Recent South East Queensland Developments in Integrated Water Cycle Management – Going Beyond WSUD

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Abstract

In the last 2-3 years, several major integrated water cycle management related developments have been proposed in South East Queensland, which, if they come to fruition, will challenge the conventional urban water cycle paradigm adopted in Australia and worldwide. These developments adopt key elements of what has been seen as conventional WSUD from a stormwater management perspective (e.g. the use of roadside swales for drainage and water quality control purposes in replacement of piped drainage and the capture and reuse of roofwater from individual houses), however they also embrace a much wider gamut of integrated water cycle management techniques including the capture and reuse of rainwater at several spatial scales, the reuse of wastewater for sub potable uses and the beneficial reuse of urban stormwater.

The paper presents key details of these projects, the lessons learnt by the authors from their involvement in the projects, attempts to predict where the projects will go in coming years and highlights potential knowledge that will be gained from them.

1. INTRODUCTION

When the phrase 'water sensitive urban design' (WSUD) was first promulgated (Whelans and Halpern Glick Maunsell, 1994) some 10 years ago in Western Australia, it was referred to as '*a new approach to urban planning and design, based on the premise that conventional water supply, sewage disposal and drainage practices which rely upon conveyance and centralized treatment and discharge systems cannot be sustained in the long term*'. Unfortunately, State and Local government regulators and the stormwater management industry in Australia have seen the stormwater element of WSUD as dominating what was originally a more ***holistic*** concept, to the extent that what was originally WSUD is now more often referred to as Integrated Water Cycle Management (IWCM).

In this paper, we present several exciting South East Queensland (SEQ) based projects with illustrate that the original 'vision' for WSUD is at last being implemented. We also provide some insights into the experience and knowledge gained in working on these projects, and attempt to predict trends in the WSUD/IWCM field in coming years.

2. KEY PROJECTS

There are three key projects with which the authors of this paper have been involved which illustrate the potential changes in what is seen as WSUD in the SEQ region. These projects are presently in various stages of development, and are as follows:

- Currumbin Ecovillage;
- Coomera Pimpama Water Futures; and
- Yarrabilba.

Summary details of the first two of these projects, and more detailed descriptions of the latter, are provided below.

2.1. Currumbin Ecovillage

The EcoVillage project is being developed on a 110ha site in the Currumbin Valley on the Gold Coast. The proposal provides for 144 eco-homes in a variety of residential configurations, together with comprehensive community oriented facilities including a Village Centre and a school.

From a water perspective, the key elements of the Currumbin Valley Ecovillage are autonomy in potable water and wastewater (i.e. no external reticulated water connection and minimal wastewater discharges) and integrated internal water quality control measures that exemplify WSUD principles.

The product of 7 years of extensive research both in Australia and overseas, the Currumbin Ecovillage will set a benchmark for sustainable residential development, with environmental, social and economic sustainability as its integrated driving principles.

2.2. Coomera Pimpama Water Futures

The Gold Coast is one of the fastest growing regions in Australia, expecting to triple its population over the next 50 years. This level of growth will place increased demands on water and wastewater infrastructure within a region that has recently experienced the worst drought on record.

The Coomera Pimpama region is a new urban development, which will experience a high proportion of this population growth in the coming years. Plans to implement smarter water systems position the region to be one of Australia's first truly water sustainable communities.

Gold Coast City Council initiated the Coomera Pimpama Water Futures Project in late 2002. The project will deliver a Master Plan for the region that provides water and wastewater services in a more sustainable way. Figure 1 shows one of a number of options being considered for water management in the project.

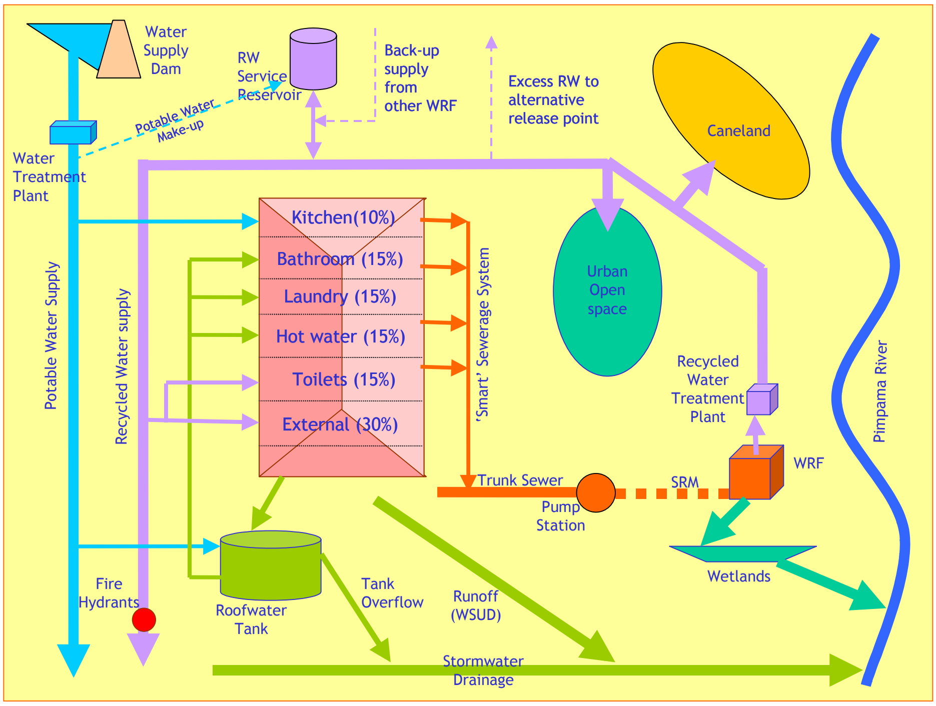

Figure 1 - Coomera Pimpama Water Cycle Illustration

The Master Plan is a blueprint for the delivery of water and wastewater services to the Coomera Pimpama region that will see the implementation of a fully integrated urban water management strategy for the region, including the introduction of alternate water sources such as recycled water and rainwater. It will also see a greater emphasis on the protection of the environment through improved stormwater management, with the integrated water cycle and stormwater elements being developed using 'complete' WSUD principles. The Master Plan will be the planning basis for the provision of all water related services in the region.

Since January 2003 all new development in the Coomera Pimpama region has been required to install recycled water mains as well as drinking water mains. Whilst this was put in place before the Advisory Committee made a final decision on the detail of the Master Plan it was an important step in ensuring that most of the properties in the area would be able to take advantage of the future access to recycled water.

2.3. Yarrabilba

Delfin Lend Lease Ltd (DLL) is developing the suburb of Yarrabilba, in the Shire of Beaudesert, Queensland. DLL is currently preparing a development application for the proposed development, which involves the creation of between 11,500 and 23,000 urban residential dwellings, incorporating several elements such as residential neighbourhoods, a town centre, schools, light industrial areas, public open space, and community facilities.

See Section 3.0 below for a detailed description and discussion of this project.

3. YARRABILBA PROJECT

The development site covers an area of approximately 2000 hectares, approximately 6km south of Logan Village. The location of Yarrabilba is shown in Figure 2. The land uses within the development are shown in more detail in Figure 3.

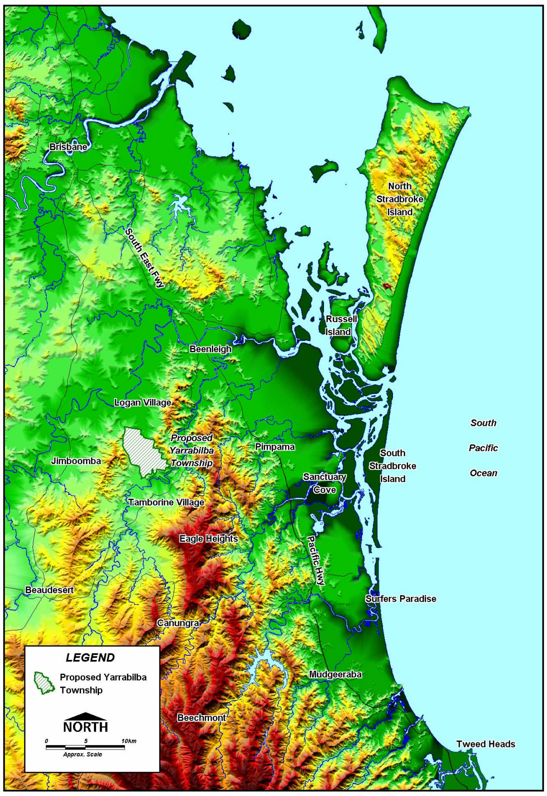

Figure 2 - Yarrabilba Locality Map

A critical component of the feasibility analysis of the Yarrabilba development was an assessment of its overall likely potable water demand and wastewater generation characteristics, given potential limitations in future potable water supply and recognised water quality degradation of the nearby

Logan and Albert Rivers due to existing point and diffuse sources of pollutant loading (EHMP 2004). As such, there was a requirement to assess the likely integrated water balance of Yarrabilba. In particular, hydrological, lot scale and development scale water balance modelling was required to examine the complete water cycle behaviour of the proposed development under different potential lot and catchment configurations.

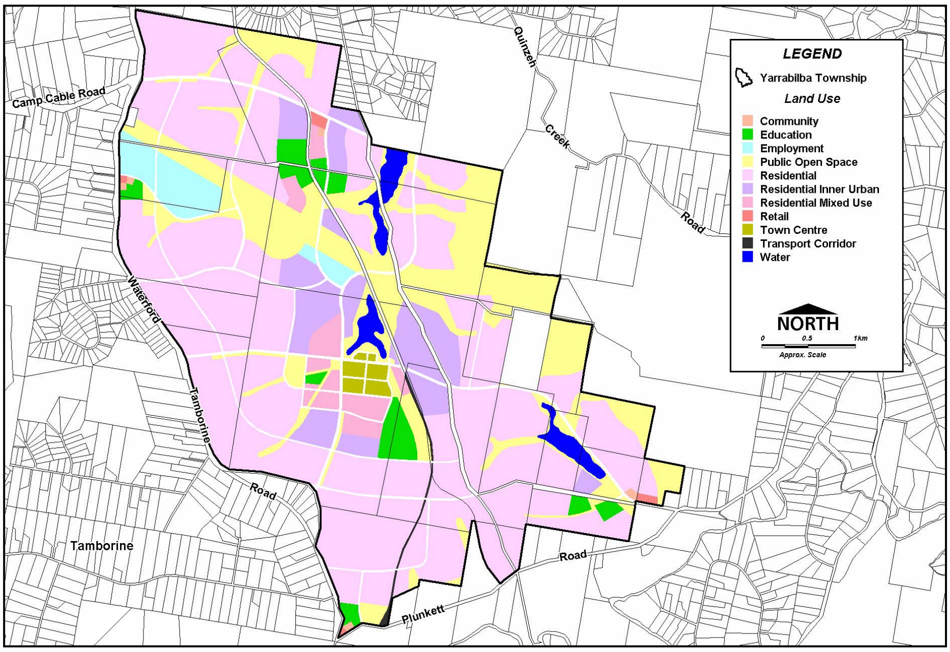

Figure 3 - Yarrabilba Land Uses

Modelling of the Yarrabilba water cycle involved the integration of three primary modelling tools, focused at three different spatial scales: the catchment scale, the lot scale and the development scale. Both the lot and catchment scale-modelling results fed directly into the development scale water cycle model using climate and scale specific transfer processes. The development scale model was then used to investigate issues such as:

- The overall performance of various urban water cycle management techniques, as measured by their impact on:
  - Mains water demand;
  - Wastewater and stormwater discharges; and
  - Potential external wastewater harvesting.
- The variation of intra-annual water cycle behaviour; and
- The probabilistic reliability of proposed water cycle management tools as measured by their ability to meet the demands of the entire development.

This integrated approach required the execution of four distinct modelling phases:

1. Hydrologic catchment definition and land use re-assignment;
2. Catchment stormwater modelling;
3. Lot-scale water balance modelling (including the behaviour of rainwater tanks and other devices); and
4. Global water balance modelling of the entire development, including the roles of sewage treatment plant storages, stormwater storages and imported mains and wastewater.

The following sections describe the later three of these phases as the first phase is relatively straightforward.

3.1. Hydrological Assessments

Approach

In order to provide an estimate of the likely stormwater volumes generated on site, catchment modelling was undertaken for both the pre and post development scenarios using the SimHyd model. SimHyd is a daily conceptual rainfall-runoff model that simulates daily streamflow from daily rainfall and areal potential evapotranspiration data. It is a component of the Rainfall Runoff Library (RRL) of models recently produced by the Cooperative Research Centre for Catchment Hydrology (CRCCH). The conceptual framework of SimHyd is shown in Figure 4.

The model estimates runoff generation from three sources

- Infiltration excess runoff;
- Interflow (and saturation excess runoff); and
- base flow.

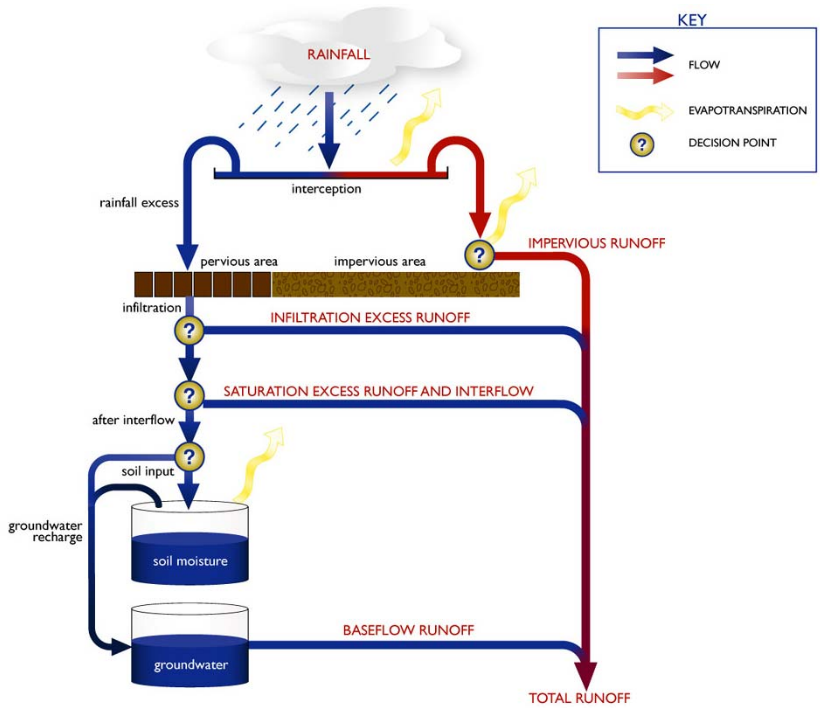

Figure 4 - SimHyd Conceptual Framework

Calibration
Since Yarrabilba does not exist at present, the catchment model could not be calibrated to site-specific data. As such, calibration of the SimHyd model was undertaken using previously collected daily rainfall and flow data from a representative existing urban catchment in Brisbane. This selected catchment was Sandy Creek, Indooroopilly, Queensland, which has the most comprehensive local data set of rainfall and runoff for an urban catchment. Calibration was undertaken using data collected over the period 1/9/1994 to 27/12/1995, inclusive. The SimHyd calibration parameters derived for Sandy Creek, achieved using optimization routines available within the Rainfall Runoff Library, are shown in Table 1 while the corresponding correlation between modelled and measured flow is shown in Figure 5. The modelled runoff shows an excellent correlation with the observed values, both to the entire data set and the specific range of smaller flows (to remove any biasing to the fewer, larger flow events), with an overall correlation coefficient of 0.94.

Table 1 - SimHyd Calibration Results

Parameter	Value
Baseflow Coefficient	0.45
Impervious Threshold (mm)	1.73
Infiltration Coefficient	371
Infiltration Shape	7.0
Interflow Coefficient	0.14
Pervious Fraction	0.70
Rainfall Interception Storage Capacity (mm)	3.58
Recharge Coefficient	1.0
Soil Moisture Store Capacity (mm)	281

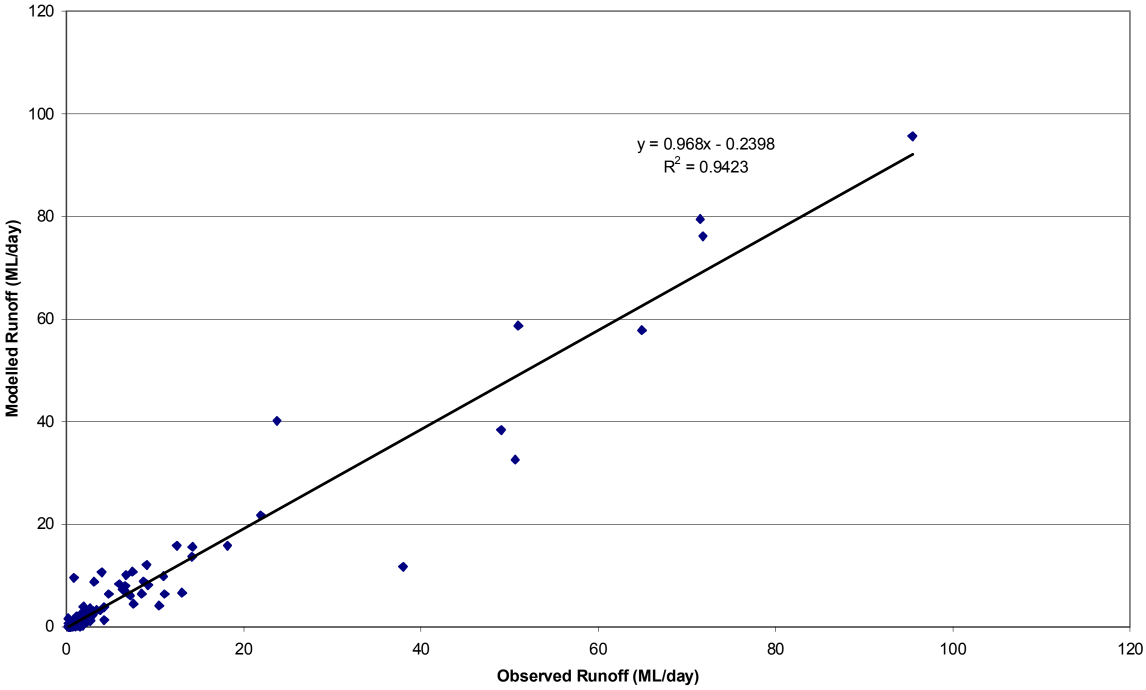

Figure 5 - SimHyd Calibration for Sandy Creek

3.2. Lot Scale Assessment

Approach

The Probabilistic Urban Rainwater and wastewater Reuse Simulator (PURRS) model developed by Urban Water Cycle Solutions was used to assess the behaviour of the lot scale water balance for the Yarrabilba site. This model has undergone extensive process and methodology testing over the past five years and has been widely used throughout Australia in studies similar to the Yarrabilba project. We note that there are other models in use for similar applications within Australia (e.g. Aquacycle (Mitchell *et.al.*, 2001) and Watercress (Clark *et.al.*, 2002) to name just two). PURRS was chosen in this case as it was considered to be appropriate given the short time step used in its simulation and also due to the considerable body of research by its author, Dr. Peter Coombes, which has underpinned its development. The close linkage between the lot scale PURRS model and the development scale WATHNET model was also a key consideration.

The PURRS model uses continuous simulation techniques to simulate the long-term performance of source control measures including rainwater tanks, water efficient appliances, wastewater reuse and other stormwater management devices on urban allotments at short time steps (< 6 minutes), and determines the impact of rainwater tanks and other lot scale water reuse measures on the provision of water supply, sewage and stormwater infrastructure (Coombes, 2004). A schematic diagram of the processes modelled by PURRS, and their interrelationship, is reproduced from Coombes (2004) in Figure 6.

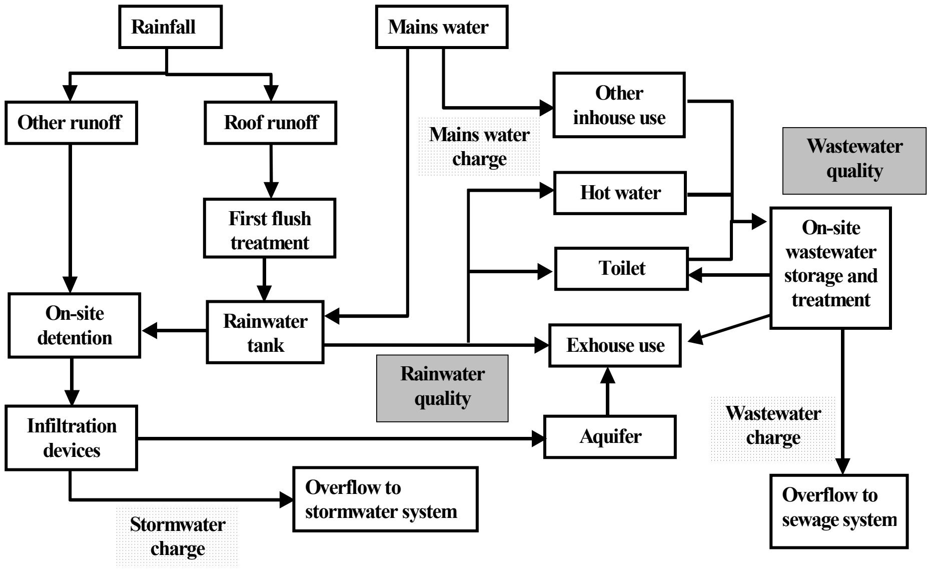

Figure 6 - Schematic of the PURRS Water Balance Model

Model Application

The PURRS model was tailored for use on each Yarrabilba housing type identified by DLL. As PURRS is a process-based model that simulates actual lot scale hydraulics and water balances, it does not require calibration, as was required in the catchment modelling phase. Regardless, model results were assessed against the results of other studies to ensure that they were realistic.

In setting up the Yarrabillba PURRS models, a wide range of raw data were required, including:

- Rainfall;
- Monthly Average Daily Indoor Water Usage;
- Monthly Average Daily Outdoor Water Usage;
- Maximum and Minimum Temperature Data;
- Average Daily Rainfall;
- Diurnal Water Usage Pattern;
- Soil Type;
- Rainwater Tank Configurations;
- Roof and Allotment Areas; and
- Demand Management.

Scenarios

A total of six suites of PURRS production runs were completed in the study. These scenarios comprised a ‘business as usual’ (standard urban lot configuration with no rainwater tanks or wastewater reuse), plus 5 scenarios with different rainwater tank sizes and wastewater reuse.

The ‘business as usual’ scenario assumed ‘standard’ urban development lot configurations with potable mains water supplying all indoor and outdoor demand, with no wastewater reuse. The PURRS model was run for 108 years for each of eleven dwelling types, and for each of 1 through 5 people per dwelling. This equated to a total of 55 PURRS simulations. Simulation results for a typical dwelling type with three occupants are shown in Table 2.

Five scenarios were also simulated including the use of rainwater tanks on each dwelling type (with mains trickle top up), and wastewater reuse, differentiated on the basis of rainwater tank size, which varied from 3kL to 31.5kL. Specifically, these scenarios modelled 3, 5, 10, 20 and 31.5kL rainwater tanks. Every dwelling style (11 in total) was modelled for each rainwater tank size, with 1 through 5 people, inclusive. This equated to 5 x 11 x 5 = 275, 108 year, PURRS simulations. These were then used as inputs to the global water cycle model.

Table 2 - PURRS Modelling of Business as Usual 'Traditional' Dwelling Style, 3 People Household, with Demand Management

Description	Value (kL per annum)
Mains Supply Total	231
Total Demand	264
Total Tank Supply	0 (no tank)
Wastewater Reuse	0 (no ww reuse)
Uncaptured Roof Runoff	166

The specific water allocation details of these simulations are as follows.

- Wastewater Reuse. All simulations assumed that wastewater reuse comprised:
  - 20% of indoor use (toilet flushing only); and
  - Outdoor use (variable, dependant on season).
- Rainwater Tank Use. All simulations assumed that rainwater tank use comprised:
  - 70% of indoor use (i.e. all use except toilet flushing (20%) and kitchen tap drinking water (10%)); and
  - Outdoor use (variable, depending on whether a given scenario employs reclaimed water for external watering).
- Mains Water. All simulations assumed that mains water comprised:
  - 10% of indoor use (i.e. kitchen tap drinking water only); and
  - Rainwater tank trickle top up.

Indicative Results

As an example, PURRS simulation results for a typical dwelling type with three occupants using 3, 5, 10, 20 and 31.5kL rainwater tanks are shown in Figure 7. We note that the rainwater tank simulations also include wastewater reuse so reductions in mains water are not solely due to the inclusion of rainwater tanks within the analysis.

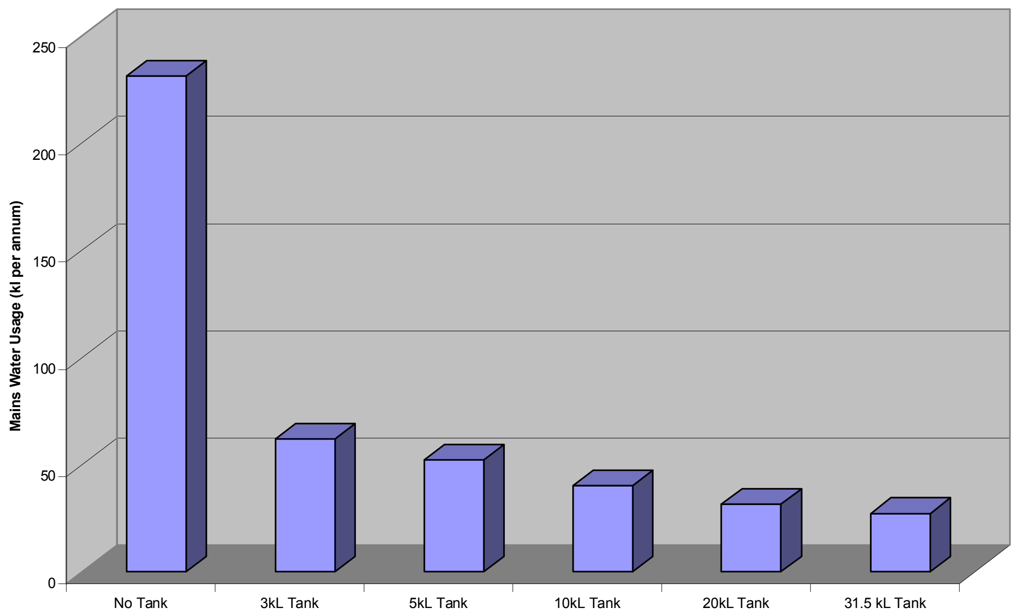

Figure 7 - Mains Water Usage for Different Rainwater Tank Sizes

Figure 7 shows that a dramatic reduction in lot scale mains water usage is possible using rainwater tanks and wastewater reuse on the traditional style dwelling with three occupants.

We note that whilst the above PURRS results are of interest on their own, it is only the integration of these results into the global development scale model, and the subsequent execution of global scenarios, that allowed determination of the likely behaviour of the entire Yarrabilba development. This is discussed in detail in the following section of this paper.

3.3. Development Scale Assessments

The final, and most important, component of the modelling undertaken was the construction and execution of global water balance models, and the assessment of the reliability of various integrated water cycle management alternatives for different household demand scenarios. The model used to this end was WATHNET V3.04 (Kuczera, 1992).

WATHNET is a suite of programs for generalised water supply simulation using network linear programming. In the programs, a water supply system is operated at seasonal (daily) time steps in accordance with the following hierarchy of objectives:

1. Satisfy water demand at all demand nodes (rules may be used to restrict demand);
2. Satisfy all instream flow requirements;
3. Ensure that reservoirs are at their end-of-season target volumes;
4. Minimise water delivery costs; and
5. Avoid unnecessary spills from the system.

Seven different node and two arc types are available in WATHNET to allow the construction of a model of a water supply system. The different types of nodes include reservoirs, demands, gravity diversions, pump diversions, conduit junctions, stream junctions and a waste node. The two arc types are streams and conduits. An extensive range of options is available to control arc behaviour.

Model Parameters
WATHNET does not require specific parameters for simulation. Rather, it relies on specific model inputs (discussed below) for its simulation process.

Model Inputs
A network file forms the basis for all WATHNET simulations. The network comprises demand nodes, generation nodes (for both stormwater and wastewater), reservoirs (both inflow, sewage treatment plant storages and stormwater ponds), links (including streams and conduits), junctions and a single waste node.

Demand nodes represent the demand for both potable water and wastewater in aggregated urban areas, and the wastewater generation nodes represent the wastewater generated in the same areas. Reservoirs were included to simulate potable water storage, sewage treatment plant storage, stormwater collection ponds and external wastewater supplies (where appropriate). All reservoirs, generation and demand nodes were connected via links, which represented either stream flow or piped conduit flow. In special cases, ‘rules of conveyance’ were placed on appropriate linkages to adjust the default priority with which water was distributed throughout the network.

Scenarios
Several potential Integrated Water Cycle Management (IWCM) scenarios were executed using WATHNET, as presented in Table 3. These scenarios were designed to cover the entire scope of development situations, ranging from the traditional ‘business as usual’ urban design approach, through to the innovative use of rainwater tanks, wastewater reuse, demand management and external wastewater importation.

Scenarios were run in two phases: the first was a scoping phase that examined the variations in potable water importation and wastewater discharges with various development configurations, and the second examined the detailed behaviour of the sewage treatment plants. All scenarios were run in duplicate: one for 11,500 dwellings and the other for 18,500 dwellings.

Table 3 – Yarrabilba IWCM Scenario Configurations

Code	WW Reuse	RWT	DM	WW Loss	PW Loss	SW to WW	SW Ponds	WW Irrigation	Comments
BAU0	×	×	×	10%	20%	5%	×	×	Older style development with leaky sewerage system, leaky potable water supply system and ingress of stormwater to sewerage system
BAU	×	×	×	×	5%	×	×	×	Standard urban development with upgraded sewerage system and minor water supply leakage
BAUD	×	×	20%	×	5%	×	×	×	As per BAU but with 20% demand management
IEWW	✓	×	20%	×	5%	×	×	✓	Dual reticulation wastewater reuse to outdoor and toilets, 20 % demand management and minor water supply leakage
3kL	✓	3kL	20%	×	5%	×	✓	✓	Dual reticulation wastewater reuse to outdoor and toilets, 3kL rainwater tanks, 20 % demand management, minor potable water supply leakage and irrigation of treated wastewater
5kL	✓	5kL	20%	×	5%	×	✓	✓	Dual reticulation wastewater reuse to outdoor and toilets, 5kL rainwater tanks, 20 % demand management, minor potable water supply leakage and irrigation of treated wastewater
10kL	✓	10kL	20%	×	5%	×	✓	✓	Dual reticulation wastewater reuse to outdoor and toilets, 10kL rainwater tanks, 20 % demand management, minor potable water supply leakage and irrigation of treated wastewater
20kL	✓	20kL	20%	×	5%	×	✓	✓	Dual reticulation wastewater reuse to outdoor and toilets, 20kL rainwater tanks, 20 % demand management, minor potable water supply leakage and irrigation of treated wastewater
31.5kL	✓	31.5kL	20%	×	5%	×	✓	✓	Dual reticulation wastewater reuse to outdoor and toilets, 31.5kL rainwater tanks, 20 % demand management, minor potable water supply leakage and irrigation of treated wastewater

Results

Figure 8 illustrates the total water cycle results obtained from the WATHNET simulations (only data for the 18500 dwelling case are reported for stormwater as this was not the main focus of the study). We note that Table 3 contains details of the various assumptions implicit in each scenario mentioned on the x-axis of these figures.

These results were invaluable in determining stormwater, external water supply and wastewater infrastructure required of the project, and they also highlight the significant benefits to be gained by the IWRM approach in reducing stormwater volumes, potable water requirements and the volumes of excess wastewater produced by the project.

Summary

The previous sections have described the WATHNET model results for a range of scenarios for 11500 and 18500 dwellings as a subset of 23,000 dwelling assessments. Key results from these scenarios are:

- The combination of wastewater recycling and rainwater tanks provides up to approximately 75% reduction in potable mains water usage, compared to standard urban developments;
- There is no value in using large (i.e. >10kL) rainwater tanks when trickle top up from mains is employed. The optimum rainwater tank size for Yarrabilba is between 3kL and 10kL, with the tank size varying across the development, with large tanks installed on larger dwellings, and vice versa;
- The inclusion of wastewater reuse and irrigation of public open space significantly reduced wastewater treatment plant storage overflows;
- Total stormwater volumes generated from the project site are reduced significantly by the capture and reuse of roofwater; and
- Wastewater treatment plant storages run dry up to 40% of the time, indicating a potential wastewater shortage, and that importation of externally sourced wastewater may be an option. Alternatively, wastewater irrigation could be suspended during shortages.

The study showed the benefits of using best practice integrated water cycle management technologies in the proposed Yarrabilba development, especially rainwater tanks and wastewater reuse (including public open space irrigation).

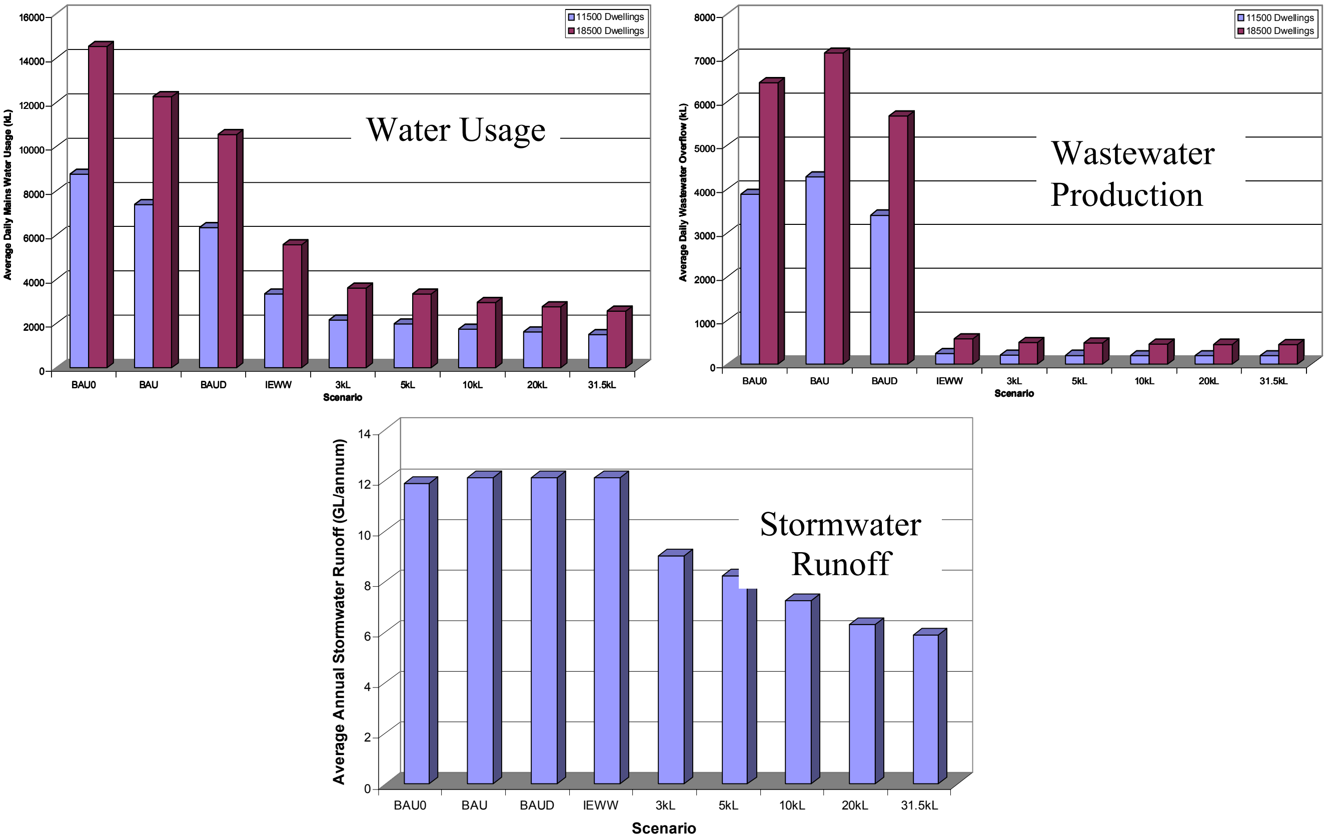

Figure 8 - Example WATHNET Model Results

4. EXPERIENCE AND KNOWLEDGE GAINED

There are several key items that have been common to each of these projects, and which the authors believe should be highlighted in this paper, as follows:

- One of the most difficult elements of all the projects has been the development of an appropriate method to enable interactions between the various water and wastewater streams to be simulated. Various techniques have been used, ranging from spreadsheets (Currumbin), to detailed lot scale assessments with aggregated spreadsheet system models (Coomera) to complete and detailed combined lot scale/system assessments (Yarrabilba). In the authors' opinion, the approach taken at Yarrabilba is preferred; however there may be situations were more simplistic approaches could be taken. We believe that the water industry would benefit from investment in better predictive tools in this regard, and probably more importantly in ongoing research into the ways in which these tools are formulated and applied;
- To the inexperienced, the synergistic benefits of the multi-water stream IWCM approach are often overlooked. For example, the use of rainwater tanks enables smaller stormwater pipes and stormwater quality infrastructure to be adopted, with commensurate cost savings. The IWCM practitioner needs to be cognizant of this fact from the initiation of any project so that maximum economies can be obtained.
- One of the primary challenges of such studies is to communicate often complicated and detailed modelling to a lay audience. The use of simple charts as per Figures 7 and 8 have been shown to be of considerable value in this regard, supported by detailed reports for the more technically minded reviewer

A transformation methodology (developed at the University of Newcastle and modified in collaboration with WBM) was utilized in the Yarrabilba case to transfer lot scale results into the regional scale modelling. The approach utilized statistics describing urban form, demographics and spatial location to overcome the variable and non-linear impacts of scale on IWCM benefits**.** This approach showed that:

- A combination of methodologies (tools) can produce a rigorous understanding of IWCM;
- This approach can manage the significant non-linear interactions between IWCM approaches such as demand management, rainwater tanks and wastewater reuse;
- Small rainwater tanks, in combination with the IWCM strategy, produced considerable benefits;
- Wastewater reuse will significantly reduce impacts on the environment due to urban developments by reducing discharges and enabling less abstractions from rivers for potable requirements; and
- A 75-80% reduction in mains demand is possible, and could be considered as an aspirational target for all new developments

5. FUTURE TRENDS

The authors believe strongly that the application of IWCM techniques will rapidly become the norm, rather then the exception, in future urban developments in Australia, especially once projects of the scale of Coomera-Pimpama and Yarrabilba come to fruition. The obvious imperatives in this regard are the reductions in potable water demand and stormwater and wastewater discharges that are associated with such IWCM applications, and commensurate environmental benefits. Our industry should be supporting and encouraging developers to embrace these techniques, however the imposition of State and Local Government based targets may be required to 'persuade' the development community in this regard.

6. ACKNOWLEDGEMENTS

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