A Flexible Modelling Environment for Integrated Urban Water Harvesting and Re-use

Un modèle d'environnement flexible pour la récupération et la réutilisation de l'eau en milieu urbain

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RÉSUMÉ

La croissance constante de la population urbaine et le changement climatique potentiel qui risquent d'affecter la quantité d'eau utilisable dans les systèmes d'alimentation en eau donnent aux études sur la récupération des eaux de pluie et le recyclage des eaux usées une priorité de premier ordre. La proposition de base est que tout système d'alimentation en eau réduisant la quantité d'eau tirée des réservoirs principaux est bénéfique pour la région entière, en particulier en ce qui concerne la sécurité en termes de sécheresse. Cet article décrit un cadre versatile de modèle pouvant simuler une large variété de combinaisons de schémas de traitement des eaux urbaines, centralisés ou décentralisés, et applicables à un bâtiment ou à tout un quartier. Le cadre combine deux approches de modélisation. Tout d'abord, urbanCycle peut simuler la consommation et la demande en eau, les quantités d'eaux de pluie et d'eaux usées à l'échelle d'un lot d'habitations. UrbanCycle est basé sur l'hypothèse que le réseau forme un graphe acyclique, bien que les simulations puissent être opérées avec beaucoup de détail. Cela permet de simplifier la logique de connectivité mais limite le contrôle des systèmes avec réserves décentralisées, retours et routes multiples. Pour surmonter ce problème, un deuxième modèle, basé sur la programmation linéaire, est inclus dans le cadre d'urbanCycle, pour permettre la modélisation des options de recyclage et de récolte. De plus, ce second modèle permet de prendre des décisions immédiates pour l'offre et la demande, basées sur les résultats attendus plutôt que sur des règlements préétablis.

ABSTRACT

The steady increase of urban population and the possible onset of climate change that may adversely affect the amount of water available in current water supply systems, makes the study of stormwater and rainwater harvesting and wastewater recycling a high priority. The basic proposition is that any system of water supply that can reduce the amount of water drawn from main reservoirs will be of benefit to the whole supply region especially in terms of drought security. This paper describes a versatile modelling framework which can simulate a wide variety of combinations of centralised and decentralised Integrated Urban Water Management schemes from the allotment to the whole suburb scale. The framework combines two modelling approaches. The first, called urbanCycle, simulates water supply and demand, stormwater and wastewater using allotments as the basic building block. Although urbanCycle can simulate processes in great detail, it assumes that the network forms a directed acyclic graph. This simplifies the connectivity logic but precludes investigation of systems with decentralized storage, feedbacks and multiple supply paths. To overcome this, a second model, based on network linear programming, is embedded in the urbanCycle framework to enable the modelling of recycling and harvesting options, as well as on-the-fly supply and demand decision making, based on objectives rather than pre-set operating rules.

KEYWORDS

Modelling, urban, recycling and re-use, harvesting

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1 INTRODUCTION

In Australia, most residential and industrial areas in the larger cities obtain their water from large centralised supply systems. The continued expansion of these metropolitan areas coupled with possible reductions in rainfall due to climate change will almost certainly put these centralised systems under considerable stress. The problems of persistent low rainfall climate conditions were highlighted during the recent extended drought, with nearly all major water supply systems dropping to historically low levels in 2005 and 2006, and with all major cities working on major augmentation schemes such as desalination or wastewater recycling.

Studies (Mitchell, 2005; Kuczera 2008) have shown that, if these centralised water supply systems can be augmented by a series of decentralised systems harvesting water from impervious surfaces such as roofs and urban catchments, so that the centralised system is only drawn on if the decentralised systems cannot meet demand, then this can significantly increase regional drought security. This is especially so for Australia’s eastern coastal cities, where the centralised storage catchment areas have significantly lower rainfall than the urban areas that they supply. A large proportion of the urban rainfall in cities like Sydney and Melbourne is discharged as stormwater and is a lost resource. In some parts of Australia, especially south east Queensland, governments are insisting that new major urban expansions cannot rely solely on centralised reservoirs for their water supply and must reduce the demand on the centralized supply significantly below that of a normal residential area, if the approval is to be granted.

Before decentralised systems can be seen as viable options, it will be necessary to show that they can be effective as an augmentation of the centralised supply system. This study presents a versatile and flexible modelling framework which can simulate a wide variety of combinations of centralised and decentralised schemes (henceforth referred to as Integrated Urban Water Management Schemes or IUWMS), from the allotment to the estate scale. To achieve this, the study combines two existing types of model architecture:

1) A simulation model capable of working at a very detailed level but restricted to a directed acyclic network topology, coupled with:

2) A network linear program, capable of allocating water regardless of topological complexity.

2 MODELLING INTEGRATED URBAN WATER MANAGEMENT SCHEMES.

In considering combined centralised and decentralised systems, there are several capabilities that the modelling environment should support if it is to be appropriate for uses such as decision support, and what-if scenario investigations. These include:

- Detailed and accurate harvesting of water of different qualities.
- Detailed simulation of demand for different classes of water.
- Supply and demand simulated at consistent and appropriate time scales
- Recycling of different grades of water.
- Storage and treatment requirements.
- Meeting environmental flows and water quality requirements.
- Bi-directional transfers between storages.
- Meeting demands from several possible supply points.
- Prioritising of demand and supply.
- Effect of implementation of ‘restrictions’ and other operating requirements.

The modelling environment presented in this study is able to incorporate these aspects at scales from a single allotment scale up to the estate or even small suburb scale, depending on complexity and computer power available. It consists of two parts: ‘urbanCycle’, which is a directed acyclic, allotment level, run-off and demand simulator, and ‘urbanNet’, which is a network linear program capable of supply and demand balancing from a variety of different sources. A brief description of each of these models is provided below.

2.1 urbanCycle

urbanCycle (Hardy, 2009) is a hierarchical network based model that seeks to represent system dynamics at appropriate space and time scales. It allows a network design for a single allotment that can differ from allotment to allotment, but also has ‘styles’ that allow allotments to have the same properties with a simple selection. To manage network complexity, urbanCycle supports embedded hierarchical networks, an example of which is illustrated in Figure 1.

urbanCycle can work at an allotment scale, providing run-off data, demand data, etc depending on the details of a particular allotment. For example, rainwater tanks can be included at this scale, or roof run-off can be channelled separately from stormwater run-off. urbanCycle can also work at the cluster scale, where individual allotments provide run-off data along a flow network. Each allotment could have the same or different embedded network. Clusters of houses can then be grouped together to act as a single unit, thus enabling a larger urban area to be modelled.

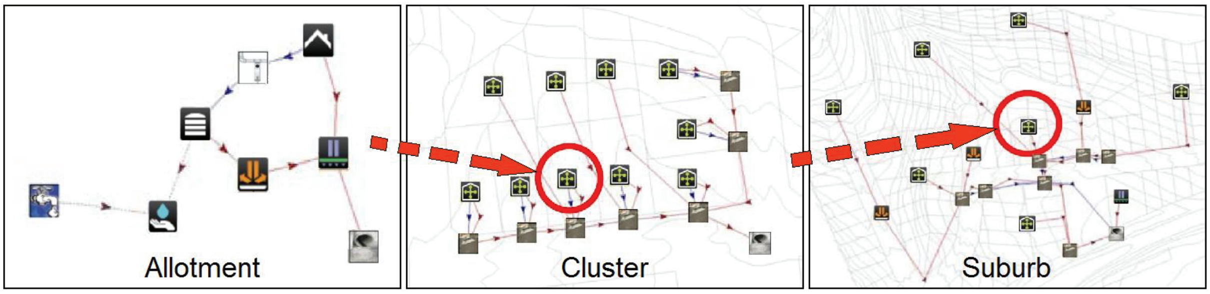


Figure 1. The embedded hierarchical structure of urbanCycle.

2.1.1 Run-off.

Within an allotment, runoff can be simulated from roofs, impervious and pervious area, and allotment water tanks. This allotment run-off can be channeled through detailed stormwater systems of conventional or Water Sensitive Urban Design (WSUD) styles. Parks and road surfaces are also catered for. urbanCycle can simulate run-off at intervals of the order of 1 minute, and can then collate this data at daily time steps.

2.1.2 Rainfall.

urbanCycle offers users a choice in rainfall input methodology. It supports Australian Rainfall and Runoff (Pilgrim, 1997) design storms and also the ability to carry out long-term continuous simulation, which is the more appropriate type of simulation for IUWM. Long term rainfall input can be derived from historic or external sources or generated by the Disaggregated Rectangular Intensity Pulse (DRIP) stochastic rainfall model (Heneker, 2001), which has been incorporated into the urbanCycle framework.

2.1.3 Demand

To meet demand, each allotment can request supply from up to four sources on a priority basis. UrbanCycle manages the water availability from allotment based water tanks at sub-daily intervals, but does not keep track of the availability from other water sources; it assumes that water is always available. Cluster based water tanks must be managed outside urbanCycle. The demand is split up into indoor and outdoor uses, with individual uses, prorated, on a percentage basis. The patterns of demand are generated at an individual allotment level within urbanCycle and are based either on Average Monthly Daily Demand or on a Probabilistic Demand Model derived from Coombes (2002). Each allotment can be assigned different seasonal and diurnal demand patterns, which may depend on occupancy, garden area and end-use specification (the demand end-use model of Thyer (2008) is currently being implemented). Because of the modular design of urbanCycle, there is scope for adding or modifying the demand models to implement new developments. Demand scenarios for industry, commerce, agriculture, parks etc could be readily accommodated either as a ‘style’ or as new modules within urbanCycle.

2.1.4 Waste Water

urbanCycle allows directing different indoor uses to different wastewater types. The networks for different wastewater types can be routed through a pipe network, or can be ‘directly connected’, which assumes instantaneous translation to the final collection point.

2.1.5 Limitations

While urbanCycle is capable of very detailed runoff, demand and wastewater simulation at sub-daily time scales, it assumes that all networks form Directed Acyclic Graphs (DAG), which guarantee that simulations are undertaken in a set order, such that at any node, the simulations of all upstream nodes have already been completed. This means that urbanCycle does not have the capability to analyse networks where water may be transferred back to upstream nodes or may need to be transferred between nodes on a bi-directional basis. It also does not have the ability to carry out such tasks such as monitoring day to day storage levels of local reservoirs, making decisions about where water is supplied from, implementing cluster scale recycling and treatment of different types of water, or in general coping with any facets of the water supply system that are not strictly directed acyclic in nature. Nor can it deal with headworks-scale water distribution systems where complex operating rules, relating to the availability and consumption of water, dictate how flows are managed. To implement these features, a different type of modelling environment is required.

2.2 urbanNet

urbanNet is a Network Linear Program based on WathNet (Kuczera 1997). It has been modified to provide a highly flexible system for modelling integrated water supply networks. It allows the user to model many facets required in the operation of IUWMS, including the following:

- carry out mass balances and keep track of reservoir storage
- allocate water delivery to demand depending on class and availability
- allow for flexible environmental flows
- adjust demand according to demand restriction rules
- apply operating rules on-the-fly based on one or more criteria
- allow for losses due to transfer, treatment and evaporation
- enable the recycling, feedback or transfer of water to any part of the network
- ‘time of travel’ while allowing ‘look ahead’ for water releases
- monitor water savings from implementation of different facets of the scheme

The model can operate at a daily or monthly time step so is appropriate for small to medium IUWMS but can still model regional supply networks if desired. However, it assumes that demands and supplies are provided externally from a data file or are provided on a step by step basis from a program such as urbanCycle. (urbanNet can, in fact, use a combination of both urbanCycle data and external data, so long as the data dates and time scale are consistent)

2.3 Combining urbanCycle and urbanNet

The complimentary capabilities of urbanCycle and urbanNet allows the merging of these two modelling frameworks into a single modelling environment with substantially enhance IUWM capabilities. In merging the two environments, the following decisions regarding inter-operability were made:

Time scale: The models were linked at the daily time scale, as this has been shown (Mitchell, 2005) to be appropriate for the cluster to small suburb scales. It also allows external data such as other inflows, and evaporation to be included at the daily time scale, as well as allowing decision making about the sources of water, transfers between reservoirs, environmental flows etc. to work at this time scale.

Nodal links: In urbanCycle, there may be many nodes, but only a few may be required to be linked to UrbanNet. Thus, each node in urbanCycle has an option that allows the user to indicate that it will be used as an urbanNet link node. A list of the selected nodes is then created by urbanCycle, and saved for use by urbanNet. In urbanNet, all inflow, demand, and reservoir nodes can be linked either to a node from this list of urbanCycle nodes or to nodal data columns from an external data file.

Running a simulation: The simulation protocol starts with urbanCycle carrying out its flow and demand simulations at sub-daily time steps and aggregating the results at a daily time step, and then passing the required information to urbanNet. In turn, urbanNet balances the overlying IUWM network, accepting inflows, keeping track of reservoir levels, meeting demands as applicable, and meeting other objectives defined by the modeller.

3 PROOF OF CONCEPT: CASE STUDY

A hypothetical case study is presented to illustrate the concepts and the capabilities resulting from merging urbanCycle and urbanNet. Three simple scenarios are included to show the flexibility of the system. The initial scenario, which is used to describe the modelling procedure, attempts to minimise the reliance on the centralised reservoir by fully implementing urban water harvesting and re-use.

3.1 Step one: Set up urbanCycle network with link points.

A small cluster was created consisting of 20 identical allotments (identical, to enable easy checking of the results). Figure 2 shows the layout within each allotment. Each allotment has the following attributes:

- A dwelling with a 250m^2 tiled roof directly connected directly to a piping system.

- Impervious areas of 50m^2 and pervious areas of 100m^2 draining as stormwater.
- A “second pipe” supply of non-potable water is connected as an “alternate” supply.
- Grey water and black water are collected separately.
- Roof run-off is collected separately from road and garden stormwater.

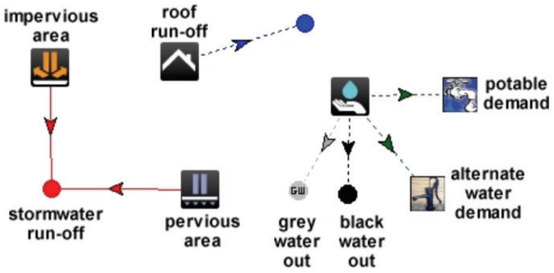
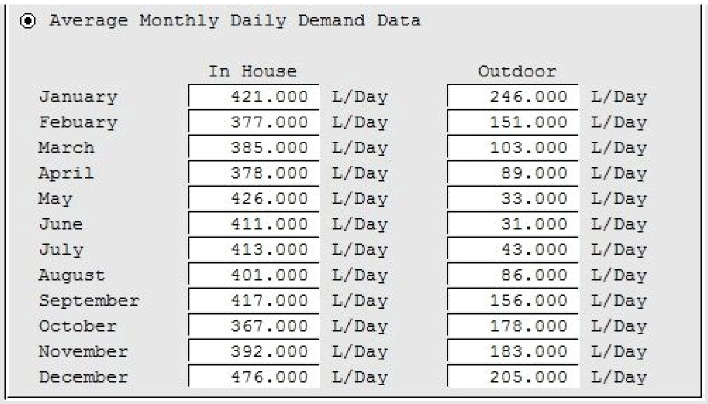


Figure 2: urbanCycle allotment layout

An ‘Average Monthly Daily Demand’ model is used, as shown in Figure 3, which disaggregates indoor and outdoor usage at monthly time step. These values were based on studies done in the Kotara area in Newcastle, NSW.

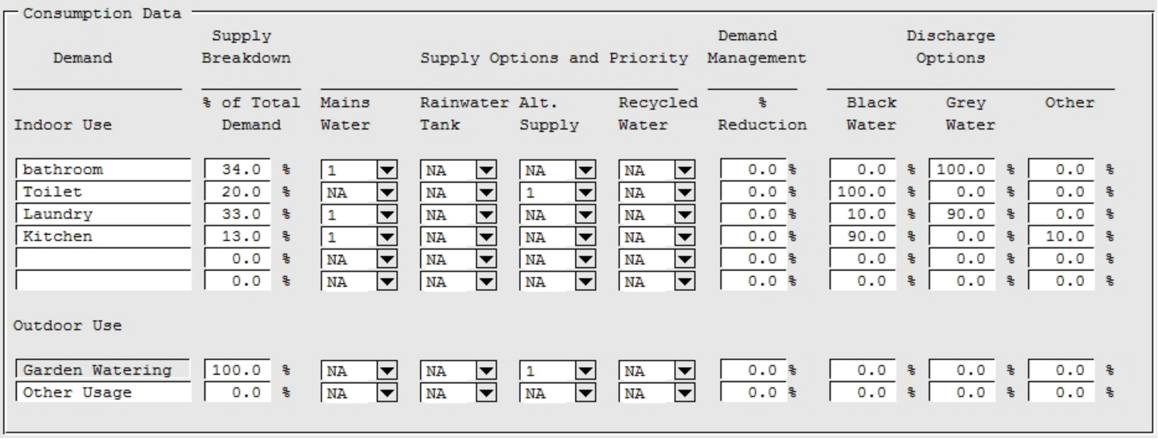


◉ Average Monthly Daily Demand Data

	In House		Outdoor	
January	421.000	L/Day	246.000	L/Day
Febuary	377.000	L/Day	151.000	L/Day
March	385.000	L/Day	103.000	L/Day
April	378.000	L/Day	89.000	L/Day
May	426.000	L/Day	33.000	L/Day
June	411.000	L/Day	31.000	L/Day
July	413.000	L/Day	43.000	L/Day
August	401.000	L/Day	86.000	L/Day
September	417.000	L/Day	156.000	L/Day
October	367.000	L/Day	178.000	L/Day
November	392.000	L/Day	183.000	L/Day
December	476.000	L/Day	205.000	L/Day

Figure 3: Monthly indoor and outdoor water usage.

This monthly demand was then further disaggregated by usage so that the sources of water and the discharges could be varied. Figure 4 shows how the sources and waste water flows are calculated for each allotment. The dialog box shows, for example, that bathroom water was supplied from the main supply and discharged fully to the greywater collection system, while toilet water was from the alternate (2nd pipe) supply, and was discharged fully as blackwater. (Mains Water, in column 1, is actually the supply from the cluster rainwater collection tank, see the urbanNet linkages next page)



Consumption Data

Demand	Supply Breakdown	Supply Options and Priority				Demand Management	Discharge Options		
Indoor Use	% of Total Demand	Mains Water	Rainwater Tank	Alt. Supply	Recycled Water	% Reduction	Black Water	Grey Water	Other
bathroom	34.0 %	1	NA	NA	NA	0.0 %	0.0 %	100.0 %	0.0 %
Toilet	20.0 %	NA	NA	1	NA	0.0 %	100.0 %	0.0 %	0.0 %
Laundry	33.0 %	1	NA	NA	NA	0.0 %	10.0 %	90.0 %	0.0 %
Kitchen	13.0 %	1	NA	NA	NA	0.0 %	90.0 %	0.0 %	10.0 %
	0.0 %	NA	NA	NA	NA	0.0 %	0.0 %	0.0 %	0.0 %
	0.0 %	NA	NA	NA	NA	0.0 %	0.0 %	0.0 %	0.0 %
Outdoor Use									
Garden Watering	100.0 %	NA	NA	1	NA	0.0 %	0.0 %	0.0 %	0.0 %
Other Usage	0.0 %	NA	NA	NA	NA	0.0 %	0.0 %	0.0 %	0.0 %

Figure 4: urbanCycle water usage breakdown dialog box.

Following design of the base allotments, the cluster, shown in Figure 5, was constructed. The cluster includes 20 allotments in addition to roads and a stormwater pipe network. For this case study, all other connections were assumed to be directly connected to their respective collection points.

The layout contains six collection points each of which is "marked" as a linkage point to urbanNet and set to aggregate flow and demand data at a daily interval. In a larger cluster, allotment links can be connected in groups, which in turn are linked to the final collection points, with only these final collection points being marked as urbanNet link points.

Once the urbanCycle layout was finalized, the set of linkages points, plus a rainfall link and a net evaporation link, were saved to a file for use by urbanNet.

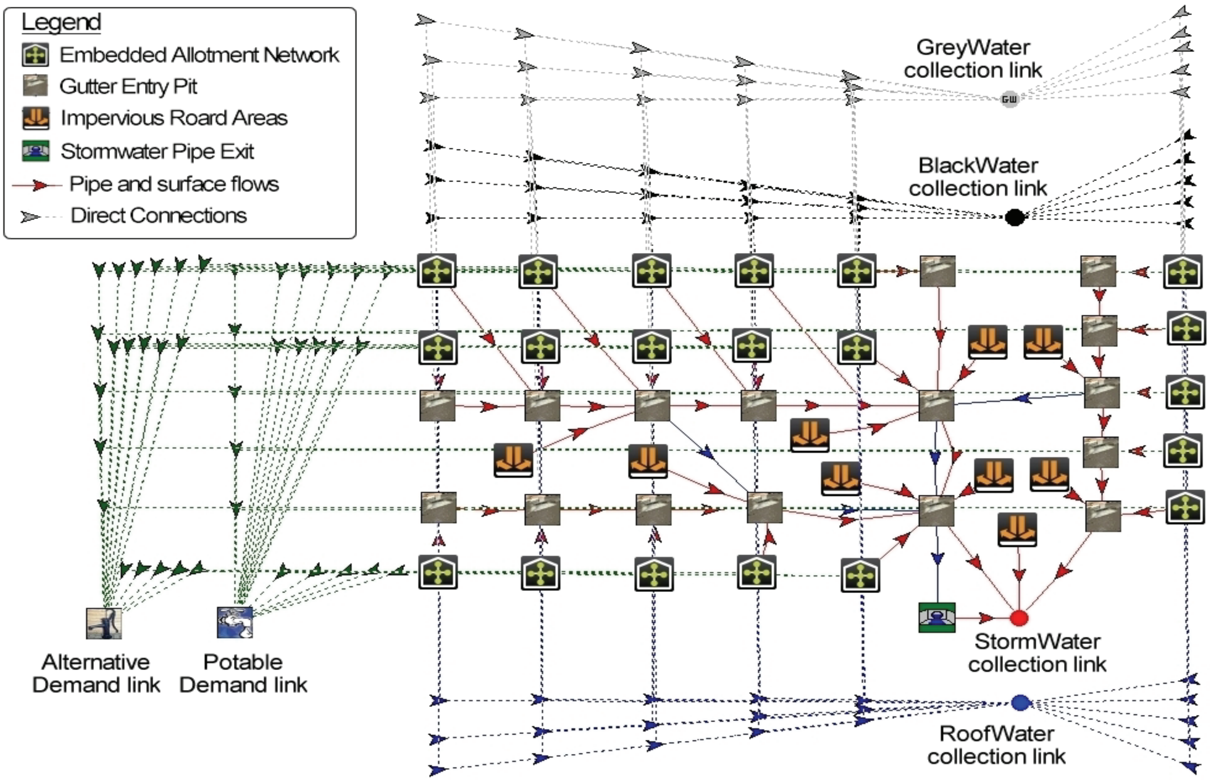


Figure 5: urbanCycle cluster layout

3.2 Step Two. Design the urbanNet network.

From within urbanCycle, the urbanNet model is accessed to configure the cluster reservoir and supply network shown in Figure 6.

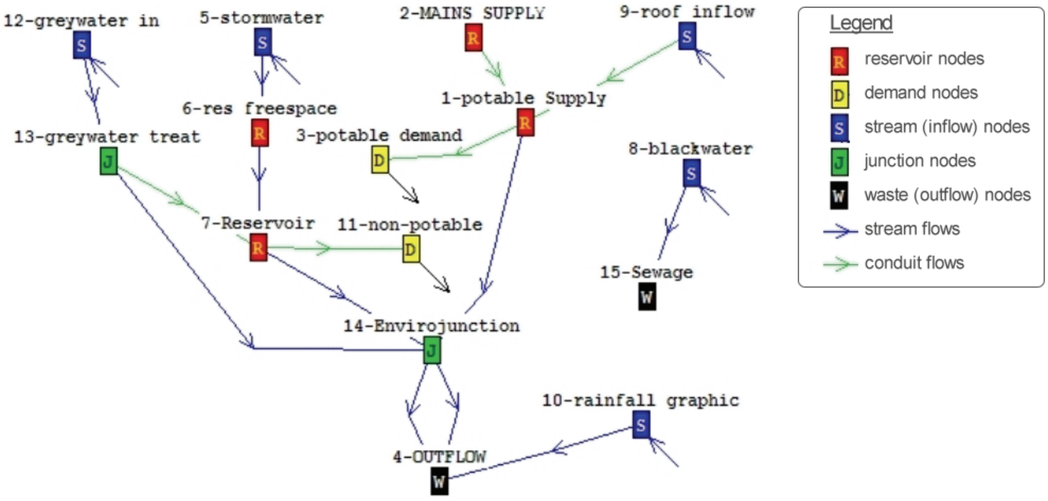


Figure 6: urbanNet network

The main features of the urbanNet network in Figure 6 are listed below:

i) The Potable Supply Tank (node 1) has a capacity of 200kL and is fed from roof run-off, but will be topped up by the centralised supply should the tank become empty.

ii) The Stormwater reservoir has a capacity of 1ML, with allowance for evaporation.

iii) The network attempts to meet an environmental flow of 10,000L per day (between nodes 14 and 4) which is halved if the stormwater reservoir drops below 50% of capacity (this is done using a ‘script’ on the environmental arc.) The stormwater reservoir and treated greywater are to be used to help meet this environmental flow, as applicable.

iv) If the stormwater reservoir drops below 50% of capacity, it is topped up with treated greywater. This, combined with (iii), keeps the reservoir level fairly constant for aesthetic purposes.

v) The Mains Supply (node 2) is a back-up supply from the centralised water supply network, used only when necessary. This is achieved using a high ‘cost’ on the Mains Supply reservoir. The Mains Supply reservoir is also marked as a ‘drawdown’ reservoir which resets after each year and tracks the yearly use of water from the centralised supply network.

vi) Roof rainwater is the primary source of potable water, assumed treated to potable standards.

vii) Potable demand is always met since the Mains Supply acts as a back-up. It is noted that one of the main objectives of using cluster roof run-off as the primary potable supply is to minimise the drawdown from the centralised water supply network.

viii) Blackwater is sent to an external sewage network, and therefore is not included in any recycling.

ix) A rainfall node is also included, its purpose being to provide a summary of the daily rainfall.

x) Since potable demand is always met, there will always be greywater outflow from the allotments, thus there will always be some non-potable water available. If stormwater plus greywater cannot meet non-potable demand, non-potable shortfalls may occur.

3.3 Step 3: Establish links between urbanCycle and urbanNet

In urbanNet, the “Edit..urbanCycle Links” dialog was used to create the necessary links to the urbanCycle data. Figure 7 shows how the nodes of urbanCycle were linked to those of urbanNet

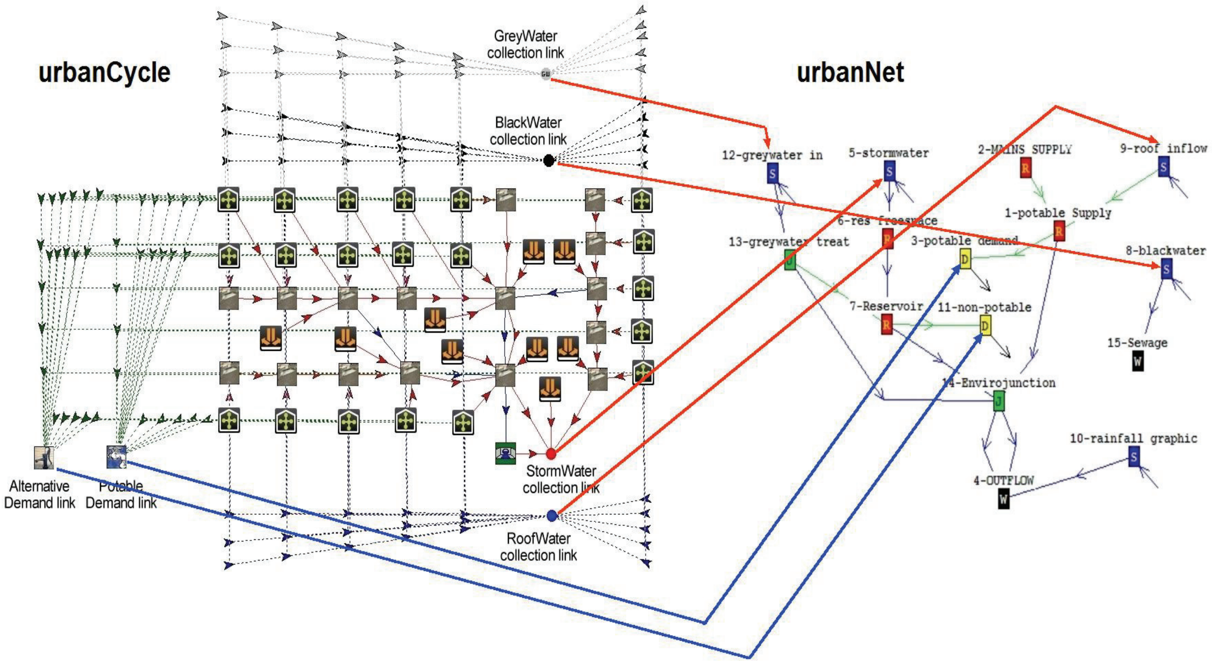


Figure 7: urbanCycle to urbanNet links

3.4 Results

The main aim of this case study was to show that the concept of combining two different modelling environments was feasible and gave reliable results upon implementation. Figures 8 to 10 show some of the urbanNet outputs for a one-year simulation of the linked urbanCycle / urbanNet model. urbanCycle provided the flow and demand data, while urbanNet kept track of reservoir levels and made decisions as to where water is sourced etc.

3.4.1 Stormwater Reservoir

One of the objectives of the urbanNet network was to keep the Stormwater Reservoir at a reasonably constant level. The stormwater reservoir time series in Figure 8 shows that this objective has been largely met, except during and just after high rainfall events when some peaks in level occur..

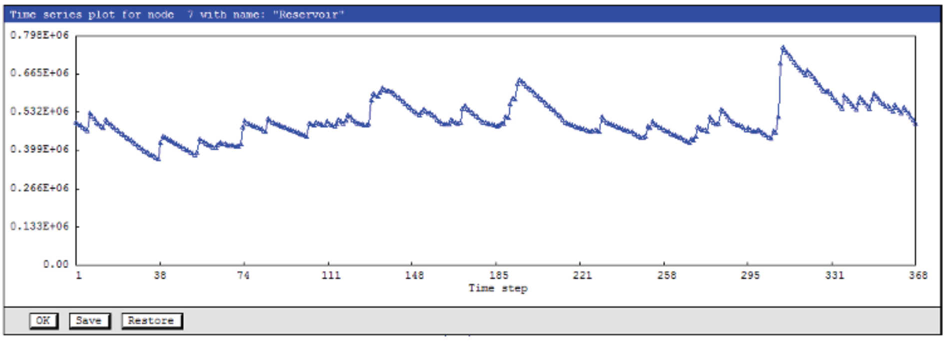


Figure 8: Stormwater Reservoir Level.

3.4.2 *Rainwater Storage Tank*

The initial rainwater tank size trialed was 200kL. Figure 9 shows the rainwater storage tank levels. While the level fluctuated somewhat, there were only three or four short periods during the year when the rainwater storage tank emptied and mains water back-up was invoked.

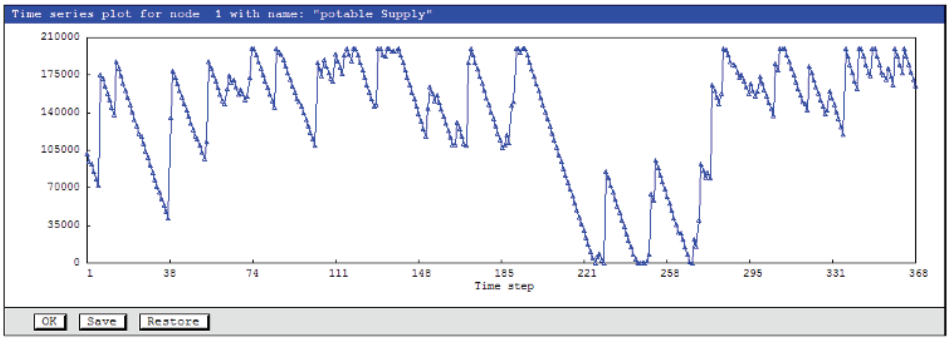


Figure 9: Rainwater Storage Tank Level (200kL capacity).

3.4.3 *Drawdown from the Centralised Reservoir*

One of the main aims of the urbanNet network was to minimise the drawdown from the centralised water supply system. Figure 10 shows the drawdown of mains water from the centralised network which occurred whenever the 200kL rainwater storage emptied. The figure shows that the drawdown amount was quite small. Indeed the total yearly centralised drawdown was 34.5kL out of a total yearly water demand of 3.925ML. This represents a mains water saving of approximately 99.1% of the total demand compared to a conventional network where all water is drawn from the centralised system.

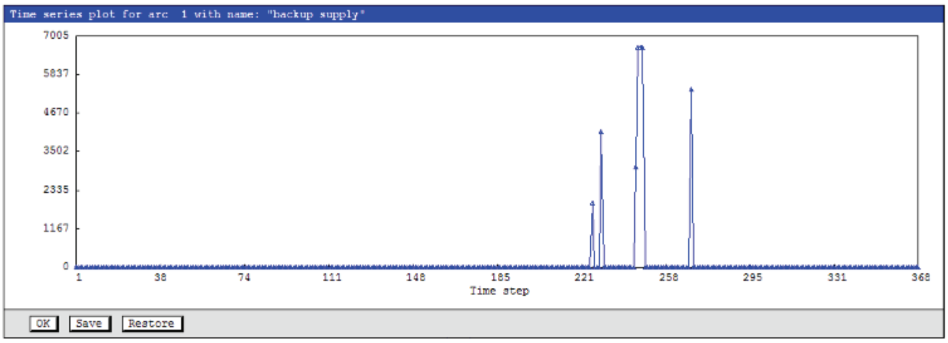


Figure 10: Water used from the centralised supply (200kL rainwater tank).

To investigate the effect of different rainwater storage tank sizes, the simulation was re-run with tank sizes of 100kL, 150kL and 250kL. The saving for the 100kL tank was 95.4%, for the 150kL tank the saving was 97.8%, while for the 250kL tank there was no requirement for drawdown of water from the centralised system at all. This data clearly illustrates the effectiveness of this type of water harvesting and recycling system.

3.4.4 *Overflow from the system*

Another objective of the system was to minimize outflow or wastage from the system.

The analysis of simulations with different tank sizes showed that for the 200kL tank, approximately 0.98ML water was lost as overflow, while for 100kL, 150kL and 250kL tanks, the amounts were 1.15ML, 1.05ML and 0.93ML respectively. As the largest overflow on any one day was approximately 300kL, it would have required a much larger tank to fully capture all the roof run-off. By trading-off the overflow and water savings against financial costs, decisions can be made as to which tank capacity was preferred for this particular IUWM scheme.

3.5 DIFFERENT SCENARIOS

To show the flexibility of the modelling environment, two other scenarios were modelled. Both cases use the same urbanCycle cluster layout, but different methods of supplying the water are implemented in urbanNet and in the demand dialog of urbanCycle. Figure 11 shows the slight change made to the urbanNet layout for both scenarios, namely the reorganisation of the supply to the potable and non-potable demand nodes so that the decentralised storage supplies the potable demand, while non-potable demand is met from the harvested rainwater storage.

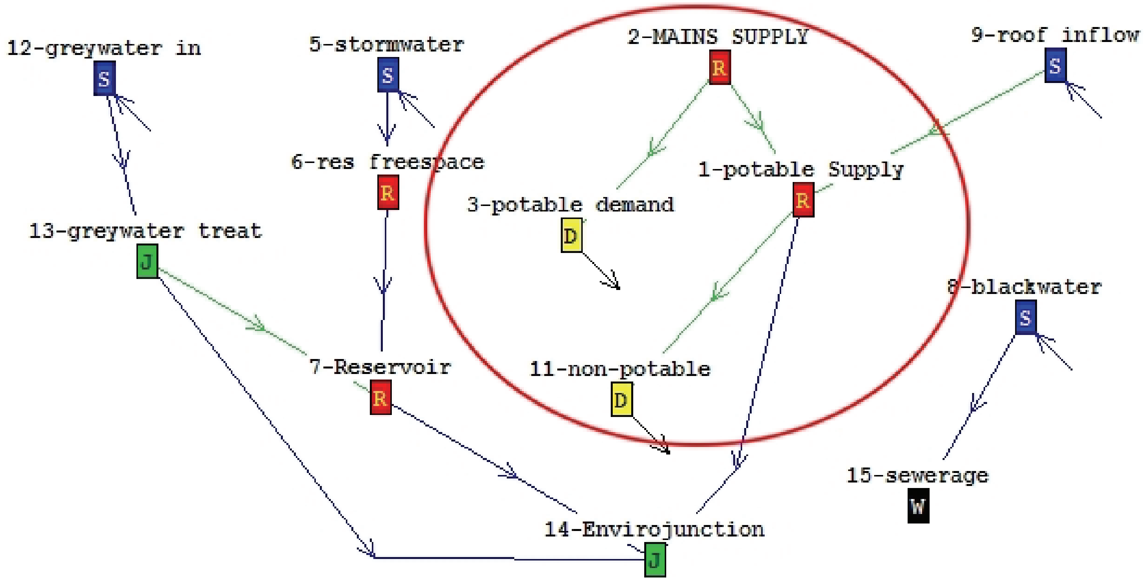
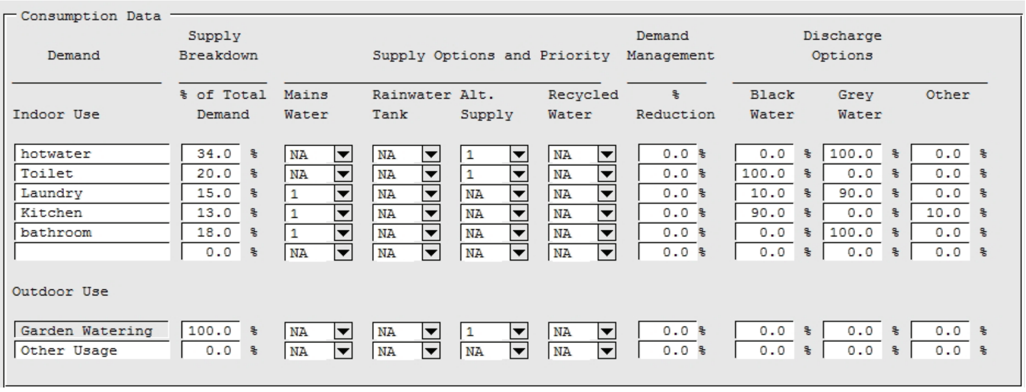


Figure 11. Modified urbanNet layout

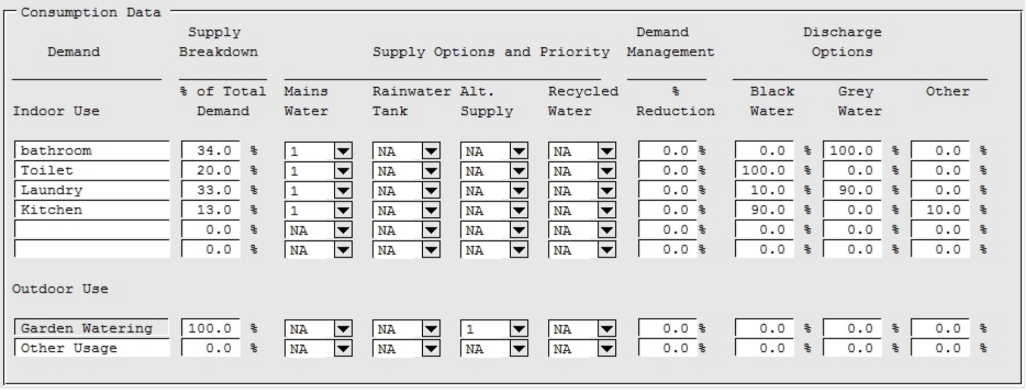
In urbanCycle, scenarios 2 and 3 use different usage settings, as shown in Figures 12a and 12b. When these scenarios were run, there were large differences in the amount of water drawn from the main centralised reservoir. Remembering that the total demand is 3.925ML for the year, and that the initial scenario was optimised so it did not draw any water, scenario 2 drew 1.37ML, while scenario 3 required 2.98ML. These 3 different scenarios, plus the mains only usage, give four points on a water savings curve that could be used by optimisation routines to help decide which is the most appropriate type of integrated urban water management scheme for a particular development.



Consumption Data

Demand	Supply Breakdown	Supply Options and Priority				Demand Management	Discharge Options		
Indoor Use	% of Total Demand	Mains Water	Rainwater Tank	Alt. Supply	Recycled Water	% Reduction	Black Water	Grey Water	Other
hotwater	34.0 %	NA	NA	1	NA	0.0 %	0.0 %	100.0 %	0.0 %
Toilet	20.0 %	NA	NA	1	NA	0.0 %	100.0 %	0.0 %	0.0 %
Laundry	15.0 %	1	NA	NA	NA	0.0 %	10.0 %	90.0 %	0.0 %
Kitchen	13.0 %	1	NA	NA	NA	0.0 %	90.0 %	0.0 %	10.0 %
bathroom	18.0 %	1	NA	NA	NA	0.0 %	0.0 %	100.0 %	0.0 %
	0.0 %	NA	NA	NA	NA	0.0 %	0.0 %	0.0 %	0.0 %
Outdoor Use									
Garden Watering	100.0 %	NA	NA	1	NA	0.0 %	0.0 %	0.0 %	0.0 %
Other Usage	0.0 %	NA	NA	NA	NA	0.0 %	0.0 %	0.0 %	0.0 %

Figure 12a: scenario 2 - toilet, garden and hot water (to kill pathogens) use alternate supply (harvested roofwater)



Consumption Data

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Indoor Use	% of Total Demand	Mains Water	Rainwater Tank	Alt. Supply	Recycled Water	% Reduction	Black Water	Grey Water	Other
bathroom	34.0 %	1	NA	NA	NA	0.0 %	0.0 %	100.0 %	0.0 %
Toilet	20.0 %	1	NA	NA	NA	0.0 %	100.0 %	0.0 %	0.0 %
Laundry	33.0 %	1	NA	NA	NA	0.0 %	10.0 %	90.0 %	0.0 %
Kitchen	13.0 %	1	NA	NA	NA	0.0 %	90.0 %	0.0 %	10.0 %
	0.0 %	NA	NA	NA	NA	0.0 %	0.0 %	0.0 %	0.0 %
	0.0 %	NA	NA	NA	NA	0.0 %	0.0 %	0.0 %	0.0 %
Outdoor Use									
Garden Watering	100.0 %	NA	NA	1	NA	0.0 %	0.0 %	0.0 %	0.0 %
Other Usage	0.0 %	NA	NA	NA	NA	0.0 %	0.0 %	0.0 %	0.0 %

Figure 12b: scenario 3 - only external water uses alternate supply (harvested roofwater)

4 FURTHER INVESTIGATIONS

The case study was designed as a simple proof-of-concept study to illustrate the basic features of the proposed modelling environment. A much larger concept study is underway to investigate the effects of IUWMS in more depth. It will contain some 400+ allotments as well as retail, parkland and mixed use clusters. Some of the questions that will be investigated are:

- Is there an optimum size for cluster roofwater harvesting?
- Is there an optimum size for cluster greywater harvesting and re-use?
- How can urban clusters be integrated into larger, regional scale models?
- What costs are incurred in implementing different IUWM scenarios, and how can these be offset against other issues such as regional drought security?

5 CONCLUSION

The combination of a directed acyclic (tree-type) modelling environment with a network linear program shows great promise for the realistic modelling of cluster size water harvesting, recycling and supply networks. With sufficient computer power, the modelling system could be extended to small suburban scenarios that could operate as almost self-sufficient subsections of the larger water supply network thus reducing drawdown on the centralised reservoir, thereby increasing regional drought security.

Future work will focus on running simulations of different scenarios using real urban developments to study the concept of the cost vs water savings curve, for possible implementation into regional scale modelling.

6 LIST OF REFERENCES

Coombes, P.J, Thyer, M.A., Frost,A., Kuczera, G., Grimster, I. (2002) "*Development of Stochastic Multisite Rainfall and Urban Water Demand for the Central Coast Region of New South Wales*" 28th International Hydrology and Water Resources Symposium

Hardy, M. (2009): "*Integrated Urban Water Cycle Management and the urbanCycle Modelling Framework* " PhD Thesis, University of Newcastle, Callaghan. NSW. Australia

Heneker, T.M., Lambert, M.F. and Kuczera, G., (2001). "*A point rainfall model for risk-based design"*. Journal of Hydrology(247): 54-71

Kuczera, G.A. (1997) "*WATHNET: Generalised Water Supply Headworks Simulation using Network Linear Programming. Version 3.00*"

Kuczera, G.A. (2008) "*Urban Water Supply Drought Security: A comparative Analysis of Complimentary Centralised and Decentralised Storage Systems*" 31st Hydrology and Water Resources Symposium. Adelaide 2008

Mitchell V.G., Siriwardene N., Duncan H. and Rahilly M. (2008). "*Investigating the impact of temporal and spatial lumping on rainwater tank system modelling*". 31st Hydrology and Water Resources Symposium. Adelaide

Mitchell, V.G. (2005) "*Integrated Urban Water Management: A review of current Australian practice*" Australian Water Conservation and Reuse Research Program. ISBN0 643 09187 4

Pilgrim, D. H. & Institution of Engineers, Australia. (1997) "*Australian rainfall and runoff : a guide to flood estimation"* Institution of Engineers, Australia, Barton, A.C.T.

Thyer, M., L. Cui, T. Micevski, P. Coombes, and G. Kuczera (2008), "*Urban Water Use Modelling Framework*", Summary Report June 2008, eWater CRC.