
		W27	20.2
		WC15	17.3
		WC19	19.0
		WC4	16.7
		G23	19.1
		NC14	20.9
		NC18	19.1
		NC911	19.9
		W0	21.3
		W2	16.7
		WC0	22.5

Streamflow Impacts on Macroinvertebrates

Table 98: Zero ARI analysis for macroinvertebrates

	Day calculations						**Index calculations**					
	1-in-1 year			**1-in-2 year**			**1-in-1 year**			**1-in-2 year**		
	Base	**Harvesting**	**% Change**	**Base**	**Harvesting**	**% Change**	**Base**	**Harvesting**	**% Change**	**Base**	**Harvesting**	**% change**
DavidSt	24.6	30.7	25%	33.2	42.1	27%	4.2	4.0	-5%	3.9	3.6	-8%
DunlopPond1	30.7	43.0	40%	41.9	102.5	145%	4.0	3.6	-10%	3.6	1.6	-56%
DunlopPond2	38.2	22.0	-42%	64.7	152.0	135%	3.7	4.3	15%	2.8	-0.1	-102%
Ginninderra	39.0	44.0	13%	65.6	99.2	51%	3.7	3.5	-5%	2.8	1.7	-40%
Gungahlin	31.1	45.5	46%	42.8	73.7	72%	4.0	3.5	-12%	3.6	2.5	-29%
IsabellaPond	25.0	26.3	5%	34.3	39.3	15%	4.2	4.1	-1%	3.9	3.7	-4%
LakeTugger	34.9	50.0	43%	56.5	83.5	48%	3.8	3.3	-13%	3.1	2.2	-29%
LowerStrangerPond	33.5	38.0	13%	52.5	63.2	21%	3.9	3.7	-4%	3.3	2.9	-11%
Nicholls pond	42.3	47.0	11%	69.0	113.0	64%	3.6	3.4	-4%	2.7	1.2	-54%
PointHut pond	38.3	43.0	12%	64.7	74.5	15%	3.7	3.6	-4%	2.8	2.5	-11%
Tuggeragong Weir	28.7	32.3	13%	40.7	48.5	19%	4.0	3.9	-3%	3.6	3.4	-7%
UpperStranger Pond	29.8	37.0	24%	41.9	62.5	49%	4.0	3.8	-6%	3.6	2.9	-19%
WestBelconnen	43.0	21.2	-51%	126.0	115.5	-8%	3.6	4.3	20%	0.8	1.2	44%
Yerrabi	42.3	44.0	4%	68.5	100.5	47%	3.6	3.5	-2%	2.7	1.7	-39%
B14		17.2			21.9			4.4			4.3	
B28		28.7			40.6			4.0			3.6	
T2		38.2			63.7			3.7			2.9	
T3		32.4			43.5			3.9			3.6	
T4		29.5			40.7			4.0			3.6	
W19		37.3			62.5			3.8			2.9	
W27		38.2			64.0			3.7			2.9	
WC15		26.6			39.6			4.1			3.7	
WC19		33.4			51.5			3.9			3.3	
WC4		24.9			35.4			4.2			3.8	
G23		29.0			38.7			4.0			3.7	
NC14		43.0			76.5			3.6			2.5	

	Day calculations						**Index calculations**					
	1-in-1 year			**1-in-2 year**			**1-in-1 year**			**1-in-2 year**		
	Base	**Harvesting**	**% Change**	**Base**	**Harvesting**	**% Change**	**Base**	**Harvesting**	**% Change**	**Base**	**Harvesting**	**% change**
NC18		34.7			57.5			3.8			3.1	
NC911		34.7			55.5			3.8			3.2	
W0		41.5			67.0			3.6			2.8	
W2		20.5			29.5			4.3			4.0	
WC0		35.0			59.7			3.8			3.0	

APPENDIX S ECOLOGICAL ASSESSMENT TECHNICAL DETAILS

See next page.

APPENDIX T FOCUS GROUP QUESTIONS

Background

This research forms part of a study on assessing Integrated Urban Water Management (IUWM) options in Canberra. The overall objective of this study is to assess the feasibility of achieving 3 GL/yr reuse target across Canberra giving emphasis to stormwater harvesting. This workshop is to research the social impacts of this project, including a specific interest in the Weston Creek Pond project as well as more general consideration of water in Canberra.

Introductions

We invite you to introduce yourselves. Who do you represent, and what is the importance of water in your role?

General Questions

Who do you see as responsible for managing water in Canberra, and who is able to bring about change in practices?

Have you had experiences already with water re-use or water re-cycling?

What are you general concerns about water re-use and water re-cycling?

In what ways could water re-use and water rec-cycling be used?

Do you think water re-use and water re-cycling can help Canberra's water needs in general?

At this point, provide information about the project.

Project Related Questions

What are your interests in the water re-use project?

What are the benefits of the water re-use project? (if any)

What are you concerns about the water re-use project? (if any)

Who should have access to the water?

Do you have confidence in the technical or scientific basis of the project?

What are appropriate uses for the water from the project?

Do you think the project will help Canberra's water needs?

Are there any other issues you would like to raise or questions you would like to ask?

Closing statement: what happens now?

APPENDIX U SURVEY QUESTIONS

1. Who do you see as responsible for managing water in Canberra?
- ACT Government
- ACTEW
- ActewAGL
- Businesses
- Residents
- Federal Government
- National Capital Authority
- Catchment groups
- Other (please specify)

2. How complex do you find the arrangements for water management in Canberra?

3. We are interested in your opinion on the ability of different organisations and groups to bring about change in water management. How much ability do the following have to bring about change in practices?
- ACT Government
- ACTEW
- ActewAGL
- Businesses
- Residents
- Federal Government
- National Capital Authority
- Catchment groups
- Other (please specify)

4. What do you see as suitable options for the following regions (Weston Creek, Woden, Tuggeranong, Gungahlin, Inner North Canberra, Belconnen) of Canberra (select all that apply)
- Sewer mining
- Stormwater collecting
- Ground water recharge
- Don't know

5. What do you see as suitable options for your suburb? (select all that apply)
- Sewer mining
- Stormwater harvesting
- Ground water recharge
- Other (please specify)
- Don't know

6. How well do you understand the following water collection and recycling approaches?
- Roof water harvesting (e.g. rainwater tanks)
- Recycling household water (i.e. 'greywater')
- Collecting and using stormwater (e.g. in ponds for re-use)

- Wetland projects for water quality improvements
- Reusing treated sewage for irrigating parks etc
- Ground water recharge*

*e.g. injecting (recycled) water underground for storage in an aquifer and subsequent retrieval (comments welcome)

7. Do you agree that the following are appropriate forms of water collection and recycling in Canberra?

- Roof water harvesting (e.g. rainwater tanks)
- Recycling household water (e.g. laundry, shower)
- Collecting and using stormwater (e.g. in ponds for re-use)
- Wetland projects for water quality improvements
- Reusing treated sewage for irrigating parks etc
- Ground water recharge*

*e.g. injecting (recycled) water underground for storage in an aquifer and subsequent retrieval (comments welcome)

8. If stormwater were to be collected, which is the best way to store it? (please choose only one)

- In new ponds (which could run dry in summer)
- In existing ponds and lakes (so water level could vary)
- Underground in tanks
- Underground in the groundwater system
- Don't know
- Don't care
- Other (please specify)

9. How concerned are you about the following aspects of water collection and water recycling?

- Water quality
- Injury risk
- Odours
- Aesthetic impact
- Economic viability
- Mosquitoes
- Comments welcome:

10. As a resident, do you collect and use rain water (e.g. in rain water tanks) or recycle greywater? Please select all that apply

- Collect and use rain water for garden/lawns
- Collect and use rain water for household use
- Collect and use rain water for drinking
- Recycle greywater on gardens/lawns
- Recycle greywater for household use
- Other (please specify)

11. When considering the options for new water management projects in the ACT, how important are the following issues?

- Quantity of drinking water conserved
- Financial cost to install
- Financial cost to maintain
- Potential for community education

- Opportunities for recreation
- Aesthetic appearance
  Impact on future housing development
- Impact on land prices
- Health and safety
- Ecological habitat
- Equity of access to water
- Other (please specify)

12. Which of the following do you see as appropriate uses of collected stormwater and recycled water?
- Use on residential gardens
- Irrigation of parks and public gardens
- Irrigation of sports grounds
- Drinking
- Use by golf courses
- Use by industry

13. Do you agree that collected stormwater and water recycling will:
- Solve Canberra's water needs completely?
- Contribute towards Canberra's water needs?
- Be an inappropriate way to address Canberra's water needs?

14. What strategies do you see as being the most effective for meeting Canberra's overall water needs?
- Roof water harvesting (e.g. rainwater tanks)
- Recycling household water (e.g. laundry, shower)
- Collecting and using stormwater (e.g. in ponds for re-use)
- Wetland projects for water quality improvements
- Reusing treated sewage for irrigating parks etc
- Increasing dam size
- Reducing water demand
- Ground water recharge*

*e.g. injecting (recycled) water underground for storage in an aquifer and subsequent retrieval (comments welcome)

15. How important are the following factors in affecting whether Canberra meets its water needs?
- Population growth
- Lower rainfall
- Garden design
- Increasing water use per person

16. What are the landscape elements (European trees on public land, Native Australian trees on public land, Public lawns, Sports fields, School grounds, Public parks, Public nature strips, Golf courses, Turf farms, Trees in private gardens, Horticulture farms, Vineyards, Lawns in private gardens, Other private gardens, Other) that should be watered in Canberra?
- Should be watered always
- Should not be watered during water shortages
- Should not be watered at all
- Should not be there at all

17. Which type of water do you see as appropriate for the following uses (European trees on public land, Native Australian trees on public land, Public lawns, Sports grounds, Public parks, Public nature strips, Golf courses, Turf farms, Trees in private gardens, Horticulture farms, Vineyards, Lawns in private gardens, Other private gardens)?

- Tap water
- Stormwater or recycled water
- Groundwater
- All types
- None

18. How would you describe the level of information that is publicly available about water management in Canberra?

- Too much information
- Sufficient information
- Insufficient information
- No information
- Don't know
- Don't care

19. Are you male or female?

- Female
- Male

20. Please indicate your age:

- 0-14
- 15-24
- 25-34
- 35-44
- 45-54
- 55-64
- 65 and over

21. How many people live in your household?

- Children (under 16 years old)
- Adults

22. Please indicate your dwelling type

- Unit/apartment
- Townhouse/duplex
- Detached house
- Retirement village
- Caravan/temporary dwelling
- Other (please specify)

23. Please indicate the suburb where you live.

24. How often do you drink the following sorts of water?

- Tap water
- Filtered tap water

- Bottled water
- Bore water
- Tank water

25. Please indicate your highest level of education
    - Primary school
    - Secondary school
    - TAFE/trade
    - Diploma
    - Tertiary degree
    - Post-graduate

26. Please indicate your annual gross income
    - below $25,000
    - $25,000 - $50,000
    - $50,000 - $75,000
    - $75,000 - $100,000
    - over $100,000

27. Do you have any other comments?

28. If you would like to be notified when the report from this research is available, please provide your email address.

APPENDIX V DEMANDS USED FOR DEVELOPING MASTER PLANS B AND C

Table 99 List of potential end users considered for development of master plans

Designation (Cluster Name)	Individual End uses	Section	Block	Estimated Demand (ha)	Estimated Demand, 2030 Climate (ML/y)	Combined Demand for Cluster (ha)	Combined Demand for Cluster (ML/y)	Sport and Recreation Services (SRS) Comments	Sport and Recreation Services (SRS) Priority Facilities	Additional Comments
BELCONNEN										
Fraser	Fraser Neighborhood Oval	40	1	1.3	8.3	1.9	12.1	Facility managed by Department of Education and Training. No guarantee that the facility would continue to be irrigated under School Based Management.	■	
	Fraser Primary School	40	2	0.6	3.8			Facility not suitable for sporting competition purposes.	■	
Charnwood 1	Charnwood Neighborhood Oval	118	2	1.1	7.1	2.8	17.9		✓	
	Charnwood Primary School	93	1	1.7	10.8			Facility not suitable for sporting competition purposes.	■	
Charnwood 2	Charnwood District Playing Fields	112	14	8.5	53.8	10.5	66.8		✓	
	St Thomas Aquinas Primary School	97	14	2.0	12.9			Facility not suitable for sporting competition purposes.	■	
Macgregor	Macgregor Neighborhood Oval	58	11	1.7	10.8	3.1	19.7		✓	
	Macgregor Primary School	81	3	1.4	8.9			Facility not suitable for sporting competition purposes.	■	
Holt	Holt Neighborhood Oval	13	1	1.5	9.5	1.5	9.5		✓	
Kippax	Kippax District Playing Fields	50/51	51-53/47	14.1	89.5	17.4	110.5		✓	
	West Belconnen Regional School	48	1	2.0	12.7			Facility not suitable for sporting competition purposes.	■	
	Cranleigh School	49	1	1.3	8.3			Facility not suitable for sporting competition purposes.	■	
Higgins	Higgins Neighborhood Oval	10	19	2.4	15.2	2.4	15.2		✓	
Latham	Latham Neighborhood Oval	29	5	3.1	19.7	4.0	25.4		✓	
	Latham Primary School	30	2	0.9	5.7			Facility not suitable for sporting competition purposes.	■	
Florey 1	St John the Apostle Primary School	12	1	0.7	4.7	1.9	12.3	Facility not suitable for sporting competition purposes.	■	
	St Francis Xavier College	1	1	1.2	7.6			Priority 2 facility detailed in All Dried Up report.	✓	
Florey 2	Florey Neighborhood Oval	143	32	1.7	10.9	2.0	12.8		✓	
	Florey Primary School	143	31	0.3	1.9			Facility not suitable for sporting competition purposes.	■	

Designation (Cluster Name)	Individual End uses	Section	Block	Estimated Demand (ha)	Estimated Demand, 2030 Climate (ML/y)	Combined Demand for Cluster (ha)	Combined Demand for Cluster (ML/y)	Sport and Recreation Services (SRS) Comments	Sport and Recreation Services (SRS) Priority Facilities	Additional Comments
Page	Page Neighborhood Oval	1	5	1.9	12.1	1.9	12.1		✓	
Scullin	Scullin Neighborhood Oval	15	5	3.2	20.3	5.1	32.4		✓	
	Southern Cross Primary School	13	1	1.9	12.1			Facility not suitable for sporting competition purposes.	■	
Flynn	George Simpson Park (Flynn Oval)	18	6	2.2	14.0	2.2	14.0		✓	
Spence	Spence Neighborhood Oval	21	1	3.1	19.7	3.1	19.7		✓	
Melba 1	Copland College	25	1	0.1	0.6	5.5	34.9	Facility not suitable for sporting competition purposes.	■	
	Melba Neighborhood Oval	61	1	2.0	12.7				✓	
	Mt Rogers Community School	44	1	3.4	21.6			Facility not suitable for sporting competition purposes.	■	
Melba 2	Melba District Playing Fields	26	5	4.6	29.2	9.2	58.4		✓	
	Melba High School	27	1	4.6	29.2			Facility not suitable for sporting competition purposes.	■	
Evatt 1	Evatt Neighborhood Oval	12	1	2.1	13.3	3.6	22.9		✓	
	Evatt Primary School	11	1	1.5	9.5			Facility not suitable for sporting competition purposes.	■	
Evatt 2	Miles Franklin Primary School	82	1	1.5	9.5	3.0	18.9	Facility not suitable for sporting competition purposes.	■	
	St Monicas Primary School	86	5	0.4	2.4			Priority 3 facility detailed in All Dried Up report.	■	
	South West Evatt Oval	89	3	1.1	7.0			Facility managed by Department of Education and Training. No guarantee that the facility would continue to be irrigated under School Based Management.	■	
McKellar	Belconnen Soccer Club	71	14	0.9	5.7	3.0	19.0		✓	
	McKellar Neighborhood Oval	53	2	2.1	13.3				✓	
Giralang	Giralang District Playing Fields	85	19	6.8	43.2	7.9	50.2		✓	
	Giralang Primary School	80	4	1.1	7.0			Facility not suitable for sporting competition purposes.	■	
Hawker	Belconnen Bowling Club	3	1	0.4	2.6	13.8	87.3		✓	
	Belconnen High School	5	1	3.3	21.0			Facility not suitable for sporting competition purposes.	■	
	Hawker College	2	1	0.3	1.9			Facility not suitable for sporting competition purposes.	■	

Designation (Cluster Name)	Individual End uses	Section	Block	Estimated Demand (ha)	Estimated Demand, 2030 Climate (ML/y)	Combined Demand for Cluster (ha)	Combined Demand for Cluster (ML/y)	Sport and Recreation Services (SRS) Comments	Sport and Recreation Services (SRS) Priority Facilities	Additional Comments
	Hawker District Playing Fields	3	11-Dec	8.7	55.2				✓	
	Hawker Enclosed Oval	38	20	1.0	6.6			Potential site for Synthetic Grass Pilot Project. Seed funding of $234,300 has been provided to Capital Football. Construction is likely to commence in 2009.	✓	Assumed Irrigable area of 1.0 ha. This may be reduced by Synthetic Grass Pilot Project
	Hawker Primary School	22	9						·	
Weetangera	Weetangera Neighborhood Oval	20	3	2.6	16.5	4.5	28.6		✓	
	Weetangera Primary School	20	5	1.9	12.1			Facility not suitable for sporting competition purposes.	[redacted]	
Macquarie	Macquarie Neighborhood Oval	19	24	2.6	16.5	4.1	26.0	Facility managed by Department of Education and Training. No guarantee that the facility would continue to be irrigated under School Based Management.	[redacted]	
	Macquarie Primary School	18	2	1.5	9.5			Facility not suitable for sporting competition purposes.	[redacted]	
Macquarie/Belconnen	Benjamin Way	-	-	2.6	16.6	8.9	56.8	Not applicable to Sport and Recreation Services	[redacted]	
	Canberra High School	52	5	2.7	17.1			Priority 2 facility detailed in All Dried Up report.	✓	
	Eastern Valley Oval (Belconnen Oval)	150	2	1.6	10.4				✓	
	Jamison Enclosed Oval	54	1	2.0	12.7				✓	
Belconnen	Emu Bank Park	149	14	1.4	8.9	1.4	8.9	Not applicable to Sport and Recreation Services	[redacted]	
Cook	Cook Neighborhood Oval	13	12	2.1	13.3	2.1	13.3		✓	
Aranda	Aranda District Playing Fields	1	24	8.4	53.1	9.1	57.6		✓	
	Aranda Primary School	1	2	0.7	4.4			Facility not suitable for sporting competition purposes.	[redacted]	
AIS	AIS Multi-Purpose Playing Fields	8	37	1.7	10.8	5.6	35.2		✓	
	AIS Soccer Fields	8	37	1.8	11.4				✓	
	AIS Track and Field Facility	8	26	1.0	6.0				✓	
	Canberra Stadium	8	26	1.1	7.0			Sand based field, water demand requirements may need to be adjusted.	✓	
Bruce	ActewAGL Park	9	4	1.4	8.9	4.0	25.6		✓	
	Radford College	4	9	2.6	16.7				✓	Licensed to take 10 ML surface water. The demand shown here (16.7 ML) represents unmet demand.

Designation (Cluster Name)	Individual End uses	Section	Block	Estimated Demand (ha)	Estimated Demand, 2030 Climate (ML/y)	Combined Demand for Cluster (ha)	Combined Demand for Cluster (ML/y)	Sport and Recreation Services (SRS) Comments	Sport and Recreation Services (SRS) Priority Facilities	Additional Comments
University of Canberra	University of Canberra	3	1	4.5	28.6	4.5	28.6		✓	
Kaleen 1	Kaleen South Oval	149	9	3.0	19.1	3.8	24.1		✓	
	Maribyrnong Primary School	120	1	0.8	5.1			Facility not suitable for sporting competition purposes.	■	
Kaleen 2	Kaleen District Playing Fields	117	26	7.4	47.0	12.4	78.7		✓	
	Kaleen Enclosed Oval	117	25	3.2	20.3				✓	
	Kaleen High School	101	1	1.8	11.4			Facility not suitable for sporting competition purposes.	■	
Kaleen 3	Kaleen North Oval	76	4	3.2	20.3	5.0	31.8		✓	
	Kaleen Primary School	45	1	0.9	5.7			Facility not suitable for sporting competition purposes.	■	
	St Michaels Primary School	60	1	0.9	5.7			Facility not suitable for sporting competition purposes.	■	
TOTAL				**171.2**	**1087.1**	**171.2**	**1087.1**			
GUNGAHLIN										
*Crace	*Crace Miscellaneous	0	588	5.0	31.8	5.0	31.8	SRS plans to have a new sportsground constructed in Crace in 2009/10.	✓	
Gold Creek	Gold Creek Country Club	85/86/88/89	2/14/11/21-22	21.5	136.8	21.5	136.8	Club does have some capacity to capture stormwater in a number of dams.	✓	Licensed to take 149 ML (35 ground, 114 surface). The demand shown here (137 ML) is estimated demand not met by existing license.
Gungahlin	Burgmann Anglican School	20	1 & 2	2.5	15.6	2.5	15.6		✓	captures water in dam may be unlicensed irrigation
Nicholls	Gold Creek School (Senior)	78	11	0.6	3.8	6.6	41.9	Facility not suitable for sporting competition purposes.	■	
	Nicholls Neighborhood Oval	73	3	2.0	12.7				✓	
	The Perce Douglas Memorial Playing Fields	78	8	4.0	25.4				✓	
Ngunnawal	Ngunnawal Neighborhood Oval	134	75	2.0	12.7	2.2	14.0		✓	
	Ngunnawal Primary School	134	74	0.2	1.3			Facility not suitable for sporting competition purposes.	■	
Amaroo	Amaroo District Playing Fields	109	1	7.0	44.5	9.1	57.8		✓	
	Amaroo School	93	3	2.1	13.3			Facility not suitable for sporting competition purposes.	■	
Palmerston	Palmerston District Primary School	154	12	0.1	0.6	2.5	15.9	Facility not suitable for sporting competition purposes.	■	

Designation (Cluster Name)	Individual End uses	Section	Block	Estimated Demand (ha)	Estimated Demand, 2030 Climate (ML/y)	Combined Demand for Cluster (ha)	Combined Demand for Cluster (ML/y)	Sport and Recreation Services (SRS) Comments	Sport and Recreation Services (SRS) Priority Facilities	Additional Comments
	Palmerston Neighborhood Oval	154	7	2.4	15.2				✓	
*Throsby	*Throsby Sportsgrounds	0	718	8.0	50.8	8.0	50.8	SRS plans to have a new sportsground constructed in Throsby by 2010/11.	✓	
*Harrison	*Harrison Sportsgrounds	2	11 & 13	7.0	44.5	7.0	44.5	Construction of 3 sportsgrounds at Harrison will be completed in 2008/09.	✓	
Gungahlin Cemetery	Gungahlin Cemetery	39	5	13.0	82.3	13.0	82.3	Not applicable to Sport and Recreation Services.		Licensed to take 13ML surface and groundwater. This demand shown here (82 ML) is estimated demand not met by existing license.
Yerrabi	Yerrabi Pond District Park	181	1	6.0	38.0	6.0	38.0			
Mitchell	Belconnen Dog Obedience Club	0	601	0.9	5.7	2.2	13.7		✓	
	Canberra Harness Racing Club Training Track	0	765	1.3	8.1				✓	
TOTAL				**85.5**	**542.9**	**85.5**	**542.9**			
NORTH CANBERRA										
EPIC	Canberra Harness Racing Club Racing Track	72	5	1.4	8.7	6.1	38.5		✓	
	Exhibition Park in Canberra (EPIC)	72	5	4.4	27.9				✓	
	ACT Canine Association	0	466	0.3	1.9				✓	
Lyneham 1	National Hockey Centre	59	42	1.8	11.4	2.474	15.7099	Synthetic grass pitches that require irrigation.	✓	
	Tennis ACT	64	6	0.7	4.3			Low water demand can be addressed through other sources.		
Lyneham 2	Lyneham High School	47	2	2.7	17.1	4.1	26.035	Facility not suitable for sporting competition purposes.		
	Lyneham Neighborhood Oval	41	19	1.2	7.6				✓	
	Lyneham Primary School	41	18	0.2	1.3			Facility not suitable for sporting competition purposes.		
Dickson	Daramalan College	34	1	1.4	9.1	2.1	13.6		✓	
	Majura Tennis Centre	72	17	0.7	4.4			Low water demand can be addressed through other sources.		
Dickson/Ainslie	Emmaus Christian School	17	4	1.0	6.0	4.8	30.2	Facility not suitable for sporting competition purposes.		
	North Ainslie Primary School	43	1	1.3	8.3			Facility not suitable for sporting competition purposes.		
	Hawdon St Oval	73	3	2.5	15.9			Daramalan College sub lease this facility from ACT	✓	

Designation (Cluster Name)	Individual End uses	Section	Block	Estimated Demand (ha)	Estimated Demand, 2030 Climate (ML/y)	Combined Demand for Cluster (ha)	Combined Demand for Cluster (ML/y)	Sport and Recreation Services (SRS) Comments	Sport and Recreation Services (SRS) Priority Facilities	Additional Comments
								Sportsgrounds.		
Downer	Downer Neighborhood Oval	73	2	3.4	21.6	3.4	21.59		✓	
Watson/Dickson	Dickson College	76	1	0.2	1.3	10.067	63.92545	Facility not suitable for sporting competition purposes.	■	
	Dickson District Playing Fields	76	4	8.8	55.9				✓	
	Rosary Primary School	49	3	1.1	6.8			Facility not suitable for sporting competition purposes.	■	
Hackett	Hackett Neighborhood Oval	12	15	2.3	14.6	2.3	14.605		✓	
Watson	Majura Primary School	31	15	0.7	4.4	1.8	11.43	Facility not suitable for sporting competition purposes.	■	
	Watson Neighborhood Oval	21	8	1.1	7.0				✓	
Ainslie	Ainslie Football Park	26	19	1.9	12.1	1.9	12.065	Sand based field, water demand requirements may need to be adjusted.	✓	
O'Connor 1	O'Connor Co-operative School	89	4	0.3	1.9	1.0602	6.73227	Facility not suitable for sporting competition purposes.	■	
	St Joseph's Primary School	78	1	0.8	4.8			Facility not suitable for sporting competition purposes.	■	
O'Connor 2	Black Mountain School	84	55	0.1	0.6	0.1	0.635	Facility not suitable for sporting competition purposes.	■	
Ainslie/Braddon	Corroboree Park	79	3	2.7	17.1	7.02353937	44.599475	Not applicable to Sport and Recreation Services	■	
	Merici College	11	1	0.7	4.2				✓	Already licensed to take 2 ML groundwater. Demand shown here (4.2 ML) is estimated demand not currently met by non potable water.
	Ainslie Primary School	31	1	3.0	19.1			Facility not suitable for sporting competition purposes.	■	
	Braddon Tennis Club	24	15	0.3	1.6			Low water demand can be addressed through other sources.	■	
	Canberra City Bowling Club	25	16	0.4	2.6				✓	
Turner	Canberra North Bowling Club	66	2	0.4	2.5	2.7	17.145		✓	
	Turner Primary School	67	16	2.3	14.6			Facility not suitable for sporting competition purposes.	■	
ANU	ANU Fellows Oval	39	1	0.1	0.6	2.1	13.335		✓	
	ANU South Oval	39	1	2.0	12.7				✓	
Acton	Acton Park (Ferry Terminal)	33	22	0.2	1.3	0.2	1.27	Not applicable to Sport and Recreation Services	■	

Designation (Cluster Name)	Individual End uses	Section	Block	Estimated Demand (ha)	Estimated Demand, 2030 Climate (ML/y)	Combined Demand for Cluster (ha)	Combined Demand for Cluster (ML/y)	Sport and Recreation Services (SRS) Comments	Sport and Recreation Services (SRS) Priority Facilities	Additional Comments
City	Glebe Park	65	2	0.1	0.6	0.1	0.635	Not applicable to Sport and Recreation Services		
Campbell	Australian War Memorial	39	1	4.2	26.7	8.6	54.61	Not applicable to Sport and Recreation Services		
	Campbell High School	38	2	2.2	14.0			Facility not suitable for sporting competition purposes.		
ADFA	ADFA Parade Ground	64	1	2.2	14.0			Not Applicable to Sport and Recreation Services		
TOTAL				**60.9**	**386.6**	**61**	**387**			
TUGGERANONG										
Kambah 1	Tuggeranong Vikings BMX Club	199	5	0.0	0.2	0.0	0.2	Low water demand can be addressed through other sources.		
Kambah 2	Kambah District Playing Fields (1)	115	12	8.5	54.0	8.5	54.0		✓	
Kambah 3	Kambah District Playing Fields (3)	353	10	7.4	47.0	8.1	51.4		✓	
	Taylor Primary School	353	1	0.7	4.4			Facility not suitable for sporting competition purposes.		
Kambah 4	Kambah District Playing Fields (2)	286	30	12.0	76.2	14.0	88.9		✓	
	Kambah Park Fitness Track	286	26	1.2	7.6			Not applicable to Sport and Recreation Services		
	Urambi Primary School	239	1	0.8	5.1			Facility not suitable for sporting competition purposes.		
Wanniassa 1	Wanniassa District Playing Fields	140	1	2.9	18.4	10.2	64.8		✓	
	Wanniassa North Playing Fields	202	5	3.8	24.1				✓	
	Wanniassa School Junior Campus	142	1	0.8	5.1			Facility not suitable for sporting competition purposes.		
	Wanniassa School Senior Campus	141	1	2.7	17.1			Facility not suitable for sporting competition purposes.		
Wanniassa 2	Wanniassa Hills Primary School	253	1	1.7	10.8	1.7	10.8	Facility not suitable for sporting competition purposes.		
Wanniassa 3	Erindale College	180	8	0.9	5.7	3.2	20.6	Priority 2 facility detailed in All Dried Up report.	✓	
	Mackillop Catholic College - Wanniassa	125	8	2.3	14.9			Priority 2 facility detailed in All Dried Up report.	✓	
Wanniassa 4	Trinity Christian School	117	5						·	
Monash	Monash Neighborhood Oval	171	1	1.4	8.6	1.9	11.7	Facility managed by Department of Education and Training. No guarantee that the facility would continue to be irrigated under School Based		

Designation (Cluster Name)	Individual End uses	Section	Block	Estimated Demand (ha)	Estimated Demand, 2030 Climate (ML/y)	Combined Demand for Cluster (ha)	Combined Demand for Cluster (ML/y)	Sport and Recreation Services (SRS) Comments	Sport and Recreation Services (SRS) Priority Facilities	Additional Comments
								Management.		
	Monash Primary School	171	1	0.5	3.2			Facility not suitable for sporting competition purposes.		
Fadden	Fadden Neighborhood Oval/Primary School	335	1	2.3	14.6	2.3	14.6	Facility managed by Department of Education and Training. No guarantee that the facility would continue to be irrigated under School Based Management.		
Gowrie	Gowrie District Playing Fields	228	12	5.5	34.9	8.1	51.4		✓	
	Gowrie Primary School	229	3	1.1	7.0			Facility not suitable for sporting competition purposes.		
	Holy Family Primary School	226	15	1.5	9.5			Facility not suitable for sporting competition purposes.		
Fadden/Chisholm	Chisholm District Playing Fields	575	15	6.0	38.1	8.1	51.4		✓	
	Fadden Pines District Park	353	11	2.1	13.3			Not applicable to Sport and Recreation Services		
Chisholm	Caroline Chisholm High School	567	2	0.9	5.7	2.8	17.5	Facility not suitable for sporting competition purposes.		
	Chisholm Neighborhood Oval	549	1	1.3	7.9				✓	
	Chisholm Primary School	550	1	0.6	3.8			Facility not suitable for sporting competition purposes.		
Gilmore	Gilmore Neighborhood Oval	58	6	1.6	9.8	1.9	11.7		✓	
	Gilmore Primary School	58	7	0.3	1.9			Facility not suitable for sporting competition purposes.		
Greenway 1	Tuggeranong Valley Lawn Bowls	46	5	0.5	3.0	0.5	3.0		✓	
Greenway 2	Tuggeranong Dog Training Club	46	9	0.3	2.1	2.4	15.4		✓	
	Tuggeranong Enclosed Oval (Greenway Oval)	46	12	2.1	13.3			Sand based field, water demand requirements may need to be adjusted.	✓	
Isabella Plains	Isabella Plains Neighborhood Oval	856	40	2.8	17.7	5.8	36.6		✓	
	Isabella Plains Primary School	856	41	0.8	5.1			Facility not suitable for sporting competition purposes.		
	Mackillop Catholic College - Isabella Plains	877	16	2.2	13.9			Facility not suitable for sporting competition purposes.		
Bonython	Bonython Neighborhood Oval	21	3	2.1	13.3	2.6	16.5		✓	
	Bonython Primary School	21	4	0.5	3.2			Facility not suitable for sporting		

Designation (Cluster Name)	Individual End uses	Section	Block	Estimated Demand (ha)	Estimated Demand, 2030 Climate (ML/y)	Combined Demand for Cluster (ha)	Combined Demand for Cluster (ML/y)	Sport and Recreation Services (SRS) Comments	Sport and Recreation Services (SRS) Priority Facilities	Additional Comments
								competition purposes.		
Richardson	Richardson Oval	494	1	1.3	8.3	1.4	8.9		✓	
	Richardson Primary School	452	2	0.1	0.6			Facility not suitable for sporting competition purposes.		
Calwell 1	Calwell Oval	701	2	2.0	12.7	3.2	20.3		✓	
	Covenant College	476	1	1.2	7.6			Facility not suitable for sporting competition purposes.		
Calwell 2	Calwell Primary School	751	21	1.6	10.2	1.7	10.8	Facility not suitable for sporting competition purposes.		
	Were St Parkland	787	28	0.1	0.6			Not applicable to Sport and Recreation Services		
Calwell 3	Calwell District Playing Fields	798	17	11.0	69.9	12.4	78.7		✓	
	Calwell High School	795	11	0.7	4.4			Facility not suitable for sporting competition purposes.		
	St Francis of Assisi Primary School	796	16	0.7	4.4			Facility not suitable for sporting competition purposes.		
Theodore	Theodore Oval	666	1	1.3	8.3	2.9	18.4		✓	
	Theodore Primary School	668	3	1.6	10.2			Facility not suitable for sporting competition purposes.		
Gordon	Gordon Primary School	410	15	1.0	6.4	3.4	21.6	Facility not suitable for sporting competition purposes.		
	Point Hut Pond District Park	563	2	2.4	15.2			Not applicable to Sport and Recreation Services		
Conder	Charles Conder Primary School	286	2	0.8	5.1	10.1	64.0	Facility not suitable for sporting competition purposes.		
	Conder Neighborhood Oval	286	3	2.1	13.3			Facility not suitable for sporting competition purposes.		
	Lanyon High School	212	10	0.6	3.8			Facility not suitable for sporting competition purposes.		
	St Clare of Assisi Primary School	212	12	0.1	0.5			Facility not suitable for sporting competition purposes.		
	Gordon District Playing Fields	410/211	18/13	6.5	41.3			Block Number was incorrect – changed from 14 to 18. Sport and Recreation Services is already looking at irrigating these grounds through a connection that already exists at Point Hut Pond.	✓	Entitlement for surface water, used to pump from Point Hut until infrastructure failed
Banks	Banks Oval	12	20	2.8	17.8	2.8	17.8		✓	
TOTAL				**119.9**	**761.1**	**119.9**	**761.1**			
JERRABOMBERRA										
Symonston	Canberra Greyhound Racing Club	107	2	10.0	63.7	10.0	63.7		✓	Already licensed to take 6 ML groundwater. Demand shown here (63 ML) is estimated

Designation (Cluster Name)	Individual End uses	Section	Block	Estimated Demand (ha)	Estimated Demand, 2030 Climate (ML/y)	Combined Demand for Cluster (ha)	Combined Demand for Cluster (ML/y)	Sport and Recreation Services (SRS) Comments	Sport and Recreation Services (SRS) Priority Facilities	Additional Comments
										demand not currently met by non potable water.
TOTAL				**10.0**	**63.7**	**10.0**	**63.7**			
SOUTH CANBERRA										
Narrabundah 1	Narrabundah Neighborhood Oval	124	7	1.5	9.5	1.9	12.1		✓	
	Narrabundah Primary School	124	6	0.4	2.5			Facility not suitable for sporting competition purposes.	■	
Narrabundah 2	Mill Creek Oval	34	38	2.2	14.0	2.2	14.0		✓	
Narrabundah 3	Jerrabomberra Sports Ground	64	4	3.6	22.5	6.0	38.4		✓	
	Narrabundah College	87	1	1.8	11.4			Facility not suitable for sporting competition purposes.	■	
	St Benedicts Primary School	88	21	0.7	4.4			Facility not suitable for sporting competition purposes.	■	
Narrabundah 4	Boomanulla Oval	34	22	2.0	12.7	14.6	92.9		✓	
	Errol Kavanagh Memorial Oval	34	26	5.5	34.9				✓	
	Narrabundah Ball Park	34	32	1.0	6.4			Sand based field, water demand requirements may need to be adjusted.	✓	
	Narrabundah Pitch n Putt	34	34	6.1	39.0				✓	Already licensed to take 15 ML surface water. Demand shown here (39 ML) is estimated demand not currently met by non potable water.
Red Hill	Red Hill Primary School	27	11	0.4	2.5	0.6	3.9	Facility not suitable for sporting competition purposes.	■	
	Red Hill Tennis Club	27	20	0.2	1.3			Low water demand can be addressed through other sources.	■	
Red Hill/Griffith	Canberra Grammar	6	1	4.3	27.5	6.1	38.9		✓	Already licensed to take 4 ML ground water. Demand shown here (27 ML) is estimated demand not currently met by non potable water.
	Flinders Park (Flinders Oval)	88	29	1.8	11.4				✓	
Griffith 1	Kingston Oval	22	9	1.2	7.7	3.1	19.8		✓	Already licensed to take 5 ML ground water. Demand shown here (7.7 ML) is estimated demand not currently met by non potable water.

Designation (Cluster Name)	Individual End uses	Section	Block	Estimated Demand (ha)	Estimated Demand, 2030 Climate (ML/y)	Combined Demand for Cluster (ha)	Combined Demand for Cluster (ML/y)	Sport and Recreation Services (SRS) Comments	Sport and Recreation Services (SRS) Priority Facilities	Additional Comments
	St Clares College	29	1	1.9	12.1				✓	
Griffith 2	Canberra South Bowling Club	42	15	0.4	2.5	2.4	15.2	Canberra South Bowling Club ceased operations earlier this year.	■	
	Flinders Tennis Club	42	10	0.5	3.2			Low water demand can be addressed through other sources.	■	
	Griffith Oval	42	17	0.8	5.1				✓	
	Griffith Oval No. 2	42	17	0.7	4.4				✓	
Barton/Griffith	Manuka Oval	15	15	2.0	12.7	4.7	29.8		✓	
	Telopea Park Primary School	29	1	2.7	17.1			Facility not suitable for sporting competition purposes.	■	
Forrest	Canberra Bowling Club	12	3	0.3	2.0	0.9	5.8		✓	
	Forrest Primary School	13	1	0.6	3.8			Facility not suitable for sporting competition purposes.	■	
Capital Hill	Parliament House	1	2	32.0	203.2	32.0	203.2	Not applicable to Sport and Recreation Services	■	
Parkes	Parliamentary Triangle	58	1	120.0	762.0	120.0	762.0	Not applicable to Sport and Recreation Services	■	
Deakin 1	Canberra Girls Grammar Junior Campus	49	15	0.5	3.2	2.5	15.9	Facility not suitable for sporting competition purposes.	■	
	Deakin Enclosed Oval	36	16	2.0	12.7			Ground has recently been totally refurbished by the Canberra Deakin Soccer Club.	✓	
Deakin 2	Canberra Girls Grammar Senior Campus	9	Jan-19	0.6	3.5	0.7	4.1	Priority 2 facility detailed in All Dried Up report.	✓	
	Latrobe Park	45	14	0.1	0.6			Not applicable to Sport and Recreation Services	■	
Deakin 3	Deakin West District Playing Fields	68	13/23	10.8	68.6	14.0	88.9		✓	
	Mint Oval	65	4	3.2	20.3				✓	
Deakin 4	Alfred Deakin High School	35	76	1.5	9.5	2.3	14.6	Facility not suitable for sporting competition purposes.	■	
	The Woden School	35	21	0.5	3.2			Facility not suitable for sporting competition purposes.	■	
	West Deakin Hellenic Bowling Club	35	28	0.3	1.9				✓	
Yarralumla 1	Canberra Croquet Club	40	7	0.3	1.9	6.0	38.1		✓	
	Flynn Place	-	-	0.5	3.2			Not applicable to Sport and Recreation Services	■	
	Lennox Gardens	42	10	5.2	33.0			Not applicable to Sport and Recreation Services	■	
Yarralumla 2	Canberra Southern Cross Club - Yacht Club	42	10	0.2	1.4	0.2	1.4	Facility not suitable for sporting competition purposes.	■	
Yarralumla 3	Yarralumla Neighborhood Oval	82	13	2.5	15.9	2.8	18.0		✓	

Designation (Cluster Name)	Individual End uses	Section	Block	Estimated Demand (ha)	Estimated Demand, 2030 Climate (ML/y)	Combined Demand for Cluster (ha)	Combined Demand for Cluster (ML/y)	Sport and Recreation Services (SRS) Comments	Sport and Recreation Services (SRS) Priority Facilities	Additional Comments
	Yarralumla Primary School	82	12	0.1	0.6			Facility not suitable for sporting competition purposes.		
	Yarralumla Tennis Club	53	1	0.2	1.5			Low water demand can be addressed through other sources.		
Yarralumla 4	Forestry Oval	4	4	1.5	9.5	1.5	9.5		✓	
TOTAL				**224.7**	**1426.6**	**224.7**	**1426.6**			
WODEN VALLEY										
Curtin 1	North Curtin District Playing Fields	106	13	6.6	41.7	6.6	41.7		✓	
Curtin 2	Curtin Primary School	60	1	0.7	4.4	2.5	15.6	Facility not suitable for sporting competition purposes.		
	South Curtin Neighborhood Oval	60	4	1.8	11.2				✓	
Hughes	Clarrie Hermes Park	28	7	3.6	22.9	4.2	26.7		✓	
	Hughes Primary School	35	34	0.6	3.8			Facility not suitable for sporting competition purposes.		
Garran	Malkara School	8	45	0.8	5.1	1.5	9.4	Facility not suitable for sporting competition purposes.		
	Sts Peter & Paul Primary School	8	40	0.7	4.3			Facility not suitable for sporting competition purposes.		
Phillip 1	Canberra College Woden Campus	79	7	1.0	6.4	7.5	47.9	Facility not suitable for sporting competition purposes.		
	Canberra Southern Cross Club - Bowling Greens	24	4	1.4	8.6			The Southern Cross Bowls Club lease expires in 20010 and the site has been sold off to a developer. The developer has given no indication that it will maintain a bowls facility in the precinct.		
	Phillip Oval Football Park	23	9	2.5	15.9				✓	
	Pitch & Putt Golf Course	79	4	2.7	17.1				✓	Already licensed to take 4.5 ML ground water. Demand shown here (17 ML) is estimated demand not currently met by non potable water.
Lyons	Lyons Neighborhood Oval	55	9	2.7	17.1	3.5	22.2		✓	
	Lyons Primary School	41	5	0.8	5.1			Facility not suitable for sporting competition purposes.		
Phillip 2	Arabanoo Park	80	36	1.1	7.0	8.5	53.9	Not applicable to Sport and Recreation Services		
	Eddison Park	131	7	1.4	8.8			Not applicable to Sport and Recreation Services		Already licensed to take 2 ML surface water. Demand

Designation (Cluster Name)	Individual End uses	Section	Block	Estimated Demand (ha)	Estimated Demand, 2030 Climate (ML/y)	Combined Demand for Cluster (ha)	Combined Demand for Cluster (ML/y)	Sport and Recreation Services (SRS) Comments	Sport and Recreation Services (SRS) Priority Facilities	Additional Comments
										shown here (9 ML) is estimated demand not currently met by non potable water.
	Woden Athletic Field	131	5	1.8	11.4				✓	
	Woden Cemetery	109	1	4.0	25.4			Not applicable to Sport and Recreation Services		
	Woden Town Park	80	24	0.2	1.3			Not applicable to Sport and Recreation Services		
Phillip/Garran	Garran Neighborhood Oval	33	9	2.4	15.0	7.3	46.4		✓	
	Garran Primary School	33	1	0.7	4.4			Facility not suitable for sporting competition purposes.		
	Phillip Enclosed Oval	1	13	2.6	16.5				✓	
	Phillip Playing Fields	1	6	1.7	10.5				✓	
Mawson	Canberra Christian School	17	2	0.4	2.2	4.6	28.9	Facility not suitable for sporting competition purposes.		
	Mawson Neighborhood Oval	17	5	3.0	19.1				✓	
	Mawson Primary School	17	5	1.2	7.6			Facility not suitable for sporting competition purposes.		
Pearce 1	Marist College	49	16	6.0	38.1	10.6	67.3		✓	
	Melrose High	49	1	2.0	12.7			Facility not suitable for sporting competition purposes.		
	Pearce Neighborhood Oval	27	16	2.6	16.5				✓	
Pearce 2	Sacred Heart Primary School	43	2	0.4	2.4	0.4	2.4	Facility not suitable for sporting competition purposes.		
Torrens/Mawson	Mawson District Playing Fields	47	25	10.5	66.7	14.4	91.4		✓	
	Torrens Neighborhood Oval	20	15	2.5	15.9				✓	
	Torrens Primary School	22	13	1.4	8.9			Facility not suitable for sporting competition purposes.		
Farrer	Farrer Neighborhood Oval	25	3	2.9	18.2	3.8	23.9		✓	
	Farrer Primary School	33	2	0.9	5.7			Facility not suitable for sporting competition purposes.		
TOTAL				**75.2**	**477.7**	**75.2**	**477.7**			
WESTON CREEK										
Chapman	Chapman Neighborhood Oval	13	1	2.9	18.2	4.7	29.6		✓	
	Chapman Primary School	12	4	1.8	11.4			Facility not suitable for sporting competition purposes.		

Designation (Cluster Name)	Individual End uses	Section	Block	Estimated Demand (ha)	Estimated Demand, 2030 Climate (ML/y)	Combined Demand for Cluster (ha)	Combined Demand for Cluster (ML/y)	Sport and Recreation Services (SRS) Comments	Sport and Recreation Services (SRS) Priority Facilities	Additional Comments
Waramanga	Arawang Primary School	39	1	1.4	8.9	9.3	59.0	Facility not suitable for sporting competition purposes.		
	St John Vianneys Primary School	44	4	0.3	1.9			Facility not suitable for sporting competition purposes.		
	Stromlo High School	45	1	1.8	11.4			Facility not suitable for sporting competition purposes.		
	Waramanga District Playing Fields	46	7	5.8	36.8				✓	
Stirling	Canberra College Weston Campus	24	2	0.4	2.6	10.3	65.3	Facility not suitable for sporting competition purposes.		
	Stirling District Playing Fields	24	91	9.6	61.0			Changed Block Number from 88 to 91. Block 88 does not exist on ACTMAPI.	✓	
	Weston Creek Bowling Club	24	5	0.3	1.8				✓	
Rivett	Rivett Neighborhood Oval	27	4	3.3	21.0	3.3	21.0		✓	
Holder	Holder Neighbourhood Oval	23	1	2.5	15.9	2.5	15.9		✓	
Duffy	Duffy Neighborhood Oval	54	1	2.5	15.9	3.7	23.5		✓	
	Duffy Primary School	23	2	1.2	7.6			Facility not suitable for sporting competition purposes.		
Holder/Weston	Weston Oval	22	3	2.0	12.7	2.0	12.7		✓	
Weston	Canberra Institute of Technology & Horticultural School Weston Campus	96	6	1.8	11.1	1.8	11.1	Not applicable to Sport and Recreation Services		Already licensed to take 6 ML ground water. Demand shown here (11 ML) is estimated demand not currently not met by non potable water.
*North Weston	Australian Defence College	0	1212	1.0	6.4	5.4	34.3	Not applicable to Sport and Recreation Services		
	*Weston Pond Surrounds	0	1204	4.4	27.9			Not applicable to Sport and Recreation Services		
*Molonglo	*Molonglo 1 Neighborhood Oval	0	1171	2.3	14.6	2.3	14.6	Not applicable to Sport and Recreation Services		
National Zoo	National Zoo and Aquarium	0	1496	23.6	150.0	23.6	150.0	Not applicable to Sport and Recreation Services		Already licensed to take 80 ML groundwater. Demand shown here (150 ML) is estimated demand currently not met by non potable water.
Arboretum	Canberra International Arboretum and Gardens	0	1544	180.0	1143.0	180.0	1143.0	Not applicable to Sport and Recreation Services		Already licensed to take 10 ML groundwater. Demand shown here is estimated demand currently not met by non potable

Designation (Cluster Name)	Individual End uses	Section	Block	Estimated Demand (ha)	Estimated Demand, 2030 Climate (ML/y)	Combined Demand for Cluster (ha)	Combined Demand for Cluster (ML/y)	Sport and Recreation Services (SRS) Comments	Sport and Recreation Services (SRS) Priority Facilities	Additional Comments
									[redacted]	water.
TOTAL				**248.8**	**1580.0**	**248.8**	**1580.0**			
GRAND TOTAL				**996**	**6326**	**996**	**6326**			

Table 100: End uses already met by non-potable Water Sources

										Non Potable Water Source			
Individual End uses	**Section**	**Block**	**CSIRO Estimated Demand (ha)**	**CSIRO Estimated Demand, 2030 Climate (ML/y)**	**Current Non potable supply (ML/y)**	**Remaining Estimated Unmet Demand (ML/y)**	**Sport and Recreation Services (SRS) Comments**	**Sport and Recreation Services (SRS) Priority Facilities**	**Water Resources Comments (licences to take water)**	**Surface Water ML/y**	**Ground Water ML/y**	**Recycled Water ML/y**	**Not applicable (ML/y)**
BELCONNEN													
Magpies Belconnen Golf Club	99	11 12	52.2	331.5	331.5	0.0	The Belconnen Golf Club irrigation demands are met through access to water from the Lower Molonglo Water Quality Control Centre (LMWQCC).	**Not Applicable**	The Belconnen Golf Club holds a License to take (ground) Water 6ML		6.0	325.5	
Margaret Timpson Park	54	42	1.4	8.9	9.0	0.0	Not applicable to Sport and Recreation Services	[redacted]	PCL License to take water 9ML	9.0			
John Knight Memorial Park	65	33	3.5	22.2	35.0	0.0	Not applicable to Sport and Recreation Services	[redacted]	PCL license to take water from Lake Ginninderra 35ML	35.0			
Diddams Close Park	87 156 159 167	7 12 1 4	1.6	10.2	35.0	0.0	Not applicable to Sport and Recreation Services	[redacted]	PCL Nengi Bamir Beach License to take water 20ML	35.0			
Radford College	4	9	4.2	26.7	10.0	16.7		✓	license to take surface water 10ML	10.0			
Calvary Retirement Community	4	20	0.2	1.0	1.0	0.0				1.0			
TOTAL			**63.1**	**400.4**	**421.5**	**16.7**		▪		**90.0**	**6.0**	**325.5**	**0.0**
GUNGAHLIN													
Gold Creek Country Club	85 86 88 89	2 14 11 21-22	45.0	285.8	149.0	136.8	Club does have some capacity to capture stormwater in a number of dams.	✓	License to take surface and groundwater 126ML now 149total,35ground	114.0	35.0		
Gungahlin Lakes Golf Club	177 84	1 2 1	45.0	285.8	309.0	0.0	Large dam capacity and harvests stormwater from local area. Club also has a bore license.	✓	License to take surface 309ML and sub limit groundwater 80ML	229.0	80.0		
Yerrabi Pond District Park	181	1	11.5	73.0	35.0	38.0		▪		35.0			
Burgmann Anglican School	20	1 2	2.5	15.6	0.0	15.6		✓	captures water in dam may be unlicensed irrigation	No info yet			
Land Development Agency	31 32	1 1	n/a	0.0	16.0	0.0		▪		16.0			
Land Development Agency	66 69 70	1 1 1	n/a	0.0	5.0	0.0		▪		5.0			
Land Development Agency	2 30 57 58 73	18 1 3 1 1	n/a	0.0	95.0	0.0		▪		95.0			
Forde	5	1	n/a	37.0	37.0	0.0		▪		37.0			

										Non Potable Water Source			
Individual End uses	**Section**	**Block**	**CSIRO Estimated Demand (ha)**	**CSIRO Estimated Demand, 2030 Climate (ML/y)**	**Current Non potable supply (ML/y)**	**Remaining Estimated Unmet Demand (ML/y)**	**Sport and Recreation Services (SRS) Comments**	**Sport and Recreation Services (SRS) Priority Facilities**	**Water Resources Comments (licences to take water)**	**Surface Water ML/y**	**Ground Water ML/y**	**Recycled Water ML/y**	**Not applicable (ML/y)**
Developments													
Gungahlin Cemetery	39	5	15.0	95.3	13.0	82.3	Not applicable to Sport and Recreation Services.	[redacted]	license to take surface and groundwater 13ML	13.0			
Capital Linen Service	16	1	36.5	231.8	0.0	231.8	Not applicable to Sport and Recreation Services.	[redacted]					231.8
ACT no-waste		654	n/a	0.0	5.0	0.0				5.0			
TOTAL			**155.5**	**1024.1**	**664.0**	**504.4**		▪		**549.0**	**115.0**	**0.0**	**231.8**
NORTH CANBERRA													
Thoroughbred Park - Canberra Racing Club	69	9	6.4	40.6	49.0	0.0		✓	License to take (surface) water 49ML	49.0			
Yowani Country Club	67	2 4	50.0	317.5	280.0	37.5	Irrigation requirements include the golf course and 2 lawn bowling greens. Use dams to harvest stormwater. Has license to use Sullivans Creek stormwater.	✓	License to take surface 280ML and groundwater 35ML sublimit	245.0	35.0		
Southwell Park Sportsgrounds	59	38	9.0	57.2	57.2	0.0	Irrigation demands are already met by Southwell Park Watermining Project.	**Not Applicable**				57.2	
Northbourne Avenue	26	4	0.5	3.2	3.2	0.0	Not applicable to Sport and Recreation Services	[redacted]	ANU Fenner Hall braddon 1.5ML Groundwater		1.5	1.7	
Majura Enclosed Oval	38	5	1.6	10.2	10.2	0.0	Irrigation demands are met by North Canberra Water Reuse Scheme (NCWRS).	**Not Applicable**				10.2	
Majura Oval	38	2	2.5	15.9	15.9	0.0	Irrigation demands are met by North Canberra Water Reuse Scheme (NCWRS).	**Not Applicable**				15.9	
O'Connor Enclosed Oval	39	4	1.7	10.8	10.8	0.0	Irrigation demands are met by North Canberra Water Reuse Scheme (NCWRS).	**Not Applicable**				10.8	
O'Connor District Playing Fields	39	4	4.3	27.3	27.3	0.0	Irrigation demands are met by North Canberra Water Reuse Scheme (NCWRS).	**Not Applicable**				27.3	
Merici College	11	1	1.0	6.2	2.0	4.2		✓	License to take (ground) water 2ML		2.0		
Northbourne Oval	30	6	1.6	10.2	10.2	0.0	Irrigation demands are met by North Canberra Water Reuse Scheme (NCWRS).	**Not Applicable**				10.2	
ANU North Oval	25	1	2.0	12.7	12.7	0.0	Irrigation demands are met by North Canberra Water Reuse Scheme (NCWRS).	**Not Applicable**				12.7	
ANU Willows Oval	63	1	0.1	0.8	0.8	0.0	Irrigation demands are met by North Canberra Water Reuse Scheme (NCWRS).	**Not Applicable**				0.8	
Australian National Botanic Gardens	0	861	40.0	254.0	254.0	0.0	Not applicable to Sport and Recreation Services	[redacted]	arranging water from lake burley griffin / NCA	254.0			
Australian Film Commission	21	1	0.2	1.0	1.0	0.0				1.0			

										Non Potable Water Source			
Individual End uses	**Section**	**Block**	**CSIRO Estimated Demand (ha)**	**CSIRO Estimated Demand, 2030 Climate (ML/y)**	**Current Non potable supply (ML/y)**	**Remaining Estimated Unmet Demand (ML/y)**	**Sport and Recreation Services (SRS) Comments**	**Sport and Recreation Services (SRS) Priority Facilities**	**Water Resources Comments (licences to take water)**	**Surface Water ML/y**	**Ground Water ML/y**	**Recycled Water ML/y**	**Not applicable (ML/y)**
Reid Oval	39	5	3.9	24.8	24.8	0.0	Irrigation demands are met by North Canberra Water Reuse Scheme (NCWRS).	**Not Applicable**				24.8	
Campbell Neighborhood Oval	29	4	1.0	6.4	6.4	0.0	Irrigation demands are met by North Canberra Water Reuse Scheme (NCWRS).	**Not Applicable**				6.4	
Campbell Primary School	29	3	2.9	18.4	18.4	0.0	Irrigation demands are met by North Canberra Water Reuse Scheme (NCWRS).	**Not Applicable**				18.4	
ADFA Ovals Nos. 1 & 2	64	1	4.7	29.8	29.8	0.0	Irrigation demands are met by North Canberra Water Reuse Scheme (NCWRS).	**Not Applicable**				29.8	
ADFA Ovals Nos. 3-6	0	550	14.8	94.0	94.0	0.0	Irrigation demands are met by North Canberra Water Reuse Scheme (NCWRS).	**Not Applicable**				94.0	
RMC Golf Club	120	3	23.7	150.5	150.5	0.0	Irrigation demands are met by North Canberra Water Reuse Scheme (NCWRS).	**Not Applicable**				150.5	
RMC Playing Fields	120	3	18.6	118.1	118.1	0.0	Irrigation demands are met by North Canberra Water Reuse Scheme (NCWRS).	**Not Applicable**				118.1	
TOTAL			**190.5**	**1209.4**	**1176.0**	**41.7**		▪		**549.0**	**38.5**	**588.5**	**0.0**
MAJURA													
RMC No. 1 Sports Oval	6	2	1.9	12.1	12.1	0.0	Irrigation demands are met by North Canberra Water Reuse Scheme (NCWRS).	**Not Applicable**				12.1	
TOTAL			**1.9**	**12.1**	**12.1**	**0.0**				**0.0**	**0.0**	**12.1**	**0.0**
TUGGERANONG													
Murrumbidgee Country Club	7	16	45.0	285.8	192.0	93.8	Club currently has capture stormwater in a number of dams. Club also has bore access but not currently in use due to low aquifer levels.	✓	License to take surface and ground water, now 192Total,25ground	167.0	25.0		
Vikings Park	126	16	3.6	22.9	38.0	0.0	The Tuggeranong Valley Rugby Union and Amateur Sports Club is currently seeking DA approval for the installation of a pocket sewer mine for Viking Park. Sand based field, water demand requirements may need to be adjusted.	✓	License to take (ground) water 38ML		38.0		
Tuggeranong Town Park	62 20	4 23	7.9	50.0	50.0	0.0	Not applicable to Sport and Recreation Services	[redacted]	license to take surface water lake Tuggeranong 50ML	50.0			
TOTAL			**56.5**	**358.6**	**280.0**	**93.8**				**217.0**	**63.0**	**0.0**	**0.0**
JERRABOMBERRA													

										Non Potable Water Source			
Individual End uses	**Section**	**Block**	**CSIRO Estimated Demand (ha)**	**CSIRO Estimated Demand, 2030 Climate (ML/y)**	**Current Non potable supply (ML/y)**	**Remaining Estimated Unmet Demand (ML/y)**	**Sport and Recreation Services (SRS) Comments**	**Sport and Recreation Services (SRS) Priority Facilities**	**Water Resources Comments (licences to take water)**	**Surface Water ML/y**	**Ground Water ML/y**	**Recycled Water ML/y**	**Not applicable (ML/y)**
Canberra Greyhound Racing Club	107	2	11.0	69.7	6.0	63.7		✓	License to take groundwater 6ML		6.0		
TOTAL			**11.0**	**69.7**	**6.0**	**63.7**				**0.0**	**6.0**	**0.0**	**0.0**
SOUTH CANBERRA													
Vikings Capital Golf Club	100	23	30.0	190.5	126.0	64.5	Sources water from two bores that provides adequate supply to the course dams. Sufficient supply if bore licenses are renewed and if aquifer levels remain viable.	✓	license to take surface 6ML and groundwater 120ML	6.0	120.0		
Narrabundah Pitch n Putt	34	34	8.5	54.0	15.0	39.0		✓	license to take surface water 15ML	15.0			
Canberra Grammar	6	1	5.0	31.5	4.0	27.5		✓	License to take (ground) water 4ML		4.0		
Federal Golf Club	56	1	11.5	73.0	149.0	0.0	Heavily reliant on potable water. Bore yields have diminished and no dam storage available.	✓	License to take (ground) water 149ML		149.0		
Kingston Oval	22	9	2.0	12.7	5.0	7.7		✓	Eastlake football club license to take groundwater 5ML		5.0		
Telopea Park & Bowen Park	30 31	1 4	10.9	69.2	75.0	0.0	Not applicable to Sport and Recreation Services	■	PCL Bowen and Telopea park 75ML	75.0			
Weston Park	124	5	4.4	27.9	27.9	0.0	Not applicable to Sport and Recreation Services	■		27.9			
Yarralumla Nursery	123	2	10.2	64.8	83.0	0.0	Not applicable to Sport and Recreation Services	■	License to take surface water 83ML	83.0			
Royal Canberra Golf Club	119 121	2 1	45.0	285.8	285.8	0.0	Draws water from Lake Burley Griffin under an agreement with the Federal Government.	**Not Applicable**		285.8			
Government House	122	1	20.0	127.0	127.0	0.0	Not applicable to Sport and Recreation Services	■		127.0			
Majura Management Pty Ltd		59	n/a	n/a	24.0	0.0		■		24.0			
TOTAL			**147.5**	**936.4**	**921.7**	**138.7**				**643.7**	**278.0**	**0.0**	**0.0**
WODEN VALLEY													
Equestrian Park		677	n/a	2.0	2.0	0.0		▪		2.0			
Pitch & Putt Golf Course	79	4	3.4	21.6	4.5	17.1		✓	license to take groundwater 4.5ML		4.5		
Eddison Park	131	7	1.7	10.8	2.0	8.8	Not applicable to Sport and Recreation Services	■	Entitlement to surface water 2ML	2.0			
TOTAL			**5.1**	**34.4**	**8.5**	**25.9**				**4.0**	**4.5**	**0.0**	**0.0**
WESTON CREEK													
Canberra Institute of Technology &	96	6	2.7	17.1	6.0	11.1	Not applicable to Sport and Recreation Services	■	license to take groundwater 6ML		6.0		

										Non Potable Water Source			
Individual End uses	**Section**	**Block**	**CSIRO Estimated Demand (ha)**	**CSIRO Estimated Demand, 2030 Climate (ML/y)**	**Current Non potable supply (ML/y)**	**Remaining Estimated Unmet Demand (ML/y)**	**Sport and Recreation Services (SRS) Comments**	**Sport and Recreation Services (SRS) Priority Facilities**	**Water Resources Comments (licences to take water)**	**Surface Water ML/y**	**Ground Water ML/y**	**Recycled Water ML/y**	**Not applicable (ML/y)**
Horticultural School Weston Campus								[redacted]					
National Zoo and Aquarium	0	1496	23.6	150.0	80.0	70.0	Not applicable to Sport and Recreation Services	[redacted]	License to take (ground) water 80ML		80.0		
Canberra International Arboretum and Gardens	0	1544	180.0	1143.0	10.0	1133.0	Not applicable to Sport and Recreation Services	[redacted]	License to take (ground) water 10ML		10.0		
TOTAL			**206.3**	**1310.1**	**96.0**	**1214.1**		[redacted]		**0.0**	**96.0**	**0.0**	**0.0**
								[redacted]					
GRAND TOTAL			**837**	**5355**	**3586**	**2099**				**2053**	**607**	**926**	**232**

APPENDIX W MASTER PLAN B MAP

See next page for a map of the master plan supply–demand options.

The legend shown in Appendix B identifies the clusters shown on the map.

APPENDIX X MASTER PLAN C MAP

See next page for a map of the master plan supply–demand options.

The legend shown in Appendix B identifies the clusters shown on the map.

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