Integrated Urban Water Cycle

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Abstract

This paper looks at water sensitive urban design in its broadest context incorporating water supply, wastewater, and stormwater services. It is our thesis that cost reduction and reconsideration of the economics of water supply, wastewater and stormwater services, combined with re-examination of emerging technologies and customer attitudes, will expand the range of options available to be adopted in particular circumstances. It is our further contention, that no one solution is appropriate for all circumstances, and that increases in the range of options available will lead to better tailoring of water systems to site specific conditions. The paper outlines some of the outcomes of the CSIRO Urban Water Program that point to the opportunities to take an integrated approach to the urban water cycle.

Establishment

From the outset, it is essential that we establish what aspects of urban water systems we are referring to in discussion water sensitive urban design. Perhaps because we consider reticulated water and sewerage systems as being artificial, and rainwater as natural, there has been a tendency firstly to consider effective management of stormwater as being the principal focus of water sensitive urban design. Significant effort has been directed to conceptualising means by which natural surface water flow patterns can be mimicked; similar levels of attention need to be paid to improving the performance of underground water and sewer reticulation systems. Furthermore, it is the integration of water supply, wastewater and stormwater that should be a fundamental principle underpinning water sensitive urban design. The following quote encapsulates this concept: "*water sensitive urban design is the application of a wide range of within catchment measures to manage the impacts of urban developments on the total water cycle*" (WBM Oceanics Australia, 1999).

Consider some examples. Retardation of stormwater for later discharge also provides a store of water that could be used for, say, toilet flushing or washdown water, where potable quality water is not required. Reduction of potable demand, in turn, reduces dependence on remote water sources, possibly allowing more water to be made available for environmental flows or obviating the need for new dams to be constructed.

Similarly, transfer of sewage under pressure or by vacuum would reduce ingress into sewer systems, allowing sewage treatment plant performance to be optimised, reducing the incidence of overflows and cutting the cost of the reticulation network. The combination of improved water system performance and better sewage treatment may increase the viability of recycling and will affect the scale at which new sewerage systems should be designed (ie number of dwellings connected to a single system)

Finally, it is evident that provision made for fire flows in reticulation systems adds significantly to the costs of those systems. Better urban design to reduce fire risk, and consideration of alternative approaches to fire protection, such as domestic sprinklers, would reduce reticulation system costs, affecting, in turn, ensuring that demand management (including peak flow mitigation) would flow through more directly to system cost reduction.

Sustainability?

Let us consider firstly what is meant by sustainability. In doing so, I do not wish to debate definitions, but rather establish some common ground. We accept, I believe, that *Ecologically Sustainable Development* requires the integration of factors affecting society, the economy and the environment. It could be said that sustainability improves when a system, process or product is made more equitably (ie less impact across or between generations) more efficiently or in a way which reduces its environmental impact.

This statement may surprise some who feel that environmental protection is all that ESD is about. But consider that within an economy the greater the proportion of funds spent on one good or service, the fewer available to be spent elsewhere, including the environment. Further, passing of liabilities between or across generations reduces the ability of those groups to pay for environmental improvements and may lead to over consumption of natural resources, where those resources are considered ‘free’ goods.

It follows that if ecologically sustainable development is a multifaceted objective different solutions will be required for different locations. Likewise, water sensitive urban design encompasses many different measures that have a range of suitable applications, resulting in many different realisations of this concept, depending on the site-specific conditions of the location.

For example, in a district that has implemented demand management but is still facing water restrictions due to a paucity of storage capacity, stormwater and wastewater use may provide a means by which additional water sources can be accessed cost effectively. Similarly, an established area undergoing infill development may be able to drive its assets harder (thereby reducing materials usage) if it requires all new developments to mitigate stormwater flow and to provide flow balance tanks. What must be understood is that no one approach will be appropriate for all circumstances. Ocean discharge, for example, may be the best option where the quality of effluent disposed of meets receiving environment needs and where, say, land disposal is constrained due to lack of space or unsuitable soils and the environmental and economic cost of recycling is prohibitive. This is really the “appropriate technology” concept applied to the total urban water cycle.

The most important outcome of research into urban water systems is to increase the range of opportunities available to develop more sustainable systems. A reduction, say, in the cost of recycling may make this a viable option for a greater range of conditions. Perhaps it is not stretching an analogy too far to suggest that in as much as the robustness of ecological systems is increased through diversity, so too will the sustainability of urban water systems be improved if an increased range of options are made available enabling solutions to be tailored to local circumstances. Dogged adherence to one approach is counter productive and likely to lead to a reduction rather than an increase in sustainability.

Urban water systems are complex and inter-related. Changes to a system will have downstream or upstream impacts that will affect costs, sustainability or opportunities. For example, the approaches of demand management and the utilisation of local stormwater and wastewater resources may work against one another. It is evident in CSIRO's analysis of domestic water use patterns that the impact of the introduction of 6/3 litre dual flush toilets has been significant (ARCWIS, 1999). 65% of homes in the survey undertaken now have at least one dual flush toilet installed. This has led to toilet water use falling from the 2^{nd} largest indoor use of water behind bathroom use (MWA, 1985) to 3^{rd} position behind both bathroom and laundry use (ARCWIS, 2000). Consider, though, that flushing of toilets with stormwater or wastewater is the use of such water that is most strongly supported by consumers (see discussion below). The uptake of dual flush appliances has led to a decline in the potential market for reclaimed water for toilet flushing of almost 30%.

This is a simplistic example and in some situations demand management will improve the volumetric reliability of a particular stormwater and/or wastewater use method. But it provides illustration for the argument that pursuit of a single solution is undesirable. Far better that our research be directed to, say, reducing the cost of recycling so that both demand management *and* recycling are potentially viable: the one chosen will depend on local needs and conditions.

CSIRO Urban Water Program

The program we have tried to design within CSIRO then has been directed to increasing the range of options available in order to manage the impacts of urban development on the total water cycle. There has been a concentration on design, performance and configuration of urban water supply, stormwater, and wastewater systems. It has been attempted to develop these within a framework that considers the social acceptability of alternatives – based on an analysis of customer needs and demands – and economic efficiency. From the outset, the view was taken that approaches that were more expensive than those currently employed would not be taken up by industry and those anathema to the community, or which produced unacceptable impacts on one part of the community would not be supported.

There is insufficient space here to detail all of the outcomes of the Urban Water Program. Instead, the following section is aimed at illustrating the way in which the range of options available to the community has been increased as a result of the programs work. Bear in mind that the work completed to date has been a feasibility stage, and that the validity of the outcomes is yet to be confirmed. Although, there is sufficient confidence in the work to suggest that there are some real opportunities available that warrant incorporation into water supply, stormwater and wastewater systems in future.

Example 1 – *System reconfiguration: Pressure Management; Peak Flow Management; Recycling*

CSIRO's Urban Water Program considered closely the operation of water supply and wastewater reticulation systems, looking in detail at their performance in terms of the flow of water and contaminants through them, and the costs of their operation. Costs included traditional operating and capital costs as well as lifecycle costs and externalities and identification of the drivers of cost (eg the need to provide for firefighting).

It has been argued that the cost of direct non-potable recycling (requiring the reticulation of reclaimed water back to homes and commercial establishments) is expensive because of the need to duplicate the pipe network (one system for potable, one for non-potable). Direct non-potable recycling, if achievable would provide a significant market for reclaimed water, greater in most circumstances than that available through industrial application and watering of public open spaces). However, neither recycled nor potable systems need to be provided through traditional means. Using the flow balancing and pressure reduction techniques explained below, combined with separate greywater and blackwater systems (which increases the efficiency of operations of sewage treatment facilities and avoids dilution of nutrients) recycling can be achieved at a cost comparable to conventional systems despite the additional infrastructure required (Figure 1).

Figure 1, below, illustrates the comparative initial capital and operating costs of three different systems compared to a conventional approach. Viewed left to right, each new system incorporates the previous one. Thus, the peak flow levelled system incorporates pressure management: the system incorporating recycling, includes both pressure management and peak flow levelling.

More substantially, water reticulation design is driven to a large extent by the need to cater for peak instantaneous demand. Peaks occur in the morning and evening (Figure 2) and also display a seasonal effect. Mitigation of these peaks would also produce substantial cost reductions. This would be achieved by installing flow balance tanks closer to the user. In the example depicted in Table 1 tanks were installed at each house. Where recycling is included, flow balancing was applied to both the potable water and recycled lines. The combined size of the tanks is no greater than 1 cubic metre.

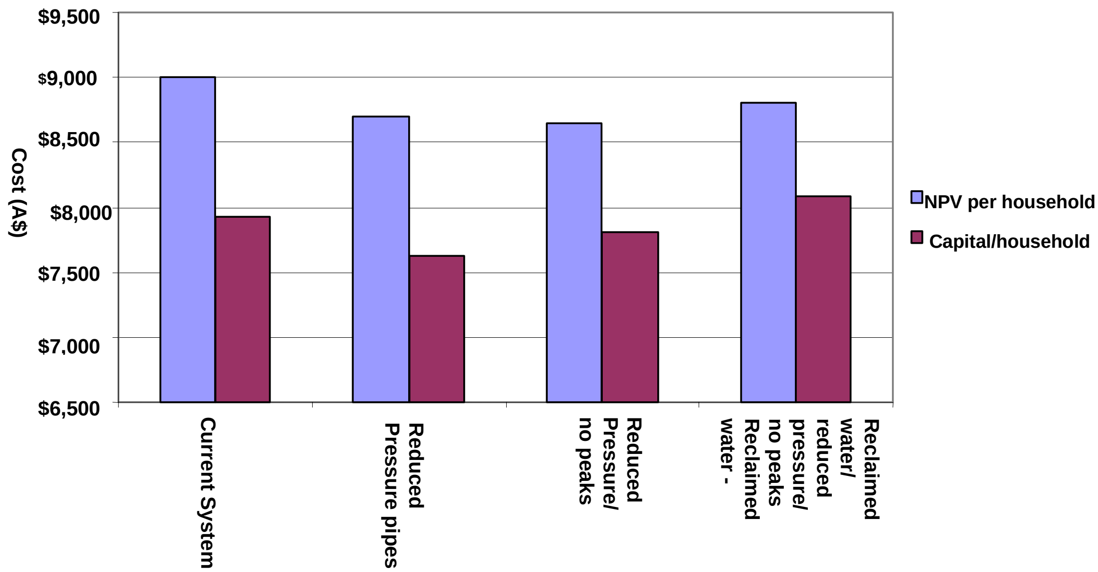

Figure 1: Costs per household for the four scenarios

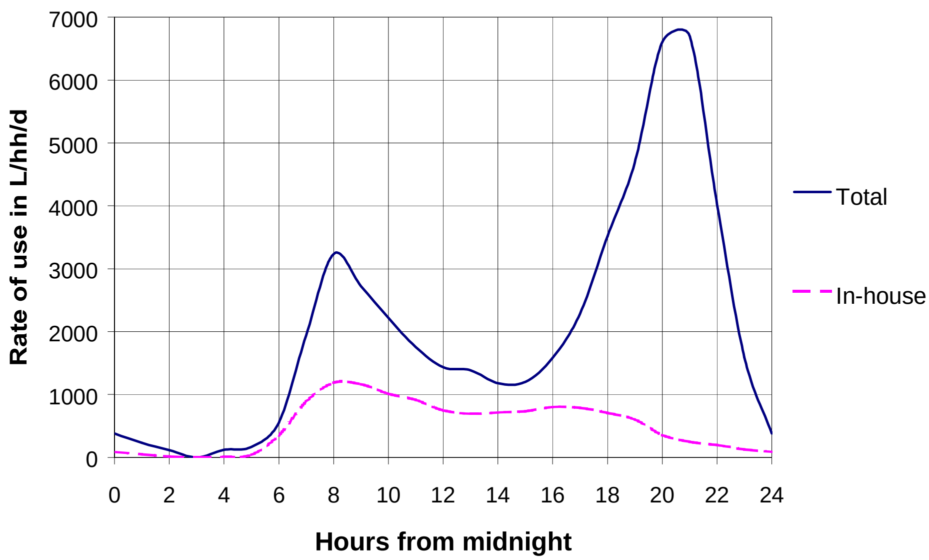

Figure 2: Design curve of diurnal variability in water supply

This should not be taken to suggest that recycling is a 'single right solution'. Rather, that where augmentation of supply is required, or the discharge of treated effluent is causing negative environmental impacts recycling could be considered an option, particularly in developing fringe areas.

Example 2 – Cost Effective Nutrient Management

The discharge of nutrients, particularly phosphorus, are strictly controlled in Australia due to their impact on receiving environments.. While most of Australia's major cities are sewered, fringe urban areas and many villages continue to rely on septic tanks. The cost of providing sewerage in these areas is high, and progress in reducing the backlog is correspondingly slow. Using the contaminant and water balance modelling capability, and data on costs of existing systems and new technologies, a comparison of a range of alternatives for installation of sewerage services has been conducted (listed in Table 1. For this exercise, six alternatives were compared. Note that this exercise was carried out for a hypothetical urban area of 10,000 connections. The results are given in Table 1.

Table 1: Comparison of alternatives for replacement of septic tanks

System	$/house	N discharge (kg/yr)	P Discharge (kg/yr)	Pathogens
1. Conventional sewage treatment – remote from urban area (tertiary treatment: 5 mg/l N, 0.5 mg/l P)	6,160	2,300	230	Low
2. Conventional sewage treatment – localised treatment (tertiary treatment: 5 mg/l N, 0.5 mg/l P)	5,450	2,300	230	Low
3. Localised blackwater treatment				
Blackwater discharge	2,325	370	37	Low
Greywater seepage		4,200	810	Moderate
Total		*4,570*	*847*	
4. Localised blackwater and greywater treatment (tertiary treatment: 5 mg/l N, 0.5 mg/l P)	5,725★ (3,240◆)	2,300	230	Low
5. Blackwater and greywater with non-potable recycle.*	6,575★ (4,085)◆	4,200*	190*	Low
6. Septic tanks (no effective removal of N or P).	n/a	54,000	6,500	High

**includes a stormwater discharge. Used Perth rainfall data (yearly time step). Estimates ignore the loads discharged by exfiltration or sewer overflows.*

★ assumes separate pipes for transport of greywater and blackwater.

◆ assumes a single pipe with scheduling of flows for transport of greywater and blackwater.

The critical finding was that local blackwater treatment alone achieved reductions in P and N to 13% and 8.5% respectively of the discharges from septic systems at only 35% of the cost of a conventional system. This indicates that superior environmental outcomes could be achieved where the right conditions exist more cost-effectively than conventional approaches.

Clearly, provision of sewerage services incorporating blackwater only treatment would not be appropriate for densely developed fringe areas. However, in peri-urban areas that lack such services (often because they are very expensive to serve) such approaches provide a way of protecting public health and substantially improving services at lower cost.

Stormwater management and utilisation

The objectives of stormwater management have broadened over the last decade, from purely flood protection, to encompass pollution control, ecological regeneration, and enhancement of stormwater amenity value (Thomas et al., 1997). Water can provide other values in our urban landscape apart from a supply source. Water bodies such as ponds and wetlands as well as creeks, streams and rivers can add significantly to the aesthetic and recreational amenity of an urban area. This view is one of the concepts that underpins the water sensitive urban design movement.

In addition to this broader view of stormwater management, stormwater is increasingly being seen as a resource that we have undervalued thus far. Stormwater utilisation is likely to be of significant environmental benefit through the reduction of non-point source pollution and minimisation of the requirement to augment traditional water supply (WBM Oceanics Australia, 1999). Options for stormwater use within an urban catchment include approaches that substitute stormwater for potable water supplies, such as on-site rainwater tanks, community collection and storage for irrigation, aquifer storage and recovery. Much of the CSIRO Urban Water Program's work to date in relation to stormwater has focused on this idea of replacing imported potable water with locally sources of stormwater.

There is no comprehensive data presently available on the extent of urban stormwater utilisation in Australia, although anecdotal evidence would suggest that only a small proportion of stormwater generated from urban areas is used. Even in South Australia, where stormwater use is widespread and the trend is for more such activity, the portion of total water use supplied by stormwater is still small (WBM Oceanics Australia, 1999). Exceptions to this trend are the cities of Perth and Canberra. In Perth, there is extensive indirect stormwater use due to the prevalence of onsite disposal of roof runoff through spoon drains and extensive use of shallow groundwater bores for non-potable water supply. The city of Canberra utilises stormwater from detention basins for non-potable uses, reported as providing 6% of it's total water needs in the mid 1990's (Anderson, 1996b).

In reference to Queensland, it has been concluded that there appears to be no serious impediments on a generic scale to prevent significantly greater use of urban stormwater than presently occurs (WBM Oceanics Australia, 1999). It is likely that this comment equally applies the rest of the states and territories of Australia. Although, any stormwater utilisation scheme would require a high level of social acceptance before it could be implemented.

Public attitude to stormwater utilisation

Consultation and market research carried out in the ACT found, that from a health perspective, the community was less concerned about the use of stormwater than of wastewater (ACTEW, 1994). This was also found in the recent domestic water use study in Perth which was conducted as part of the CSIRO Urban Water Program (ARCWIS, 1999).

In the Perth study there was slightly more support for using stormwater on home gardens (96%) as opposed to wastewater (88%) (ARCWIS, 1999). The option of using stormwater for toilet flushing was similar to the support for using wastewater for this purpose (95% and 92% respectively). Support dropped to 68% for using stormwater for laundry purposes, 50% for personal washing with stormwater, and 29% for using stormwater as a drinking water source. These results are consistence with findings of other studies that conclude that support diminishes as the use becomes more personal.

There is much support for urban stormwater use in principle among the public. If stormwater use is, however, to incorporate human contact there will be initial community disquiet (ARCWIS, 1999). The degree of acceptance will depend on assurances that there is no unacceptable health risk and that the motivation for doing so has a strong efficiency or environmental justification.

Integrating stormwater and wastewater utilisation into the urban water cycle

The main problem with the reliance on urban stormwater as the sole water source is the reliability of supply through extended dry periods. As a result, the best approach to stormwater utilisation can be in conjunction with other water resources such as currently developed potable water supplies and wastewater, to overcome need for large carryover storage.

The Urban Water Program has developed UVQ (Urban Volume and Quality) to compare conventional water systems with systems in which stormwater and wastewater are used in conjunction with existing water supplies. UVQ is a conceptual daily urban water and contaminant balance model that represents water and contaminant flows through the existing urban water, wastewater and stormwater systems, from source to discharge point.

The model can be used to investigate a large range of urban water system alternatives. For example, one could determine the impact of reuse strategies on the water and contaminant flows within an urban area. Or, one could estimate the security of supply for various water sources such as stormwater, and size the storage required. UVQ can also provide data input to environmental and human health risk assessments through the estimation of contaminant loads to the environment, and contaminant concentrations in recycle streams, loads to gardens etc.

UVQ Example – Decentralised stormwater and wastewater utilisation

Water and contaminant balance analysis was performed on a hypothetical residential neighborhood of 4000 houses, with each house having occupancy of 2.5 people (10,000 people in total). Two scenarios were considered for comparison with one another (Figure 3). The first scenario was called the base case, where potable water was supplied via a trunk main, sewage was collected and transported to a centralised sewage treatment plant and stormwater was discharged to a local watercourse. The second scenario involved utilisation of stormwater and wastewater at a local scale. The treated blackwater effluent was combined for treatment with the greywater. The treated greywater was then mixed with stormwater and held in a storage pond (with treatment) before being delivered back to the households for use in the laundry, toilet and outdoor applications. Overflow from the storage pond went to a local watercourse. The location characteristics (soil type, rainfall patterns etc) were based on the Urban Water Program case study site in the north east development corridor of Perth, WA.

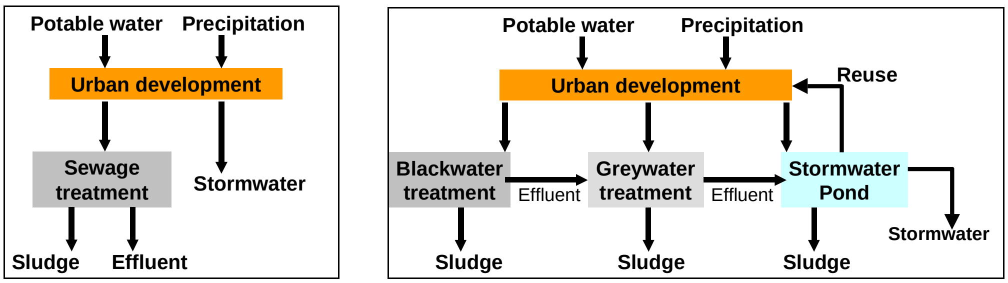

Figure 3: Base case and decentralised stormwater and wastewater utilisation system

The water supply and disposal system used in scenario two results in a 72% decrease in the average annual volume of water supply that is imported from an external source, a 25% decrease in average annual stormwater discharge and a 100% decrease in average annual wastewater discharge (Figure 4). The absence of wastewater discharge in scenario two is due to the discharge of treated effluent to the stormwater pond and the stormwater discharged is a mix of stormwater runoff and treated effluent.

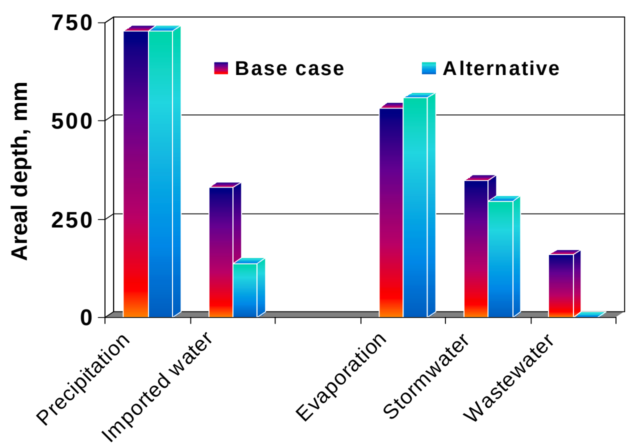

Figure 4: Change in water inputs and outputs

The results show that utilisation of stormwater and wastewater at a local scale is able to significantly decrease the nutrient (nitrogen and phosphorus) loads discharged to external water courses (see Mitchell et al, 2000 for further details). The increased load of nutrients returned to the garden as a result of water reuse, is lower than that estimated from fertiliser addition. Thus, reduced fertiliser addition is able to compensate for the extra load of nutrients supplied to the garden in the recycled water.

For metals, greater reductions in the loads discharged to external watercourses were obtained as a result of the high proportion of metals contained in stormwater. Treatment of the stormwater decreases the discharging of these elements, however, recycling returns these loads to household and increases the metal loads to the garden. The garden loads are significantly greater than those applied to the garden in the base case. The significance of the increased loads need to be interpreted by considering the ability of gardens to incorporate these metals, as well as the load of metals applied to gardens but not included in the current analysis (eg. fungicides etc).

The program permitted rapid analysis of alternative water supply and disposal systems to occur and incorporates site specific characteristics. Further use of UVQ will elucidate the strengths and deficiencies of the model, highlighting the way in which the model can be further developed to extend its usefulness and capabilities.

Conclusion

This paper has argued for an integrated approach to water sensitive urban design. Further, it has suggested that re-examination of the economics of urban water systems will increase the range of options available. Greater diversity of options will enable us to meet sustainability goals by allowing water systems to be tailoring to local conditions.

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