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Assessing Integrated Water Management Options for Urban Developments - Canberra Case Study

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Abstract:
Urban water services in the Australian Capital Territory (ACT) are currently provided through conventional centralised systems, involving large scale water distribution, wastewater collection, water and wastewater treatment. A study was conducted to assist Environment ACT in setting broad policies for future water services in Canberra. This paper presents the outcomes of a study examining the effects of various water servicing options on water resources and the environment, for two townships in Canberra, one existing and one greenfield site. Three modelling tools were used to predict the effects of various alternative water servicing scenarios, including demand management options, rainwater tanks, greywater use, on-site detention tanks, gross pollutant traps, swales and ponds. The results show that potable water reductions are best achieved by demand management tools or a combination of greywater and rainwater use for existing suburbs, while 3rd pipe systems are preferred for greenfield sites. For this specific climatic region and end use demands, modelling predicted increased water savings from raintanks compared to greywater systems alone, with raintanks providing the additional benefit of reduced peak stormwater flows at the allotment scale. Rainwater and stormwater reuse from stormwater ponds within the catchments was found to provide the highest reduction in nutrient discharge from the case study areas. Environment ACT amended planning controls to facilitate installation of raintanks and greywater systems, and commenced a Government funded rebate scheme for raintanks as a result of this study.

Keywords Integrated urban water management, Water sensitive urban design, Raintanks, Water, Wastewater, Stormwater, Water balance modelling

Introduction

Integrated urban water management (IUWM) is based on a multi-dimensional approach to water management, where water resources are optimally utilised based on the fit-for-use concept. The aim of IUWM is to include all aspects of the water cycle, wastewater, stormwater, drinking water and evaporation to optimise operation and management solutions. Water sensitive urban design (WSUD) is an aspect of IUWM, which focuses on the planning and configuration of developments to minimise impacts and move towards more sustainable systems. The protection of natural ecosystems, integration of water resources for provision of water services and reduction of peak stormwater flows are some of the objectives of WSUD and planning. A number of structural and non-structural tools can be used to achieve IUWM and WSUD objectives, the selection of which will be dependent on a large number of factors including; the type of development, catchment conditions, climate, customer acceptance and allocation of financial resources. Some examples of structural tools are rainwater tanks, greywater treatment and reuse, wastewater reuse, stormwater use, on-site detention tanks, buffers, swales, bioretention devices and ponds.

Both IUWM and WSUD encompass concepts of sustainability as they incorporate economic, social and environmental dimensions. In terms of the water cycle, the fundamental objectives of IUWM are based on both water quantity and quality and can be simplified as reducing contaminant discharge to the environment and maintaining environmental flows. These objectives are combined with economic, social and other environmental objectives to provide more sustainable options for water servicing. Moreover, the basic IUWM process consists of number of tasks for its implementation.

This current work does not encompass all aspects of the IUWM process but focuses on the water balance analysis, stormwater quality management and allotment scale stormwater peak flow management with an aim to efficient use of water resources and to maintain development conditions as far as possible close to predevelopment stage.

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Numerous studies have been conducted around the globe on the assessment of alternative water servicing options for infill and greenfield developments, but few of these studies have outcomes available in published literature. Dixon et al. (1999) indicated that the society must move toward the goal of efficient and appropriate water use for a sustainable urban future and described that the reuse of domestic greywater and rainwater was a step in this direction. Similarly, Manios and Tsanis (2006) also highlighted the importance of wastewater reuse in water resources management. Hardy et al. (2005) highlighted that the process of urbanisation and development can significantly change the input and output flows and quality from an area and can create a highly inefficient system in terms of water resources. The inputs and outputs can be minimised through the efficient use of water resources.

Mitchell et al. (2001) highlighted the use of stormwater and wastewater as a potential substitute for a portion of the fresh water from reticulated supply system and also presented a water balance model (Aquacycle) representing water flows through the urban water supply, wastewater and stormwater systems. Grimmond et al. (1986) presented a model to calculate the water balance components for an urbanised catchment. They divided the total area in three discrete surface types, namely (1) impervious area (roads, parking lots, buildings), (2) pervious unirrigated (lawns, other greenspace and open land not artificially watered) and (3) pervious irrigated (lawns parks and other areas watered). The Aquacycle model used in this study is also based on the similar concept.

Parkinson et al. (2005) examined the impact of retrofitting source control technologies e. g. rainwater and grey water usage and reduced flush toilets. They indicated that the introduction of these technologies could have implications on the performance of downstream infrastructures and treatment processes. However, these technologies would reduce domestic water demand and peak load on water supply distribution systems. Rueedi et al. (2005) also studied the impact of greywater reuse and rainwater diversion from roof runoff for irrigation along with other retrofitting scenarios for a suburb with a population of 15,000. It was reported that the household water use decreased by about 12% due to grey water usage for toilet flushing and rain water usage for irrigation decreased stormwater flows up to 16% and mains supply by 6%. Similarly Villarreal et al. (2005) analysed retrofitting rainwater collection systems in existing developments by modelling rainwater for toilet flushing, laundry, garden irrigation and car washing. Low water consumption appliances were also considered in evaluating water saving efficiency and water conservation. It was concluded that the use of rainwater contributed to important savings in drinking water.

The aim of this paper is to present a methodology for the assessment of alternative water servicing options and stormwater quality and quantity management for both greenfield and existing developments and to provide commentary on the appropriateness of the assessment tools used. More importantly, the study assisted Environment ACT to develop policies and directions for future water services in Canberra. Several modelling approaches were applied in this study to examine the impact of various water servicing options against set objectives. The township of Woden was the case study for an existing suburb and Gungaderra as a case study for a greenfield site.

Analysis methodology and modelling approach

The methodology adopted for the water resources quantity and quality modelling and assessment of servicing options is depicted in Figure 1. This includes the identification and formulation of study objectives, selection of various options for achieving objectives, development of water servicing scenarios combining various options, data collection for study area characteristics including climate & water consumption for various end users, analysis of scenarios for water, wastewater and stormwater, stormwater quality & quantity including allotment scale stormwater peak flows, interpretation of analysis and finally recommendation of options to meet objectives. Here a scenario is defined as '*a set of options that fully describes the provision of water, wastewater and stormwater options in a given area*'.

Figure 1

To compare various integrated water servicing combinations, information on the variation in total water demand, wastewater & stormwater flows and contaminant loads between selected water servicing options is essential. Three computer models were used to estimate the water and contaminants flows for various composite alternative water serving scenarios as no single model was capable to model water, wastewater and stormwater quantity and quality. The total urban water balance was modelled using Aquacycle, stormwater flows, contaminants and treatment devices were modelled using MUSIC (Model for Urban Stormwater Improvement Conceptualisation) and peak stormwater flows from allotments were modelled using PURRS (Probabilistic Urban Rainwater and Wastewater Reuse Simulator). The brief description of these models has been described below:

AquaCycle incorporates potable water, wastewater and stormwater flows into a single framework, allowing the effect of the water sensitive design measures on the total water cycle to be assessed. AquaCycle uses a daily time step and so the local climate variability is included in the model. A variety of different water servicing options can be modelled at allotment, neighbourhood and catchment scale such as rainwater tanks, grey water irrigation, on-site wastewater treatment, cluster scale stormwater & wastewater storage for reuse, aquifer storage & recovery, catchment scale stormwater and wastewater storages (Mitchell, 2001).

The MUSIC (Model for Urban Stormwater Improvement Conceptualisation) model has been used to estimate stormwater quality and simulate stormwater quality improvement measures such as gross pollutant traps, wetlands, buffers, swales, bioretention systems, ponds and sedimentation basins. MUSIC can simulate the performance of a group of stormwater management measures configured in series or in parallel to form a treatment train. MUSIC uses a six minute time step and so can simulate the mean flows, annual flows and total daily loads/ concentrations of total suspended solids (TSS), total nitrogen (TN) and total phosphorous (TP) for specified treatment train scenarios (Wong et al., 2002).

The PURRS (Probabilistic Urban Rainwater and Wastewater Reuse Simulator) model was used for event based stormwater peak discharge calculations (Coombes 2003). The model uses pluvio data and the description of the site to calculate peak flows through an on-site detention (OSD) tank. As the model is not a design tool, the sizing of an OSD tank for a given frequency of storm event (eg. 1 in 5 year storm event) was carried out by a trial and error method.

Application of methodology

Development of study objective

Following discussions between CSIRO and Environment ACT the following objectives were developed to incorporate both population growth and environmental issues for the case study sites:

1. A 25% reduction in household potable water demand
2. Peak stormwater flows for individual catchments no greater than pre-development.
3. Phosphorus loads associated with stormwater flows at pre-development levels.
4. Suspended solids loads associated with stormwater flows at pre-development levels.
5. Nitrogen loads associated with stormwater flows at pre-development levels.
6. A 20% reduction in wastewater discharged per household

The first objective of a 25% reduction in potable household water demand was identified as the critical objective, with all others being of secondary importance.

Selection of options

Various alternative water-servicing options were assessed against these objectives using computer models to predict water flows and stormwater quality & quantity. The following alternative techniques (options) of integrated water service provisions were investigated:

- Water demand management
- Raintanks,
- Greywater irrigation of gardens,

- Both raintanks and greywater irrigation of gardens,
- A local wastewater treatment plant for the supply of non-potable water for toilet flushing and garden irrigation,
- Gross pollutant traps (GPTs) and ponds for stormwater treatment and irrigation of public open space (POS) with water from stormwater ponds, and
- OSD at allotment scale to lower peak stormwater flows.

Development of servicing scenarios

Existing development (Woden) scenarios

The scenarios for the existing development contained a limited number of alternative water system measures. Dual pipe systems were considered too expensive to install in existing suburbs as previous work has indicated that the economics of water reuse schemes favours application to new developments rather than the retrofit projects (Alegre et al., 2004). In this work the advantages and disadvantages of recycling, rainwater and conservation options were reviewed and suggested that while the recycling would provide continuous supply, systems could be expensive paticularly if dual reticulation was required. Sharma et al. (2005) conducted a study for a 3062 ha greenfield development and estimated the cost of a dual pipe system, proposed to supply recycled water for toilet and garden irrigation. The cost of the dual pipe system was 73% of the water supply system designed for the remaining supply. Considering the constraints, limitations and additional cost of reinstatement works including the cost associated with the management of constraints in retrofitting dual pipe systems in existing developments, it can be reasonably considered that such an option will be expensive.

The following on-site measures were considered in existing development:

- rainwater tanks for garden irrigation & toilet supply,
- irrigation of gardens using greywater from the laundry and bathroom,
- both rainwater tanks and greywater irrigation of gardens.

If both raintanks and greywater system were incorporated for garden irrigation on a single allotment, the raintanks were used as a back up supply for garden irrigation as well as providing water for toilet flushing. Stormwater in this catchment is currently discharged to a creek via stormwater drains and open channels. Three stormwater ponds were proposed for storage of water for the irrigation of 166 ha of public open space. These ponds would also operate as a device for stormwater treatment. Two ponds 3 ha x 1.5 m deep and a third pond 4 ha x 1.5 m deep were considered.

To conceptualise the improvement in the catchment stormwater runoff quality, a number of regional stormwater treatment measures such as gross pollutant traps and bioretention systems were also considered in order to achieve stormwater quality objectives. In addition to OSD tanks at allotment scale the following treatment trains were also considered:

- Gross Pollutant Traps (GPT) and ponds in 3 suburbs
- GPTs, Ponds and Bioretention systems
- Buffers only (grass strips)
- Buffers and swales
- Buffers and bioretention systems

Greenfield development (Gungaderra) scenarios

Planned water services for the greenfield development are typical for Australia, with a conventional reticulated water system and wastewater collection and treatment at a remote location. A series of 10 stormwater ponds, with a total surface area of 11.85 ha and capacity of 159 ML, are planned to reduce the peak stormwater flows. This description of planned water services is referred to as the base case, and is used as a reference point for comparison of alternate scenarios. In the greenfield development a greater range of alternative water measures were considered, compared to those for the existing development. Allotment scale measures considered were identical to those for the existing development with rainwater tanks, greywater irrigation of gardens, rainwater tanks and greywater irrigation of gardens on the same block and on-site detention tanks. A number of off-block measures were also considered, such as swales and a local wastewater treatment plant with reclaimed water returning to residential properties for garden irrigation and toilet flushing.

To conceptualise the improvement in the catchment stormwater runoff quality, the treatment trains considered in addition to the existing 10 stormwater ponds were:

- GPTs
- GPTs and swales

Data collection

Study area description

Existing development (Woden area)

The township of Woden was developed in the early 1960's and 1970's and is located in the South East region of Canberra. The total population at the time of the study was estimated at 32,611 people, living in 13,890 dwellings over an area of 2,990 ha with an average occupancy rate of 2.35 per dwelling. For modelling purposes the residential area was divided into 13 suburbs, with an overall average household block size of 1,013 m^2 (377 m^2 min to 5,228 m^2 max). The area is categorised in to the following land uses: 49% residential, 4% commercial, 37% public open spaces and 10% roads (Mitchell, 2003). One of the suburbs, O'Malley, area 257 ha is a diplomatic sector having large lots of 5228 m^2 with only 10% as built up area and remaining 90% as garden area. Urban water services are provided by conventional systems for water supply, wastewater collection & disposal and stormwater drainage. The stormwater from the township flows into Yarralumla Creek via lined open channels.

Greenfield development (Gungaderra area)

The township of Gungaderra is in the outer North West of Canberra, and is currently in the development phase. No building had commenced at the start of this study. The total area of Gungaderra is 630 ha, of which 465 ha will be developed for detached and medium density dwellings. The detached dwellings will have an area of 379 ha consisting 5,200 dwellings with lot size of 450 m^2 for 13,520 population. Similarly medium density development in 77ha area will have 1,300 dwellings with a lot size of 300 m^2 for 3,380 populations. The population estimation is based on the occupancy rate of 2.6 persons per dwelling. This township also has an area of 9 ha allocated for commercial development. The remainder of the site will provide roads, commercial premises, open space and stormwater ponds.

Water usage and current demand management practices

Water use data for residential allotments were obtained from average household water consumption data for Canberra (Table 1). The consumption figures were then adjusted to account for increased uptake of water efficient appliances. All data on water consumption patterns, household occupancies and water savings from increased use of low water using household appliances was provided by Environment ACT. The water consumption data was based on the current demand management practices that were considered as low demand management water consumption figures in this study.

Table 1: Typical in-house water usage

Water demand	**Typical Water Usage Per Person**		
	Low rate of Demand Management	**High rate of demand management - Woden**	**High rate of demand management - Gungaderra**
	L/c/day	L/c/day	L/c/day
Kitchen	23	22	23
Bathroom	77	54	47
Laundry	50	43	38
Toilet	70	53	49

Total	220	172	157

The low demand management water use data was based on uptake rates of 57% dual flush toilets, 32% low flow shower heads, 15% front loading washing machines, 47% dishwashers, 10% reduced lawn area and 10% irrigation system. It means that 57% of houses would have dual flush toilets and so on. For Woden high rate of demand management water use data uptake rates were increased to 90% water efficient dishwashers, 77% water efficient showerheads, 82% dual flush toilets and 65% water efficient washing machines. In Gungaderra, 100% provision of water efficient appliances was considered in high rate of demand management water use figures.

The average garden irrigation figures (Table 2) were derived from water balance modelling and average annual outdoor water use data supplied by ACT Department of Urban Services. The model assumes that garden irrigation was undertaken when the soil moisture content fell below a predefined limit. This limiting value (trigger to start garden irrigation) was selected such that the estimated average annual irrigation demand was equal to the annual outdoor water usage. Water efficient garden irrigation practices were not investigated as part of this study for large blocks in O'Malley suburb.

Table 2: Average garden irrigation values for the various block sizes considered.

Suburb	Block Size m^2	Garden Irrigation	
		L/hh/d*	L/c/d**
Woden	1,022	382	162
Woden	712	311	133
Woden	5,228	3,020	1,285
Woden	367	152	65
Gungaderra	450	97	37
Gungaderra	300	86	33

* Litres / household / day and **Litres / capita (person) / day

Climate Data

Historical daily climate data from 1984 to 2003 was used for modelling purposes. The minimum and maximum mean monthly temperatures vary from 0^oC to 27^oC and the long-term average annual rainfall is 640 mm.

Water balance modelling

Optimisation of raintanks

The optimisation of raintank sizes was carried out using Aquacycle. Based upon the raintank size and volumetric reliability relationship due to different water demands, the raintank sizes for various lot sizes were obtained (Table 3). The volumetric reliability is the proportion of the total demand on the tank supply that actually comes from the tank. Raintank reliability increases with size, as increasing the size of the tank increases the amount of water available for use. The optimum size was assumed to correspond to that tank size where further increases in size produced only a small increase in reliability. Thus a volumetric reliability of 40% was considered to correspond to the optimum tank size for 350 m^2, 700 m^2 and 1000 m^2 allotments. For large allotment size, 5,200 m^2, no optimum size was observed so a 20 KL tank was assumed. The raintanks were considered for garden irrigation and toilet flushing.

Table 3: Optimal rain tank sizes for irrigation and toilet flushing

Allotment Size (m^2)	Optimal tank size in Woden area (kL)	Optimal tank size in Gungaderra area (kL)
350	3.5	
700	7	
1,000	14	
5,200	20	
All		5

On-site measures –Existing development (Woden area)

Water balance modelling (with low rate of demand management) was conducted for the following options; raintanks, grey water for garden irrigation and also combination of both as onsite measures. The impacts of on site measures on the long term average potable water use, wastewater discharge and stormwater discharge were found to provide a reduction of up to 34% for potable water demand, 20% reduction in wastewater produced and 23% for reduction in stormwater runoff (Table 4). The optimum reduction on stormwater flows occurred when only raintanks were simulated and the optimum reduction in potable water use was observed when both raintanks and greywater were simulated.

Table 4: Effect of water saving measures in Woden township

Water/ Wastewater/ Stormwater	Base case No raintanks or greywater irrigation	Raintanks in use		Greywater for garden irrigation		Raintanks and greywater in use	
	ML/yr	ML/yr	% reduction	ML/yr	% reduction	ML/yr	% reduction
Water	4765	3649	24%	4166	13%	3160	34%
Wastewater	2836	2836	0%	2256	20%	2258	20%
Stormwater	4875	3758	23%	4858	0%	3850	21%

The reductions in water, wastewater and stormwater flows were linearised to calculate the uptake rate required for a 25% reduction in potable water demand. This analysis showed that a 25% reduction in potable water usage could be achieved with the following combinations of water servicing options:

- 100% of the houses with raintanks.
- 75% of houses with both raintanks and greywater reuse.
- 60% of houses with both raintanks and greywater reuse and remaining 40% houses with greywater reuse only.

Greywater usage for garden irrigation in all the houses alone cannot achieve a 25% reduction in potable water demand without additional provision of rainwater tanks. The final selection of the option to achieve 25% reduction in potable water would depend upon the total cost, reliability and environmental considerations. The reliability of greywater availability is higher than the rainwater. The cost of a greywater system depends on the degree of treatment required, based on health and environmental guidelines. For known unit cost of raintanks and greywater systems, the cost function can be solved to estimate the optimal combination of raintanks and greywater systems subject to 25% potable water reduction constraint. The optimisation of the total cost was not conducted in this study to estimate the right mix of raintanks and greywater systems.

The effect of introducing numerous demand management tools on potable water demand was also estimated. To model this behaviour, per capita rates of water demand were modified to mimic those obtained if a high uptake rate of demand management measures were achievable. The modifications reduced per capita in-house consumption from 220L/c/day to 172 L/c/day for the existing development and to 157 L/c/day for the proposed development area in Gungaderra. The demand management techniques represented in this modelling included the use of water efficient dishwashers, showerheads, dual flush toilets and washing machines, which resulted in further saving of 0.6 KL, 26 KL, 18KL and 10 KL per household respectively in annual water usage.

The water balance modelling with revised water usage (high demand management) was conducted for Woden township to re-examine the impact of raintanks and greywater reuse alone and in combination with high demand management techniques. The water demand reduced by 12% with the implementation of high demand management techniques only (Figure 2). The combination of demand management and raintanks reduced the water demand to 33%, the combination with greywater to 22%, and the combination of all three tools reduced the water demand by 41%.

Figure.2

Comparing the alternative water servicing options required to achieve 25% water reduction objectives with high water management and usual water management techniques, the number of households required to adopt such options decreases. With high demand management the uptakes rates for the various options are reduced to:

- ≥ 60% of the houses with raintanks
- ≥ 45% of houses with both raintanks and greywater reuse
- ≥ 30% houses both raintanks and greywater reuse for garden irrigation and ≥ 40% houses with greywater reuse.

The OSD tanks were modelled at allotment scale to reduce peak stormwater flows of 5 year average recurrence interval (ARI) to pre-development level. The modelling indicated that peak stormwater flows would be reduced to pre-development levels in all allotment types except one, if rainwater tanks were provided as per Table 3. The exception to this was for the allotments with large lot size (5,200 m^2) as the low usage from these tanks led to a high water level in the raintanks before a rain event. In the absence of raintanks, the OSD sizes modelled to reduce 5 year ARI flows to pre-development stage for allotments of sizes 5,200 m^2, 1,000 m^2, 700 m^2 and 350 m^2 were 15 KL, 5 KL, 3.5 KL and 2.5 KL respectively. The PURRS model was used for this analysis.

On-site measures –Greenfield development (Gungaderra area)

The water balance was performed for each allotment size, firstly with no water saving measures and then with 100% uptake of 5 kL raintanks, greywater from both the bathroom and laundry for irrigation and 100% of the raintank and greywater irrigation combination.

A maximum reduction in potable water demand of 34% was observed for allotments having both raintanks and greywater for garden irrigation, which also produced a 20% reduction in stormwater discharge. Greywater use alone showed a 13% reduction in potable water use and a 14% reduction in wastewater flows (Table 5) and was less effective than raintanks for reducing potable water usage.

Table 5: Effect of on-site water saving measures on potable water demand- Gungaderra

Water/ Wastewater/ Stormwater	Base case	Raintanks in use		Greywater for garden irrigation		Raintanks and greywater in use	
	ML/yr	ML/yr	% reduction	ML/yr	% reduction	ML/yr	% reduction
Potable water	1588	1213	23%	1396	13%	1041	34%
Wastewater	1362	1362	0%	1175	14%	1176	14%
Stormwater	1771	1406	21%	1770	0%	1424	20%

Similar to Woden area analysis, the reductions in water, wastewater and stormwater flows were linearised to calculate the uptake rate required for a 25% reduction in potable water demand. As described for Woden area development no cost optimisation was conducted to estimate this optimal combination of rainwater tanks and greywater systems for 25% potable water reduction. The potable water demand reduction of 25% could be achieved with some of the following combinations of water servicing options:

- 85% of the houses with raintanks and 15% of houses with raintanks and greywater reuse. This would also lead to 20% reduction in stormwater flows and 2% reduction in wastewater flows.
- 58% of houses with raintanks and greywater reuse and 42% of houses also with greywater reuse. This option would result in 13% reduction in stormwater flows and 9% reduction in wastewater flows.
- 67% houses with both raintanks and greywater reuse for garden irrigation.provides the 25% potable reduction and 11% reduction in stormwater flows and 14% reduction in wastewater flows.

Again high uptake rates of raintanks and greywater reuse systems are required for significant reductions in household potable water demand to be achieved. The uptake rates required are generally higher than for the existing suburbs, as the smaller household blocks in the greenfield site were modelled with lower outdoor water use. Hence, less of the total household water demand is associated with garden irrigation, and this lowers the potable water reductions that can be achieved by substitution of potable water with raintank water or greywater for garden irrigation.

A water balance analysis for Gungaderra township was also conducted with high rates of demand management techniques, which resulted in water demand reduction by 23% (Figure 3). Smaller allotment sizes considered for Gungaderra mean that the amount of water used in the garden is small, and therefore the high rate of demand management leads to proportionally larger reductions in potable water demand than was the case for Woden. Demand management in combination with rainwater use reduces potable demand by 44%; in combination with greywater by 34%; in combination with both rainwater and greywater by 52%. With raintanks and greywater reuse, 38% reduction in wastewater flows and 16% reduction in stormwater flows can also be achieved. The 25% water reduction objective with high demand management option can be achieved with the following alternative servicing options:

- ≥ 5% houses with raintanks and greywater usage
- ≥ 10% houses with raintanks
- ≥ 10% houses with greywater usage

Figure.3

As was found with calculations for Gungaderra, the required uptake rate of onsite systems reduced drastically to achieve the water demand reduction objective, when implemented with high uptake rates of demand management techniques.

Allotment scale measures like OSDs similar to Woden development were considered for Gungadera area to lower the peak stormwater flows to pre-development levels with or without raintanks. For the 450 m^2 and 300 m^2 allotments, OSDs of 4kL and 2kL capacities without raintanks and 3kL and 1 kL with raintanks were required to reduce 5 year ARI peak flows to predevelopment level. Raintanks alone could not reduce 5 year ARI peak flows to predevelopment level in Gungadera area due to reduced outdoor water usage. The PURRS model was also used for this analysis.

It can be concluded from water balance modelling in Woden and Gungaderra areas that the reduction in potable water demand due to on-site measures is directly proportional to lot sizes, pervious area ratio, roof sizes and occupancy rate irrespective of existing or greenfield developments. Raintanks alone were effective tools in reducing peak stormwater (5 year ARI) flows to predevelopment level if the impervious area ratio was less than 0.35. In the case of lots with higher impervious ratios (Gungaderra area), raintanks alone could not reduce peak stormwater flows to predevelopment level.

Catchment (development area) scale measures

Catchment scale modelling was conducted for Woden to estimate the combined impact of raintanks as on-site measures and stormwater use from local ponds for public open space irrigation. Both, the base case where potable water is used for irrigation of POS, and raintanks along with stormwater for POS irrigation from local stormwater ponds were modelled using Aquacycle.

Raintanks and POS irrigation from stormwater ponds reduced stormwater flows by 27% (Table 6). This compares to a 21% reduction in stormwater if the effect of raintanks alone were considered. Therefore, irrigation of the POS from the stormwater ponds provides a further reduction in stormwater discharge of 6% and a potable water reduction of 25%.

Table 6: Water balance on catchment scale scenarios - Woden area

Option	Potable water		Wastewater		Stormwater	
	ML/yr	% Reduction	ML/yr	% Reduction	ML/yr	% Reduction
Base case	5524	0	3340	0	4880	0
Raintanks and stormwater use from ponds for POS irrigation	4167	25	3340	0	3565	27

For Gungaderra development, in addition to allotment raintanks and greywater, POS irrigation from local stormwater ponds and the use of treated wastewater for garden irrigation and toilet flushing was also modelled. Treated wastewater for garden watering and toilet flushing provided a slightly greater reduction in potable water demand at 36% (Table 7) compared to the 34% reduction observed for greywater reuse and raintanks (Table 5).

The reductions up to 44% in wastewater discharge were predicted when using treated wastewater for both garden irrigation and toilet flushing. Maximum stormwater reduction of 24% was achieved by the use of rainwater tanks and stormwater irrigation of POS (Table 7).

Table 7: Water balance on catchment scale scenarios – Gungaderra area

Scenarios	Potable		Wastewater		Stormwater	
	ML/yr	% reduction	ML/yr	% reduction	ML/yr	% reduction
Stormwater and rainwater	1267	20	1355	0	1419	24
Wastewater and stormwater	1022	36	759	44	1764	5

Stormwater quantity and quality modelling

Existing development (Woden area)

The conceptual layouts of stormwater flows with various combinations of treatment trains were developed for modelling purposes. It was found that a combination of ponds, GPTs and bioretention systems provided the maximum improvement in stormwater quality (Table 8) with reductions in TSS, TN and TP loads of 71%, 32% and 42% respectively in comparison to urban development with no stormwater treatment provisions. However, GPT and ponds alone gave predicted TSS, TN and TP load reductions of 68, 26 and 38% respectively. This was considered the preferred option, as the additional provision of bioretention systems did not significantly reduce contaminant loads.

Table 8: Reduction* of stormwater contaminant loads and concentrations-Woden area

Parameters	Mean flow (m^3/s)	TSS (kg/day)	TN (kg/day)	TP (kg/day)	TSS (mg/L)	TN (mg/L)	TP(mg/L)
Total area as greenfield	0.086	962	18.7	2.34	24.6	2.13	0.168
Developed area with no Treatment measures	0.186	2390	41.6	5.48	42.2	2.2	0.193
	Flow % reduction	**TSS % reduction**	**TN % reduction**	**TP % reduction**	**TSS % reduction**	**TN % reduction**	**TP % reduction**
GPT+Ponds (4ha+3ha+3ha)	0	68	26	38	59	26	25
GPT+Ponds (4ha+3ha+3ha)+ Bioretention systems	0	71	32	42	61	33	26
Buffers	0	37	18	25	28	16	24
: Buffers + Swales	0	41	18	27	26	21	20
Buffers + Bioretention	0	45	29	34	57	70	67

*Reductions in comparison to development with no treatment measures

None of the treatment trains alone were predicted to provide stormwater quality equivalent to the predevelopment level. Thus, the combined impact of raintanks and stormwater use from ponds for POS irrigation GPT and ponds was modelled, and found to predict contaminant loads of less than the predevelopment case. The provision for raintanks and stormwater reuse for irrigation also resulted in 30% reduction in mean daily stormwater flows to 0.131m^3/s in comparison to typical urban development flows, but the mean daily flows were still higher than predevelopment conditions. The MUSIC model was applied for stormwater quantity and quality assessment.

Existing development (Gungaderra area)

To conceptualise the improvement in the catchment stormwater runoff quality, two treatment trains were considered, firstly GPTs and ponds and also GPTs, ponds and swales. The dimensions of swales adopted for modelling were top width 4m, bottom width 1m and depth 0.5m with a vegetation of 0.25m.

Significant reductions were predicted in nutrient loading with GPTs and ponds as treatment measures with TSS, TN and TP loads reduced by 82%, 33% and 50% respectively in comparison to the base case (Table 9). However, the predicted TN and TP loads were still higher than the pre-development conditions. Slightly greater reductions were observed with the addition of swales, with TSS, TN and TP loads reduced by 85%, 36% and 52% respectively but this improvement was only marginal and it was concluded that the provision of ponds and GPTs was an effective option.

Table 9: Reduction* of stormwater contaminant loads and concentrations-Gungaderra area

Treatment option	Mean flow (m^3/s)	TSS (kg/day)	TN (kg/day)	TP (kg/day)	TSS (mg/L)	TN (mg/L)	TP (mg/L)
Total area as grassland with no treatment	0.017	173	3.27	0.4	24.6	1.89	0.15
Urban development with no treatment	0.057	**730**	**12.2**	**1.61**	**41.3**	**1.7**	**0.15**
	Flow %	**TSS %**	**TN %**	**TP %**	**TSS %**	**TN %**	**TP %**

	reduction	reduction	reduction	reduction	reduction	reduction	reduction
Total area as grassland with GPT+ Ponds	**0**	**86**	**45**	**52**	**50**	**33**	**12**
Urban development with GPT+Ponds	0	82	33	50	66	14	9
Urban development with GPT+Ponds +Swales	0	85	36	52	67	16	10

*Reduction in comparison to values for urban development with no stormwater treatment

Similar to Woden area, none of the stormwater treatment measures were predicted to reduce the contaminant loads to predevelopment levels in Gungaderra area. Thus the impact of the rainwater tanks alone and in combination with stormwater reuse for POS irrigation and GPTs and ponds, on stormwater quantity and quality were also modelled. The contaminant loads reduced by 25% with raintanks alone. With the combination of raintanks and stormwater reuse for POS from ponds the contaminant loads were reduced below predevelopment levels and the stormwater flows reduced by 28% in comparison to typical urban development. However, the mean daily flows were still higher than the predevelopment flows. Thus, the raintanks alone are effective in contaminant load reduction.

Discussion

Raintanks are not only effective in reducing potable water demand but also in reducing low intensity peak stormwater flows and stormwater contaminant loads in smaller allotments to predevelopment levels.

The demand management techniques are very effective means of achieving water demand reduction objectives. High uptake rates for raintanks and greywater reuse systems are required for significant reductions in household potable water demand in existing developments. In response to this and other information the ACT Government is actively promoting the use of rainwater and greywater. Planning controls have been amended to facilitate installation of raintanks and greywater systems, and a Government funded rebate scheme for raintanks has commenced.

Similarly, high uptake rates of raintanks and greywater reuse systems are required for significant reductions in household potable water demand in greenfield development. The uptake rates required are generally higher than for the existing suburbs, as the smaller household blocks in the greenfield site were modelled with lower outdoor water use. Hence, less of the total household water demand is associated with garden irrigation, and this lowers the potable water reductions that can be achieved by substitution of potable water with rainwater or greywater for garden irrigation.

In case of greenfield developments, the combination of wastewater reuse and stormwater use from catchment (development) scale ponds is very effective tool in potable water reduction in comparison to on-site rainwater and greywater usage. In this study development scale wastewater reuse reduced wastewater flows by 44% in comparison to only 14% when on-site rainwater and greywater systems are used. The combined application of stormwater use and wastewater reuse provides improved ecological benefits in comparison to on-site rainwater and greywater use.

From a policy perspective for Environmental ACT, the value of household scale measures needs to be balanced with relying on individual householders to operate such measures effectively. Should household scale measures not perform, retrofitting of measures in public spaces may be required. In consequence the general approach applied in Canberra has been to encourage rather than mandate individual household measures, on the basis that measures adopted voluntarily are more likely to be maintained.

The reduction in potable water demand due to on-site measures is directly proportional to lot sizes, pervious area ratio, roof sizes and occupancy rate irrespective of existing or greenfield developments. Raintanks alone were predicted to be effective tools in reducing peak stormwater (5 year ARI) flows to predevelopment level if the impervious area ratio was less than 0.35. In the case of lots with higher impervious ratios raintanks alone are not capable of reducing peak stormwater flows to predevelopment levels.

No single modelling tool is available to analyse the total water cycle for quantity and quality in an urban development. A combination of modelling tools is required to cover all aspects of water, wastewater and stormwater quantity and quality. In this study Aquacycle was applied to model water, wastewater and stormwater flows for various servicing options and also rainwater tanks optimal sizes for various lots. MUSIC model was used to conceptualise stormwater treatment units for stormwater quantity and quality and PURRS model was used to conceptualise on-site detention tanks and also to analyse impact of rainwater tanks on stormwater peak reduction. The raintank sizes and stormwater /rainwater reuse quantity estimated using Aquacycle was used as an input to MUSIC model to conceptualise treatment trains for stormwater quality and quantity. The information on raintanks was also used as an input to PURRS model to conceptualise OSD tanks and to estimate allotment scale peak stormwater flows at predefined ARI. The models were validated and parameters adjusted for stormwater flows.

Conclusions

The purpose of this study was to assist Environment ACT in setting broad policies for future water services in Canberra. Environment ACT amended planning controls to facilitate installation of raintanks and greywater systems, and commenced a Government funded rebate scheme for raintanks as a result of this study. The investigation provided an assessment of potential preferences of alternative water servicing options. A number of allotment and catchment scale options were investigated to achieve set objectives, and the extent to which these techniques might need to be implemented. The effect of different levels of demand management on the changes brought about by alternate water measures was also examined. A combination of three models were used in this study to model complete water cycle for quantity and quality as no single model was available to analyse all aspects of water cycle. The computer models used in this study were found suitable for water balance analysis, stormwater quality and quantity estimations and allotment scale stormwater flow estimation including on-site detention tank sizing. The output from one model was used as an input to other models.

High demand management is a very effective tool for potable water reduction at allotment scale, but it requires the use of highly water efficient appliances. Such an option may be possible in greenfield developments by financial incentives and/ or regulatory arrangements. High uptake rates are required from raintanks to achieve the 25% potable water reduction objectives. Use of on-site greywater reuse systems and raintanks was more efficient than either raintanks or on-site grey water reuse systems alone, while greywater systems alone could not achieve the potable water reduction objective. Raintanks are more efficient for Canberra than on-site greywater reuse for garden irrigation. Coupling the use of raintanks with high uptake rates of demand management significantly lowered the uptake rates of raintanks required to meet the 25% reduction in potable water demand. The potable water reduction due to on-site measures was found to be proportional to lot size, if it is assumed that the irrigation demand increases with increased lot sizes.

The raintanks not only lead to lower potable water use, but also significantly reduced peak stormwater flows at the allotment scale. Moreover, on-site detention systems are an effective means of reducing peak flows to predevelopment levels. The provision of additional treatment trains such as bioretention system or swales, ponds and GPTs did not result in any significant additional reduction in nutrient loads beyond the implementation of ponds and GTPs alone. However, the rainwater/ stormwater reuse along with the treatment trains significantly decreases nutrient from stormwater runoff.

For greenfield sites, wastewater recycling for non-potable use was the most effective and reliable means for reducing potable water demands and wastewater flows. This option is generally considered too expensive for implementation in existing suburbs, although it has not been costed.

Following this work the ACT Government established an ambitious target for potable water reduction and wastewater reuse. The demand management measures modelled in this study are being implemented through an initiative, which will continue over number of years. In addition, this work is informing infrastructure requirements for both allotment and public open space measures currently being formalised in guidelines.

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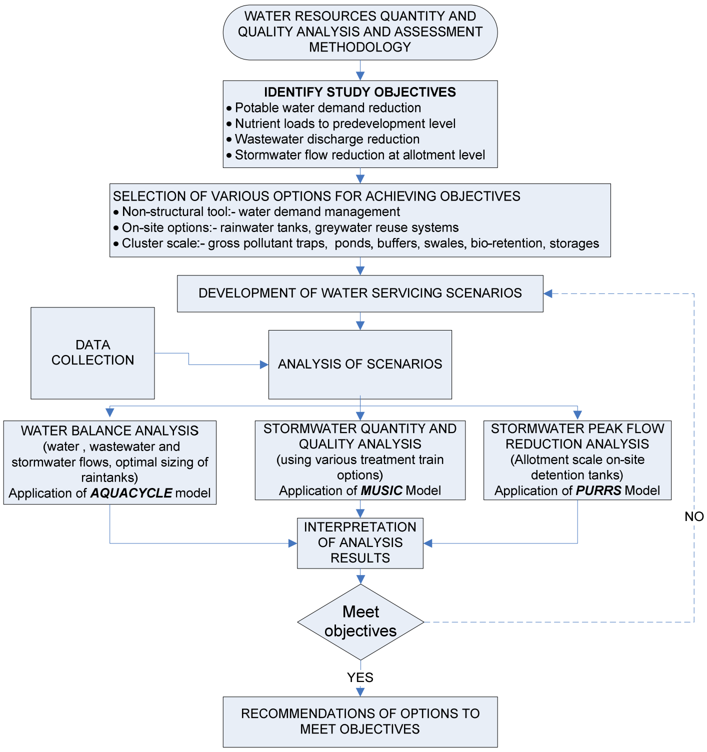

Figure 1: Water resources quantity and quality analysis modelling and assessment methodology

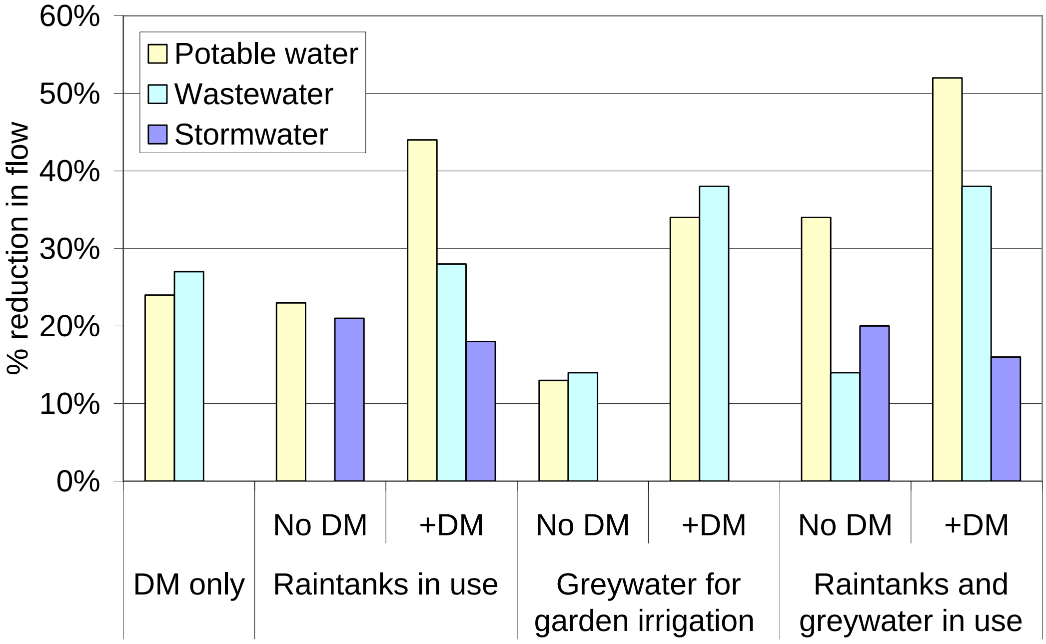

Figure 2: Effect of on-site water saving measures combined with demand management (DM) in Woden area

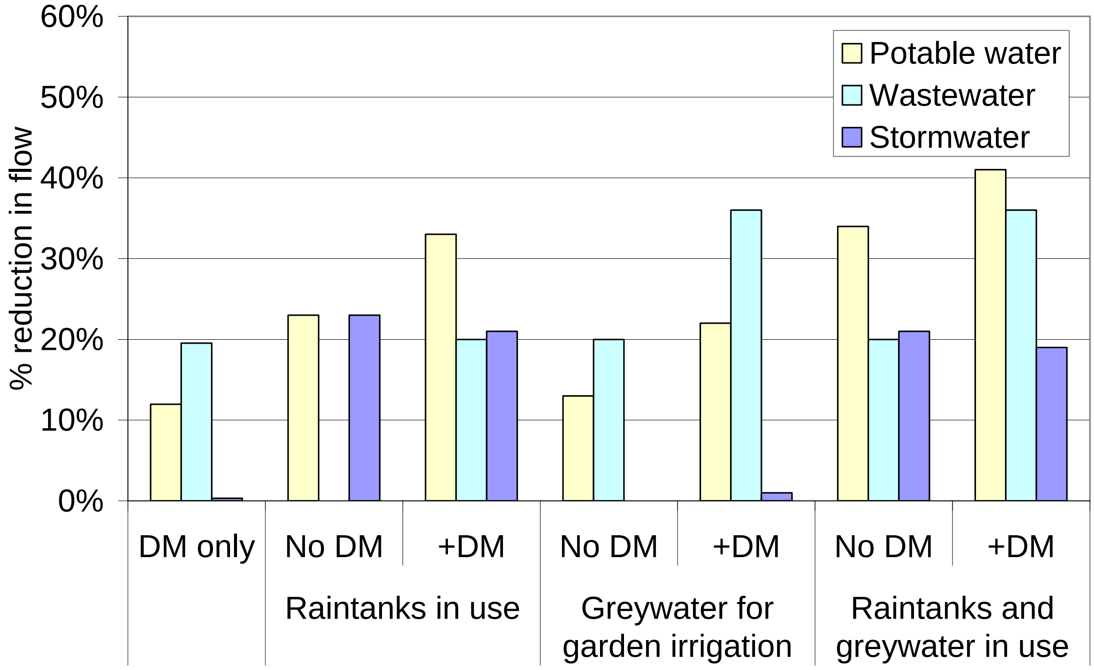

Figure 3: Effect of on-site water saving measures combined with demand management (DM) in Gungaderra area