HydroPlanner: A Prototype Modelling Tool to Aid Development of Integrated Urban Water Management Strategies

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The Urban Water Security Research Alliance (UWSRA) is a $50 million partnership over five years between the Queensland Government, CSIRO's Water for a Healthy Country Flagship, Griffith University and The University of Queensland. The Alliance has been formed to address South-East Queensland's emerging urban water issues with a focus on water security and recycling. The program will bring new research capacity to South-East Queensland tailored to tackling existing and anticipated future issues to inform the implementation of the Water Strategy.

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FOREWORD

Water is fundamental to our quality of life, to economic growth and to the environment. With its booming economy and growing population, Australia's South East Queensland (SEQ) region faces increasing pressure on its water resources. These pressures are compounded by the impact of climate variability and accelerating climate change.

The Urban Water Security Research Alliance, through targeted, multidisciplinary research initiatives, has been formed to address the region's emerging urban water issues.

As the largest regionally focused urban water research program in Australia, the Alliance is focused on water security and recycling, but will align research where appropriate with other water research programs such as those of other SEQ water agencies, CSIRO's Water for a Healthy Country National Research Flagship, Water Quality Research Australia, eWater CRC and the Water Services Association of Australia (WSAA).

The Alliance is a partnership between the Queensland Government, CSIRO's Water for a Healthy Country National Research Flagship, The University of Queensland and Griffith University. It brings new research capacity to SEQ, tailored to tackling existing and anticipated future risks, assumptions and uncertainties facing water supply strategy. It is a $50 million partnership over five years.

Alliance research is examining fundamental issues necessary to deliver the region's water needs, including:

- ensuring the reliability and safety of recycled water systems.
- advising on infrastructure and technology for the recycling of wastewater and stormwater.
- building scientific knowledge into the management of health and safety risks in the water supply system.
- increasing community confidence in the future of water supply.

This report is part of a series summarising the output from the Urban Water Security Research Alliance. All reports and additional information about the Alliance can be found at http://www.urbanwateralliance.org.au/about.html.

(USWRA Executive to insert digital signature when approved for release)

Chris Davis
Chair, Urban Water Security Research Alliance

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EXECUTIVE SUMMARY

The HydroPlanner prototype was developed to examine the feasibility of developing an integrated modelling tool of the whole urban water system by considering the interactions between sub-systems and dynamics of each sub-system. The sub-systems included supply catchments, supply sources (surface water, groundwater, desalinated water, treated stormwater, recycled wastewater and rainwater), water consumers, stormwater, wastewater and receiving water. The need for an integrated modelling tool of the whole urban water system had arisen through recent shifts from the traditional supply and demand approach to regional and metropolitan water planning to a more integrated approach which considered: (a) diversification of supply sources by considering non-traditional water sources such as stormwater, rainwater and recycled water; and (b) implications on other aspects of the system as water quality, energy consumption, greenhouse gas emissions. This shift was driven by the need to balance increasing pressures, such as population growth, reduction in inflows into reservoirs, and declining receiving water quality.

Features of the prototype version of HydroPlanner for South East Queensland (SEQ) were developed for the simulation of both water quantity and quality aspects of the urban water cycle. The development of functionality was informed by the features of a typical urbanised catchment in the Logan-Albert catchment in SEQ. The key features tested were:

- Rainfall-runoff generation process.
- Routing of flows from supply catchment to tidal limits of receiving waters.
- Surface water storage behaviour (both on and off-stream).
- Wastewater generation, treatment, discharge and recycling.
- Point and diffuse source constituent generation and filtering.
- Potential impacts of land use changes and climate change.
- Urban and regulated irrigation demands.
- Supplying water from multiple sources to meet demands using heuristic rules.
- Large scale stormwater harvesting.
- Environmental and catchment outlet constituent loads and flows.
- Supply system yield corresponding to a given level of service criteria.
- Reliability, resilience and vulnerability of the surface water system.
- Total system demand and demand shortfall.
- Uncertainty posed by climate variability (through the use of stochastically generated climate data for the simulation of system behaviour.

The HydroPlanner prototype in SEQ was developed by incorporating advances made in the previous version of HydroPlanner prototype demonstrated in Canberra, into eWater CRC’s E2 river and catchment modelling framework. The E2 framework included functionalities to perform continuous simulation of whole-of-catchment water quantity and quality. HydroPlanner extended the E2 river and catchment modelling framework by adding a new set of functionalities to represent urban water management.

The Logan-Albert catchment was also used to as a test case study. The aim of the test case was to demonstrate the viability and validity of an integrated approach to modelling a system of such size under one model. The prototype was not comprehensively calibrated for the Logan-Albert case study. However, the rainfall-runoff models were calibrated and validated. In addition, basic mass balance testing was undertaken at component model and system levels, both at the software development and application stage. The prototype model was able to conserve both water and constituents at the individual sub-catchment scale, as well as at the whole study area level, appropriately. Hence the results presented here provided a qualitative comparison of both water and constituents (i.e. total nitrogen (TN), total phosphorus (TP) and total suspended solids (TSS)) between different water management scenarios and a demonstration of capabilities of an integrated model of an urban water supply, wastewater and stormwater systems.

The study demonstrated how an integrated model of water supply, wastewater and stormwater systems could be developed by extending eWater CRC's E2 framework to include urban water consumption, stormwater and wastewater flow paths. Further, using Logan-Albert case study, the study showed that how such an integrated approach to modelling could be used to understand system-wide water quantity and quality related implications, in particular supply security and flow, TP, TN and TSS discharges to receiving water bodies, of alternative water management options. Overall, the study showed that an integrated model of the whole water system could provide the capacity to evaluate combined impact of land, water supply, demand, stormwater and wastewater management scenarios, and to quantify the potential impacts against defined targets such as water savings, flows in urban waterways and water quality, by allowing for the system behaviour arising from many complex parameters and variables.

A comprehensive calibration of the HydroPlanner prototype to Logan-Albert case study would certainly provide additional validation to the integrated approach to modelling examined in the study. However, such a calibration would require further development of the prototype to represent complex operating rules being used in the Logan-Albert catchment. Merits of further developing the HydroPlanner prototype as a full-scale integrated urban water system model were assessed against the emerging modelling capabilities of eWater CRC's Source modelling platform, which was also built on the E2 modelling framework. Given that Queensland State Government was a partner to the development of eWater CRC's Source modelling platform, it was decided not to go ahead with transforming the prototype into a full-scale model. Instead, it was decided to port learning from the prototype exercise, including the functionalities developed as part of the prototype, to eWater CRC's Source modelling platform.

Accordingly, many of the concepts tested and functionalities developed as part of the HydroPlanner prototype were ported to the eWater CRC's Source integrated modelling platform. Our concepts and functionalities were then further developed under the umbrella of the Source integrated modelling platform. The development of the Source model as part of the eWater CRC was completed in July 2012. The Source model is now available from eWater Limited (http://www.ewater.com.au/products/ewater-source/).

1. INTRODUCTION

1.1. Background

Decision making in South East Queensland (SEQ) with regard to regional water strategy development has been largely focussed on the traditional paradigms of the supply/demand balance, traditional sources such as surface water and groundwater and direct financial costs. Environmental impacts such as receiving water quality, energy consumption and greenhouse gas (GHG) emissions of different urban water management options and emerging sources such as rainwater, stormwater and treated wastewater have traditionally not been considered in detail. The SEQ Water Strategy (QWC, 2010) however, attempts to move away from the traditional approach, by recognising the importance of balancing both human and environmental water needs to support a comfortable lifestyle and a sustainable economic growth in the region.

The SEQ Water Strategy (QWC, 2010) adopts a total water cycle management (TWCM) approach, also known as integrated urban water management (IUWM) for planning. IUWM is an emerging and alternative approach for planning and management of urban water systems. The aim of IUWM is to plan and manage water supply, wastewater and stormwater systems in a coordinated manner to minimise their impact on the natural environment, to maximise their contribution to economic development and to engender overall community wellbeing and improvement (Maheepala and Blackmore 2008; Burn *et al.*, 2012).

The overarching driver for adopting the IUWM approach is to provide a sustainable urban water service to the community. There can be site, utility, state or country specific reasons that sit within this overarching driver such as rising demand for water due to population growth. Other reasons include diminishing traditional surface and groundwater supplies due to a drying climate or simply due to overuse, degrading of the surrounding environment due to pollutants in stormwater and wastewater discharges or declining the quality of source water due to land use activities in supply catchments (Maheepala *et al.*, 2009). Most cities around the globe are faced with either one or some of these challenges. In SEQ, the main drivers for adopting the IUWM approach for the development of regional water strategy include meeting the water needs of rapidly expanding population growth, a drastic reduction in inflows into surface water sources and the need for ensuring the health of catchments, aquifers, receiving waters and their ecosystems (QWC, 2010). There is an increasing interest in adopting the IUWM approach, not only in SEQ, but also by many water utilities, state or local governments around the globe, particularly for the development of regional and metropolitan water resource strategies (Maheepala *et al.* 2009).

Development of water strategies and water management plans based on IUWM principles requires understanding of different supply and demand balance options, not only in financial cost terms but also from environmental and socio-economic perspectives as well. In addition, the demand aspect of supply and demand balance must consider not only human needs but also environmental needs. To satisfy these requirements, urban water planners need a good understanding of the dynamics of the whole urban water system from supply catchments to receiving waters by considering interactions among water supply, wastewater and stormwater systems and their interactions with the surrounding environment.

Understanding the dynamics of an integrated urban water system from supply catchments to receiving waters is, however, much more complex than the traditional systems. It requires capability to forecast demand at end use level and link demands to multiple supply sources, some of which will be closed recycling loops within a mixed portfolio of rain-fed, manufactured and decentralised supplies. These different sources have different temporal and spatial yield characteristics, as well as different water quality characteristics. Uncertainties associated with climate change and population growth, varying degree of human behaviour and acceptance of alternative demand and supply management options, plus a lack of performance data about new supply options, only add to this complexity. This step change in system dynamics requires a step change in system simulation capability, research into the performance characteristics of alternative systems and more sophisticated decision support for water strategy planning and system design.

The Life Cycle Analysis and Integrated Modelling (LCA-IM) Project of the Urban Water Security Research Alliance (UWSRA) has been formulated to provide methodologies to quantify the dynamics of an integrated urban water system in terms of water flows, nutrient discharges, energy consumption and GHG emissions at local government and regional scales. These methodologies will enable urban water planners to better understand the total water cycle at local government and regional scales, together with the impact of urban water management on waterways, energy use and GHG emissions, which aid the development or review of urban water strategies and total water cycle management plans based on IUWM principles at local government and regional scales.

1.2. Purpose of the Report

The purpose of this report is to describe a methodology developed for the quantification and prediction of system-wide water quantity and quality implications of a selective set of urban water management options. The methodology is presented as a software prototype, HydroPlanner, as a way to support the idea of integrated urban water systems modelling.

Development of the prototype required a case study to identify key functionalities required to include in the prototype and test the applicability of functionalities using data. In consultation with the Queensland Water Commission (QWC), the Logan-Albert Catchment (or Logan Basin) was chosen as the test case study. This report also describes software development aspects of the key functionalities identified from the test case study and demonstrates key component models in the HydroPlanner prototype. The prototype can be used to quantify changes to water supply, demand, wastewater and stormwater discharges and generation and transfer of nutrients and sediments from catchments to receiving waters under a selective set of urban water management options in the test case study.

Calibration and verification of the whole-of-urban water system water quantity and quality simulation methodology has not been undertaken for the Logan Basin. However, we have completed calibration and verification of the rainfall-runoff models for the upstream catchments to some extent. Details of the calibration in upstream catchments of the Logan Basin are described as part this report.

1.3. Report Structure

Chapter 1 describes the background and purpose of the report.

Chapter 2 describes the importance of undertaking seamless modelling of water quantity and quality of the total water cycle and the adopted modelling approach to achieve it.

Chapters 3 and 4 describe key functionalities required to develop a whole-of-urban water system water quantity and quality modelling methodology.

Chapter 5 describes objectives of the test application of the prototype to the Logan Basin in SEQ, data sources and assumptions and outcomes of the test application.

Chapter 6 provides brief conclusions on lessons learned during the prototype development and future direction of the prototype.

2. WHOLE-OF-URBAN WATER SYSTEM WATER QUANTITY AND QUALITY MODELLING

2.1. The Need

Total water cycle management (TWCM), or IUWM, requires integration of systems that have been traditionally designed and operated as separated entities. The interactions of these systems is not always straightforward, especially if one considers water supply aiming to minimise impact on the natural environment, to maximise contribution to economic development and to engender overall community wellbeing and improvement. The decision making process is also complex as the performance of various options such as roof water use, stormwater use and wastewater recycling can be judged not only against financial criteria and supply reliability, but also against a range of criteria in multiple dimensions. For example, the criteria considered in the SEQ Water Strategy (QWC 2010) include: return on investment, regional growth, efficient water use behaviour, healthy waterways, energy usage and GHG emissions.

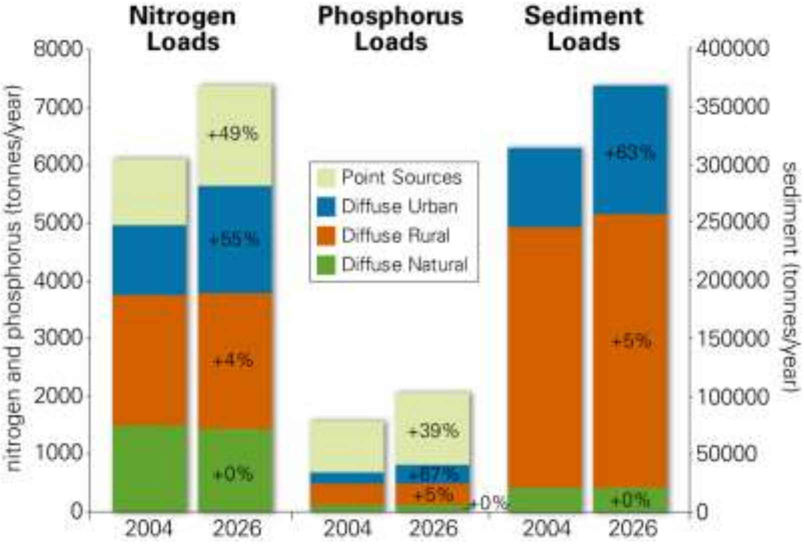


Figure 2.1 Comparison of nitrogen, phosphorus and sediment loads discharging to Moreton Bay by 2004 and 2026 (source: Paul Greenfield, Keynote speech, SEQ UWSRA Science Forum, Aug 2009).

Understanding water quantity and quality aspects of different urban water management options is fundamental to quantify any criteria being used in judging the performance of different options, particularly if the focus of water management is striking the balance between providing adequate water supplies to maintain a sustainable economic growth and improving the health of waterways in the SEQ region. Figure 2.1 shows a comparison of projected nitrogen, phosphorus and sediment loads discharging to Moreton Bay in the SEQ region in 2004 and 2026 from different sources. Whilst the loads of nutrients and sediment originating from rural land uses are significantly larger than those originating from urban land uses and point sources, nutrient and sediment loads originating from urban areas by 2026 are expected to increase by more than 50% compared to only a 5% increase in the nutrients and sediment originating from rural areas. Figure 2.1 also shows that increases in urban areas due to rapid population growth in the SEQ would result in more than a 40% increase in nutrient discharges from point sources to waterways by 2026 compared to 2004 levels. Some fundamental questions in this regard are:

- What are the appropriate urban water management options that have the potential to reduce the amount of nutrients and sediments discharging to waterways?
- What are their contributions to secure water supplies?
- What are the financial cost, energy use and greenhouse gas emission of such options?

A good understanding of the potential implications of different water management options on flow, nutrient and sediment regimes are essential to provide answers to these questions. The common method that can be used in this regard is undertaking appropriate water quantity and quality modelling at a system scale. This requires capability to generate runoff and constituents (i.e. nutrients, sediments, etc.) from different land uses; forecast demand at the end use level to supply water fit for purpose, and link demands to multiple supply sources, by accounting for uncertainty posed by climate variability and change and the growth in population. Some of the supply sources may be closed recycling loops within a mixed portfolio of rain-fed, manufactured and decentralised supplies, all with different temporal and spatial yield characteristics. This type of modelling is called integrated modelling (Schmitt and Huber 2005).

The interaction of different components and feedback loops adds complexity to integrated modelling, particularly when there are conflicting goals such as water harvesting to maximise water security versus environmental flow releases or treatment of wastewater and stormwater discharges to minimise adverse impacts on the ecosystem (Butler and Schütze 2005; Fletcher, *et al.* 2007). For example, Fletcher *et al.* (2007) showed that the use of stormwater harvesting schemes could reduced the loads of TSS (Total Suspended Solids), TP (Total Phosphorus) and TN (Total Nitrogen) leaving a development when compared to the same development without harvesting schemes. However, the same study showed that the harvesting scheme could lead to over-harvesting, with the runoff and associated loads leaving a development being smaller than the pre-development case. In this case, whilst the harvested yield was maximised, the environmental flows and associated constituent loads could be greatly reduced or be rendered non-existent. This possible undesired result is only highlighted by undertaking integrated modelling of hydrological, water quality, receiving water/ecological aspects in tandem. In addition, (Butler and Schütze 2005), using advances in wastewater treatment control modelling, showed a complex relationship between dry and wet weather flows, treatment plant performance, sewage overflow and receiving water quality. Surprisingly, expected outcomes such as reduced sewerage overflow or reduced discharge volume do not directly result in improvements in receiving water quality due to associated changes in the discharge concentrations (Butler and Schütze 2005).

A key question in this context is “Are the urban water systems modelling tools currently in use in SEQ for water quantity and quality adequate to aid a wider adoption of the total water cycle management approach identified in the SEQ Water Strategy and for future planning?” This will require appropriate modelling tools to aid the development of total water cycle plans at both local government (e.g. Logan Basin) and regional scales (i.e. SEQ-wide). A consultation with key stakeholders in SEQ was conducted to seek answers to this question. It concluded that despite the considerable development and extensive use of models in the SEQ, there are still a number of gaps currently not addressed (WBM 2008):

- Current key models primarily use or provide predictions at annual or monthly averages, which may overlook important system dynamics occurring at shorter time steps;
- There is considerable spatial averaging applied to all models;
- There is some uncertainty in regard to how the more distributed, ‘alternative’, water supply sources (e.g. rainwater tanks, stormwater harvesting, etc) have been simulated in some of the highly temporally averaged models; and
- Some of the existing tools mainly focused on the water supply/demand balance, without adequate consideration of more holistic, multi-criteria considerations which include energy, environmental flows, water quality or other relevant considerations.

A review of over 60 urban water systems modelling tools was also carried out by Mitchell *et al* (2007). The review found that there were no commercially available modelling tools for the integrated modelling of water quantity and quality of urban water systems. However, there were a couple of emerging modelling tools. Some were applicable at the development scale, such as Aquacycle (Mitchell *et al.*, 2001) and UVQ (Mitchell and Diaper 2005), and some were applicable at regional and local government scales such as HydroPlanner (Maheepala *et al.* 2005; Grant *et al.* 2006; Maheepala *et al.* 2007) and WaterCress (Clark, Pezzaniti and Cresswell 2002). All emerging IUWM models were developed specifically to address a selected set of research questions in a specific location, mainly for demonstration purposes, i.e. not as commercial or business applications. Therefore, they all had a limited applicability to any specific location.

Findings of key stakeholder consultation in SEQ and outcomes of the review of integrated modelling tools mentioned above clearly indicated a lack of an appropriate modelling approach to quantify the water quantity and quality aspects of different urban water management options at local government and regional scales in SEQ to enable the development of local government and regional scale total water cycle plans. This led us to undertake development of a prototype modelling tool capable of providing quantitative assessment of the urban water cycle in terms of water quantity and quality at the city, catchment and regional scales. We called this prototype modelling tool HydroPlanner. The purpose, intended audience, user requirement, modelling approach and the challenges faced with software development are described below.

2.2. Purpose of HydroPlanner Prototype

HydroPlanner was developed as a prototype modelling tool for simulating the behaviour of whole-of-urban water system in terms of water quantity and quality. Components of the urban water system included in HydroPlanner are shown in Figure 2.2. They include supply catchments, surface water sources, bulk water supply system, water consumption, stormwater and wastewater trunk system, wastewater treatment, receiving waters and alternative sources such as recycling, stormwater harvesting, rainwater harvesting and desalinated water.

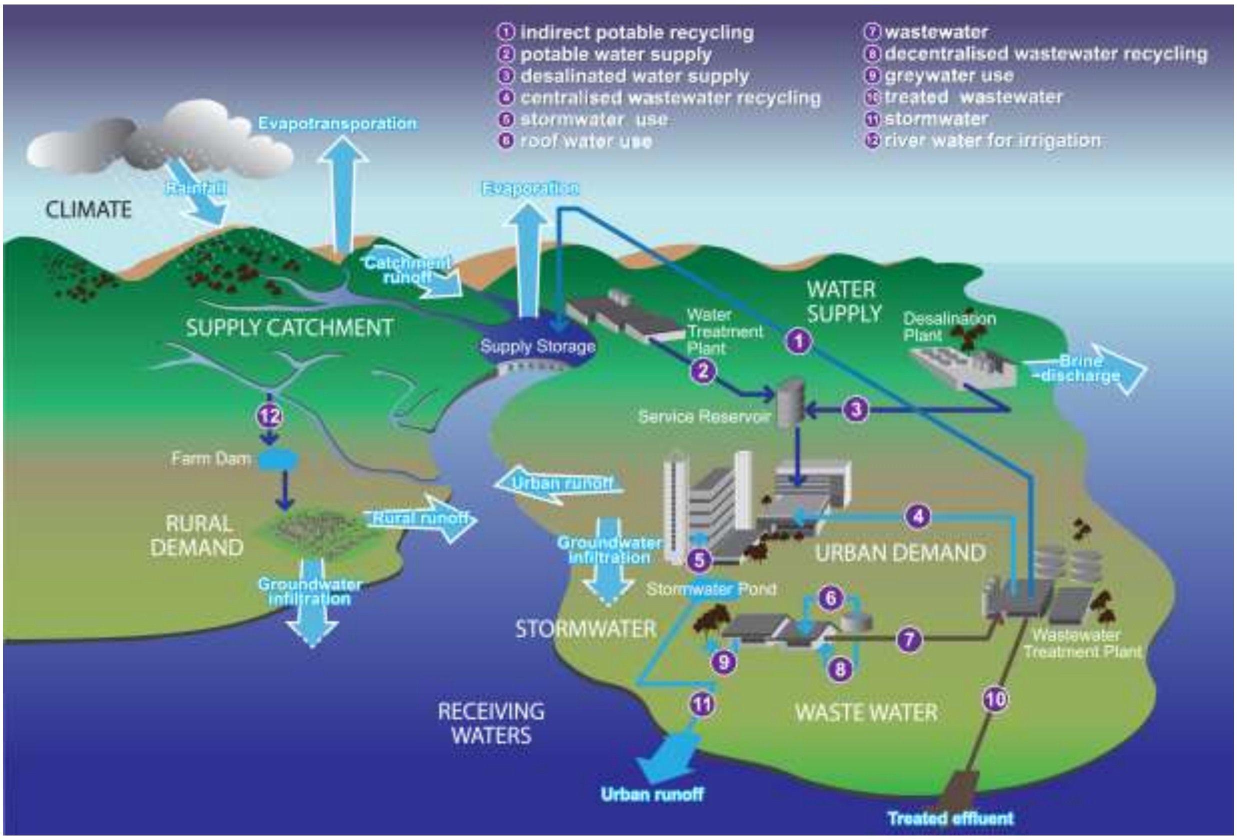


Figure 2.2 Components of the urban water system included in HydroPlanner (Maheepala, Blackmore *et al.* 2009).

The objective of developing the HydroPlanner prototype was to provide numerical modelling capabilities in an integrated and seamless portal to aid decisions on selecting the optimal urban water management options that maximises water supply security while minimising adverse water quality impacts on urban waterways and receiving waters and, the carbon footprint. HydroPlanner was designed to use at town, city, local government and regional scales. It aimed to assist urban water planners to better understand the water cycle, together with the impact of urban water management on waterways, energy use and GHG emissions, which inform the development and review of urban water strategies and town, metropolitan, local government and regional scale total water cycle plans.

When fully developed, it was expected that HydroPlanner would have the capability to:

- Quantify changes to water and constituent balances, energy usage and GHG emissions at local government and regional scale under different urban water management options;
- Quantify the potential impact of different urban water management options on supply system yield, shortfalls, resilience, reliability and vulnerability, levels of water service and receiving water quality;
- Quantify cumulative impacts of changes to climate, land uses, urban development and urban water management on supply system performance (e.g. system yield, reliability, resilience and vulnerability), flow regimes in urban waterways, nutrient and sediment load discharges to receiving waters and system-wide energy usage and greenhouse gas emissions; and
- Identify the optimal urban water management option that has the potential to maximise supply reliability while minimising adverse impact on receiving waters and GHG emissions.

2.3. Audience

Key users of the fully developed HydroPlanner are those involved urban water systems planning, in particular planners involved in local government and regional total water cycle plan development as part of developing and reviewing town, city, local government and regional scale urban water strategies. For organisations such as regional city councils which are involved in different aspects of urban water management and total water cycle management planning, HydroPlanner can provide a transparent method for understanding the magnitude of water streams and associated constituents, both temporally and spatially, which can inform decisions on both water and land management.

State Government agencies such as the Department of Energy and Water Supply and the Department of Environment and Heritage Protection can use HydroPlanner to evaluate both local government and regional scale TWCM plans. Organisations such as the Healthy Waterways Partnership and can use the same tool to evaluate which of the options have the potential to improve the health of waterways.

2.4. User Requirements

As discussed in the previous section, the intended purpose of the HydroPlanner prototype was to examine the feasibility of developing a modelling capability to quantify system-wide implications of alternative urban water management options in terms of water quantity and quality, to assist in developing local government and regional scale total water cycle plans. The alternative urban water management options can include demand management, rainwater tanks, stormwater harvesting, decentralised recycling, indirect potable recycling, desalination, surface and groundwater sources and water sensitive landscape features.

The high-level attributes sought from the HydroPlanner prototype, to meet these requirements are described in Table 2.1.

Table 2.1 High level user requirement of HydroPlanner.

The overall capability	Ability to quantify flow, sediments and nutrients regimes and energy consumption and GHG emissions originating from alternative urban water management options, to feed into triple bottom line analysis of water management options.
Spatial Scale	Whole-of- urban water system at both SEQ scale (i.e. regional scale) and SEQ's regional catchment scale (i.e. local government scale such as Pine Rivers catchment and Logan-Albert catchment). Components to be included in the HydroPlanner include supply catchments to receiving waters (inclusive) as shown in Figure 2.2.
Temporal Scale	In general, monthly scale is considered as adequate for modelling water quantity aspects of urban water planning, whereas sub-daily scale is considered as adequate for water quality modelling. Since the purpose of HydroPlanner is to aid planning of both water quantity and quality aspects, a compromise is needed between sub-daily and monthly scales. A daily scale is considered as an appropriate compromise for seamless modelling of both water quantity and quality.
Climate	• Ability to simulate the effect of historical and future climates. • Climate variability: multiple runs with stochastic climate data. • Climate change: ability to model outcomes of UWSRA's climate and water project.
Water demand	• Demand forecast based on climate and demographics. • Demand management options. • Possibility of linking outputs of the SEQ's end use demand model. • Irrigation demands in sub-regions.
Supply catchments	Runoff/constituent generation and routing processes.
Conventional supply system	• Storage behaviour. • Diversions to urban consumption via pipes/channels. • Regulated flows to the environment. • Inter basin and inter storage transfers. • System yield and losses. • Constituent movement in flow paths. • Supplying water to both urban and irrigation demands.
Wastewater	Generation, transport, treatment and disposal of flows and constituents.
Stormwater	• Generation, transport, treatment and disposal of flows and constituents; and • Ability to represent WSUD at local government scale.
Centralised supplies	• Large scale stormwater harvesting using ponds, lakes, and Managed Aquifer Recharge; and • Wastewater recycling, desalination, new dams and groundwater.
Decentralised systems	• Regionalised effect of decentralised systems (rainwater tanks, local recycling, stormwater harvesting and grey water use). • Linking with research outcomes of UWSRA's projects on decentralised systems and stormwater harvesting.
System performance assessment measures	• Surface water supply system: system yield for a given level of service criteria; system reliability, resilience and vulnerability; total storage. • Total system demand and demand shortfall. • Daily flow, nutrient and sediment regimes at any point in the system.

2.5. Modelling Approach of the Prototype

The HydroPlanner prototype in SEQ was built by incorporating advances made in the previous version of HydroPlanner (Maheepala *et al.* 2005; Grant *et al.* 2006; Maheepala *et al.* 2007; Maheepala and Blackmore 2008) into a generic water management modelling framework developed by eWater CRC. The CRC's generic water management modelling framework was known as E2 river and catchment modelling framework (Argent *et al.* 2006) and it was developed within the TIME (The Invisible Modelling Environment) (Rahman, Seaton *et al.* 2003) model development framework.

The E2 river and catchment modelling framework (the E2 framework) included functionalities to perform continuous daily simulation of whole-of-catchment water quantity and quality and water allocation at a river basin scale. However, at that stage of model development, it lacked the functionality required to represent urban water management, in particular alternative water sources such as rainwater and stormwater harvesting, wastewater recycling and desalinated water, and quantify implications of different water management options on flow, nutrient and sediment regimes in waterways.

The modelling approach adopted in the HydroPlanner prototype involved extending eWater CRC's E2 framework to add a set of new functionalities to represent urban water management. In the E2 framework, the new functionalities could be created as new component models and add them to the existing component models of similar functionality to create a library of component models. This allowed modellers to choose component models suitable to a particular study by considering the availability of data.

It should be noted that the previous version of the HydroPlanner prototype developed as part of the Canberra Integrated Waterways Study (Maheepala *et al.* 2009) was also built by extending the E2 framework by including urban water management functionalities. However, at that time, the E2 framework did not include water allocation functionalities. Hence, the previous HydroPlanner prototype linked to the REALM model (Victoria University and Department of Sustainability and Environment 2005) to provide water allocation functionality and an End Use Demand model (Water Services Association of Australia 2006) to represent the urban water demand. The new HydroPlanner prototype replaced the previous version's third party models (i.e. REALM and the End Use Demand model) with in-built functionalities, fully compatible with the E2 river and catchment modelling framework, which allowed easy integration of component models and achieving greater accuracy in outputs.

The key functionalities included in the HydroPlanner prototype to perform whole-of-urban water system water quantity and quality are shown in **Error! Reference source not found.**. Capabilities from the E2 framework such as runoff and constituent generation from catchments, transfer of runoff and constituents along a river network and diversions from a river system to supply water to demands are highlighted in 'blue'. HydroPlanner added new functionalities required for the simulation of the urban system at a regional scale, highlighted in 'purple'. New functionalities allowed representation of urban demand in a spatially explicit view of the urban water system, wastewater generation, transfer and treatment processes, stormwater generation, transfer and treatment processes and a range of alternative water sources (e.g. wastewater, rainwater, stormwater, desalinated water and greywater) as well as traditional sources such as surface water and groundwater. However, not all new functionalities were available in the prototype HydroPlanner, some were developed as part of Stage 1 development, described in this report, and some were proposed to be developed as part of future Stages of the prototype development.

Functionalities required for the development of Stage 1 of the prototype HydroPlanner are identified in Chapter 3. Detailed specifications were developed only for those functionalities that were not available from the E2 framework. These are described in Chapter 3.2.

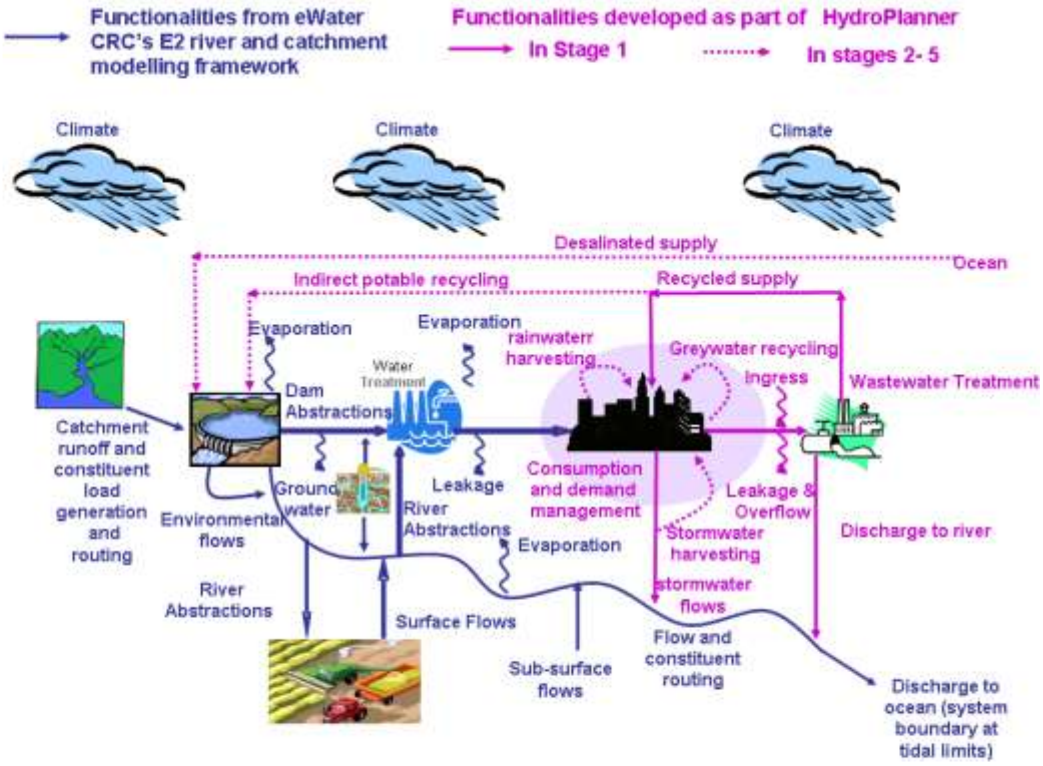


Figure 2.3 Key functionalities included HydroPlanner to perform whole-of-urban water system water quantity and quality modelling.

2.6. Software Development Approach of the Prototype

The E2 river and catchment modelling framework and the HydroPlanner prototype are both written for the Microsoft Windows platform. Whilst the E2 framework has a plug-in mechanism by which developers can add functionality to the base program, the HydroPlanner prototype was built as a separate extension. This allowed the HydroPlanner prototype to change building blocks of the E2 framework such the node/link network, which is essential for the development of an appropriate Graphical User Interface for the urban specific functionality provided in the prototype.

The software development of the prototype included adding the following items to the E2 framework:

- New component models, which are to be executed at the every time step of simulation, e.g. Wastewater Treatment Plant Model.
- New functionality, which are to be executed to compute response variables that are of interest to urban water management, e.g. system yield.
- New features added to the Graphical User Interface which are required for users of HydroPlanner to interact with the software.

The software development aspects of the prototype were undertaken incrementally, allowing identification of deficiencies in the prototype early in the software development cycle. However, this approach posed several challenges since the E2 framework was still under development and was used/shared by many projects (e.g. eWater CRC's WaterCAST and River Manager projects). This approach was advantageous as it allowed incorporation of new features being developed for non-HydroPlanner projects to be available for HydroPlanner. However, some of the drawbacks included: errors being introduced by code change in other projects; limitations on adding new software features without affecting the other projects; and maintaining a stable prototype on a changing foundation, which required spending time and resources on understanding some aspects of the E2 framework that were not relevant to the HydroPlanner prototype.

3. KEY MODELLING COMPONENTS OF THE PROTOTYPE

This section outlines key modelling components needed in the HydroPlanner prototype. The approach followed involves, firstly identifying key modelling questions of the test case study (i.e. Logan-Albert catchment) in consultation of the QWC, and secondly, identifying key component models required to address the key modelling questions of the test case study.

Since the HydroPlanner prototype was built by extending the E2 framework by adding new component models or providing modifications to existing component models, the characteristic of most interest was whether an existing software component existed in the E2 framework to handle the modelling needs of the test case study, and if not, what modifications or additions were needed to overcome this.

The development of new components or the redevelopment and enhancement of existing parts is what distinguishes the HydroPlanner prototype from a standard version of the E2 river and catchment modelling framework (Argent *et al*. 2006). These specialised components allow the modeller to consider urban water management options and gain an understanding of their impact in an integrated system sense.

3.1. Key Modelling Questions for the Test Case

The key modelling questions identified for the test case were as follows:

What would be the impact of proposed urban development and climate change over next 50 years on receiving water quality and supply system dynamics (e.g. storage levels and system yield), with and without following water management options?

- recycling for urban and irrigation uses;
- stormwater harvesting for urban and irrigation uses;
- proposed point and diffuse pollutant reduction schemes; and
- rainwater tanks for urban uses.

The following sections describe key functionality (or component models) required for addressing the above modelling questions, assess the adequacy of existing component models from the E2 framework to meet the needs of the test case study and identify where new functionality and/or modifications to the existing functionality were needed.

3.2. Climate Variability

Component Name	Climate variability
Purpose	Read historical daily climate as an input Generate stochastic climate data based on the historical data
Key Attributes	• Access climate data in various time-steps from various sources • Generate climate data stochastically • Use both historical and stochastic climate data for simulations
Existing component models in CRC's E2 platform	Generates stochastic climate data using Stochastic Climatic Library Allows multiple runs
Limitations of the existing component model	None
Modifications / Additions	None

3.3. Climate Change

Component Name	Climate change
Purpose	Read daily climate data series that reflect changes to climate as input data. Generate stochastic climate data corresponding to input data series (if the effect of climate variability is required).
Key Attributes	• Access climate data in various time-steps from various sources. • Generate data stochastically. • Use both input climate series (with the effect of climate change) and stochastic climate data for simulations.
Existing component models in eWater CRC's E2 platform	Use the component on climate variability, but use the climate data series that reflect changes to climate as input data, not the historical time-series.
Limitations of the existing component model	None
Modifications / Additions	None

3.4. Catchments, Rainfall-Runoff, Constituents and Filtering

Component Name	Runoff and constituent generation from subcatchments.
Purpose	Processes linked to rainfall/runoff (R/R), constituent generation and filtering are represented at the level of subcatchments. Route generated runoff and to the catchment's outflow point.
Key Attributes	• Ability to logically segment the subcatchment into different land use types (called functional units or FUs). • Associate processes on R/R, constituent generation and filtering to functional units. • Accept rainfall and evaporation as inputs to R/R models.
Existing component models in eWater CRC's E2 platform	Subcatchment polygons generated from a map or derived from DEM model.
Limitations of the existing component model	No modifications possible after creation. Limited edit functions when creating from map.
Modifications / Additions	Add an ability to import a node/link layer created in a GIS system outside of the E2 platform. This layer then becomes the basis for creation of the link and node network instead of manual drawing method.

3.5. River Routing

Component Name	Routing of river flow through a network of nodes and links.
Purpose	Route water through a river system.
Key Attributes	Describe river system using a network of nodes and links. Water balance for inflow and outflow from nodes. Run at daily time step.
Existing component models in eWater CRC's E2 platform	Link and Node models.
Limitations of the existing component model	Cannot add nodes without catchments, but such nodes are required to represent wastewater treatment plants.
Modifications / Additions	Add extra functionality to allow modeller to add both nodes and links without catchments in certain circumstances.

3.6. Surface Water Storages

Component Name	Surface Storage, Dam or Reservoir.
Purpose	Ability to represent physical water storage features with inflows, losses and releases to meet different needs.
Key Attributes	Balance inflows and outflows from the storage. Preserves the system water balance.
Existing component models in eWater CRC's E2 platform	E2 Storage Model.
Limitations of the existing component model	No routing within the storage. Assumes fully mixed system, no stratification.
Modifications / Additions	None (i.e. above limitations are acceptable to HydroPlanner prototype).

3.7. Urban Water Demands

Component Name	Functional Unit Demand Model.
Purpose	Ability to represent urban demands at subcatchment level to provide some degree of spatial explicitly. Ability to supply from multiple sources with some degree of control on priority of sources.
Key Attributes	Accept demand as an input daily time-series. Ability to source supply from multiple sources. Allows a degree of control on priority of sources.
Existing component models in eWater CRC's E2 platform	Demand Node, Extraction Node.
Limitations of the existing component model	Can only access one supply source. Limited to placement on one node in the network. The extracted volume disappears from the system.
Modifications / Additions	Attach demands functional units as a Functional Unit model. Demand models to access multiple sources of supply.

3.8. Supplying Water from Sources to Meet Demands

Component Name	Multiple Supply Path.
Purpose	To supply water from multiple sources to meet demands as per the priority of sources specified by each demand
Key Attributes	Represent multiple sources. Demands to request the amount of water required from each source by considering the order of priority of sources. Rules to specify environmental flow releases to maintain minimum flow requirement in the river. Rules to minimise spills from surface water storages.
Existing component models in eWater CRC's E2 platform	Water ordering (or single supply path functionality).
Limitations of the existing component model	Cannot supply water from multiple sources (i.e. only one supply per demand). Need Multiple supply path functionality. There are plans to develop this functionality as part of the E2 platform, but timing of the development does not match with the development of HydroPlanner prototype. However, it is possible to make modifications to the Single Supply Path functionality to develop a quasi-Multiple Supply Path approach.
Modifications / Additions	Develop a quasi-Multiple Supply Path approach to supply water from surface water storages and alternative sources.

3.9. Wastewater Generation

Component Name	Functional Unit Wastewater Generation Model.
Purpose	To generate wastewater flows in response to demand.
Key Attributes	Linked to demand. Can configure volume of Wastewater generated Can direct wastewater flows to a treatment plant.
Existing component models in eWater CRC's E2 platform	None.
Limitations of the existing component model	Not Applicable.
Modifications / Additions	Require a new model assigned to functional unit.

3.10. Wastewater Treatment Plant

Component Name	Wastewater Treatment Plant.
Purpose	To accept wastewater as inflow and produce treated water available as a supply.
Key Attributes	Link with wastewater generators to receive inflow. Suitably treated wastewater is available as a supply to demands. Discharge unused treated wastewater to river network.
Existing component models in eWater CRC's E2 platform	None.
Limitations of the existing component model	Not Applicable.
Modifications / Additions	Require a new model assigned to a node. Modeller can assign concentrations to discharge stream.

3.11. Off-Stream Storage

Component Name	Off-Stream Storage.
Purpose	To represent a storage that lies off the main river network. It does not receive inflow from a catchment. Inflow is supplied from a diversion from the river network
Key Attributes	Does not have a catchment of its own Can supply water Can be added at any location on the network
Existing component models in eWater CRC's E2 platform	Flow Partitioning node model.
Limitations of the existing component model	The Flow Partitioning node model is an abstract class, existing classes that implement it are not appropriate in this case. Does not provide some of the key attributes mentioned above. Unaware of orders places downstream of it, potentially leading to the diversion of water already allocated to meet demands further downstream.
Modifications / Additions	Require modifications to Splitter functionality in the E2 Platform to incorporate above-mention attributes.

3.12. Unsupplemented Demand

Component Name	Flood Harvesting Model.
Purpose	To extract water from the river to meet unsupplemented demands where the extraction is "opportunistic" i.e. gets water when it can, given a set of conditions.
Key Attributes	Extract water opportunistically. Obeys rules about flow in the river and annual licence. Does not consider water released to meet orders downstream as water to extract.
Existing component models in eWater CRC's E2 platform	Flood Harvesting Diversion Node Model.
Limitations of the existing component model	Does not differentiate between water released for satisfying a demand and the water available for opportunistic extraction. Therefore, it is possible in some cases for water that is released from a dam to meet a specific demand to be diverted at such a node and thus cause an artificial shortfall. Extracted water leaves the system, with no option to return (e.g. runoff from irrigation).
Modifications / Additions	Require modifications to differentiate water released for satisfying a demand and the water available for opportunistic extraction.

3.13. Stormwater Harvesting with Ponds and Lakes

Component Name	Stormwater Harvesting Pond.
Purpose	To capture runoff from predominately urbanised catchments as an alternative source.
Key Attributes	Water captured in ponds/lakes can supply to demands. Allow pre- and post-treatment if required.
Existing component models in eWater CRC's E2 platform	E2 Storage Model. TEDI farm dams model.
Limitations of the existing component model	E2 Storage Model: Not designed for harvesting stormwater, but has the potential to mimic harvesting stormwater with pre-treatment, which requires catchments of suitable size and suitable filtering models to functional units in the catchment with the stormwater pond. The pond has to be located at the outlet of the subcatchment. TEDI farm dams model: Not directly suitable, but might be applicable with suitable modifications; requires a full assessment.
Modifications / Additions	Modifications are required to provide post treatment, but this is not considered as a high priority for the HydroPlanner prototype. Modifications are also needed for other forms of stormwater harvesting such as managed aquifer recharge, off stream ponds and bleeding to sewer network, but this is not considered as a high priority for the HydroPlanner prototype.

3.14. Rainwater Harvesting

Component Name	Rainwater Tanks.
Purpose	To quantify the impact of adding rainwater tanks as an alternate source of supply.
Key Attributes	Model the impact of rainwater tanks at a regional scale. Influence the rainfall/runoff model to account for rain harvested by tanks.
Existing component models in eWater CRC's E2 platform	None.
Limitations of the existing component model	Not applicable.
Modifications / Additions	Need research on spatial lumping and averaging to represent household level rainwater tanks in a regional scale modelling system. Hence this feature will not be included in the HydroPlanner prototype.

3.15. Summary

This Chapter outlined which components of the E2 river and catchment modelling framework were useable, and which components required extra development.

The aspects of the test case study where rainfall, routing, storage and constituents were involved were generally covered by existing and proven components.

Where the modelling needed urban specific capabilities, such as demand, recycling, multiple supplies or SEQ specific needs such as off-stream storage, development was needed to add these capabilities to the E2 framework. In some cases, the additions could be built on existing components and in other cases wholly new component models were to be developed.

The next section details the components added and modified to provide the modelling goals of the test case study that could not satisfactorily be met with unchanged component models of the E2 framework.

4. DETAILS OF NEW MODELLING COMPONENTS

This chapter describes the components added to meet the modelling objectives of the HydroPlanner prototype that could not satisfactorily be met with the existing functionalities of the E2 river and catchment modelling framework.

New modelling methods were required to represent the following system components in the HydroPlanner prototype:

- Supplemented demands.
- Un-supplemented or flow-constrained demands.
- Supplying water from multiple sources.
- Off-stream surface water storages.
- Wastewater generation, transportation, treatment and recycling.
- Supply system performance indicators.

Details of the new modelling methods are described below.

4.1. Supplemented Demands

The Logan Basin included two types of demands: - supplemented and un-supplemented. Supply to supplemented demands was not constrained by river flow, whereas, for un-supplemented demands, supply was constrained by river flow. Approximately half of urban demand and irrigation demands in the Logan Basin were supplemented demands, the remainder, stock and domestic and water harvesters, were un-supplemented demands.

Because demands were generated by certain types of land uses (e.g. urban and irrigation land uses), the method used to represent any type of demand was to associate demands with the functional units (FUs). A functional unit is a fundamental element of the E2 framework and it represents a (geographically undefined) area of a sub-catchment with a common response or behaviour, typically corresponding to land use, to which models could be attached (Argent *et al.* 2006). In the E2 Framework, three types of component models, called functional unit models, were associated with each FU: *rainfall-runoff*, *constituent generation* and *filter*.

The HydroPlanner prototype extended the E2 framework by adding a new functional unit model of type *demand*, to represent supplemented demands. It could be assigned to a functional unit in the same way as a rainfall-runoff model, a constituent generation model or filtration model was assigned to a functional unit. The prototype had only one type of demand model and it required the user to specify demand as a daily time-series.

Parameters of the demand functional unit model were:

- Daily time-series of demand
- Supply sources. This can be in-stream surface water sources, off-stream surface water sources or a wastewater treatment plant with recycling facility
- Categories of uses for the demand. Categories defined how to split the demand into different use types, where each had as different order of priority and breakdown for accessing the various types of supply. The list of suppliers was traversed in an order determined by two factors: (1) priority set for each type of supply; and (2) within each type, the order from top to bottom of sources listed
- Location. This was not an essential parameter. The user may assign a location for the demand in the functional unit. It should be noted that the E2 framework did not give a spatial location to FUs. They were located in sub-catchments, which had a definite spatial location. But, we extended the E2 framework by adding the capability to specify a location to FUs with Demand

Models. This was used as a location reference to display water transfer path and direction relative to the network.

4.2. Un-supplemented Demands

As mentioned before, supplies to some irrigation demands were constrained by river flow. Such demands were called flow-constrained demands or un-supplemented demands.

Flow-constrained demands extracted water from the river if the amount of water in the river was greater than a defined threshold flow. The amount of extraction was further constrained by the capacity of the pump used for extraction and a licensed entitlement, which defined the time period within which the extraction could occur (extraction period) and the maximum amount of extraction allowed during the extraction period.

In flow-constrained demands, threshold flow could be either zero or greater. For zero-flow-constrained demands, there was no constraint on how much water that could be extracted from the river, i.e. demands could extract whatever amount was available subject to pump capacity and licensed amount. Usually, zero-flow-constrained demands were irrigation demands, which extracted water from tributaries in headwaters.

The E2 framework included a node model called *flood harvesting node model* (Smith *et al.*, 2009), which allowed extraction of water at a defined location subject to pump capacity and licensed amount at the location of extraction. However, it did not have the capability to differentiate the flow of water released by a surface water storage located upstream of the extraction point to a supplemented demand located downstream of the extraction point. This caused an un-supplemented demand to “steal” water that belongs to a supplemented demand located downstream of the un-supplemented demand.

Modifications were required to fix this problem. We decided to delay the development of modifications in this regard due to time and resource limitations of the prototype, and the need for demonstrating capabilities of the prototype by June 09. However, since un-supplemented demands were an integral part of SEQ’s regional water management, modelling capabilities in this regard should be included the HydroPlanner as part of any future development. In addition, a detailed evaluation of the adequacy of the flood harvesting node model to represent un-supplemented demands should be undertaken for the following reasons:

- In predominantly urbanised catchments, there is a possibility for supplying water sourced from alternative sources (e.g. recycled water) to both un-supplemented and supplemented demands to increase the security of supply. At any given time, an alternative source may supply water to a number of supplemented and un-supplemented demands. Some of such demands can be climate dependent. For such situations, the flood harvesting node model is not adequate to represent extractions from the river to un-supplemented demands because the amount of extraction at any time step depends on the amount of water supplied by the alternative sources during that period, which may be a variable quantity that depends on factors such as amount of water available in the source and the nature of supplies from the source to other demands. The amount of water available in an alternative source can be dependent on the amount of water supplied to supplemented demands (e.g. availability of recycled water depends on the inflow to the wastewater treatment plant), which means there are many feedback loops that affect how much water the un-supplemented user can extracted from the river.
- The flood harvesting node model has to be placed on nodes usually placed at sub-catchment outlets, which mean un-supplemented demands in a particular sub-catchment have to be lumped to represent them in a flood harvesting node model, which is more likely to be associated with the node at the outlet of that catchment. If un-supplemented demands that have been lumped have different characteristics, for example, some demands are supplied by alternative sources and/or some demands are related to winter crops whereas others related to summer crops, it will not be realistic to lump un-supplemented demands in a particular sub-catchment.

- The flood harvesting node model extracts water from the river if the flow is above a defined threshold value, which means there is a tendency to extract more water than the required amounts during large flow events. This assumes the extractor has access to sufficiently large storage for the opportunistically harvested water to meet a demand requirement over an extended time period, which has implications for calibration of flows in node-link network. A solution to this problem may be achieved by varying licensed periods during calibration, but this may become a tedious task if there are a number of un-supplemented demands extracting water from different locations along the river and some of the un-supplemented demands can be sourced from alternative sources.
- Some flow constrained demands in the Logan basin supply water to stock and domestic use, which is likely to be a fixed and relatively climate independent demand, without access to sufficient or suitable storage to attenuate across the year. The flood harvesting node model is not suitable to represent such demands.

4.3. Supplying Water from Multiple Sources

HydroPlanner is a model for simulating water quantity and quality of the whole urban water system. It aims to provide capability to quantify the potential impacts of alternative water management options at metropolitan, local government and regional scales, in water quantity and quality terms. Impacts can be changes to flow, nutrient and sediment regimes in receiving waters, demand patterns, supply system yield and reliability and storage levels. These impacts can change over time with changes to climate, land uses, urban development and demographics. A prototype version of the HydroPlanner is now available (Ashbolt *et al.*, 2010; Maheepala *et al.*, 2009a; Maheepala *et al.*, 2009b; Mirza *et al.*, 2009).

This section outlines the recent work and status of the HydroPlanner prototype, primarily concerning implementation of Multiple Supply Path (MSP) optimisation in the HydroPlanner prototype.

4.3.1 Multiple Supply Path Optimisation in HydroPlanner

At the time of HydroPlanner development, “Multiple Supply Path (MSP)” functionality was under development by the eWater CRC (eWater CRC, 2009). Hence this functionality could not be made available through the HydroPlanner. The MSP was an optimisation-based functionality which used Network Linear Programming (NetLP) to determine the amount of water to be extracted from multiple sources to satisfy a set of demands.

4.3.2 Software Changes

As mentioned above, the MSP functionality was not available at the time of developing the HydroPlanner prototype. Instead, a method based on water ordering was available from the E2 framework to supply water from only a single source to a demand. Hence, a quasi-multiple supply path method was developed to demonstrate the potential impact of recycling on supply/demand balance as well as on receiving water quality. The quasi-MSP method is described in detail in Maheepala *et al.* (2009).

Briefly, the quasi-MSP method involved development of a new node model called a Regulated Extraction (RE) model to interact with the ordering functionality in the E2 framework, which could order water from a single storage. Each RE model included a localised artificial “bucket”. Urban demands could extract water from one or more of these “buckets” (i.e. RE node models) created at the point of extraction. The buckets kept themselves topped up from their designated storage.

Figure 4.1 illustrates the quasi-MSP method. It shows a demand centre supplied by two dams: Dam 1 and Dam 2, using RE models 1 and 2 respectively. The bucket in RE model 1 is topped up from Dam 1 whereas the bucket in RE model 2 is topped up by Dam 2. In this way, a simple form of MSP was provided. The close proximity of the buckets to the demand also negated any concerns about the travel time to the storage.

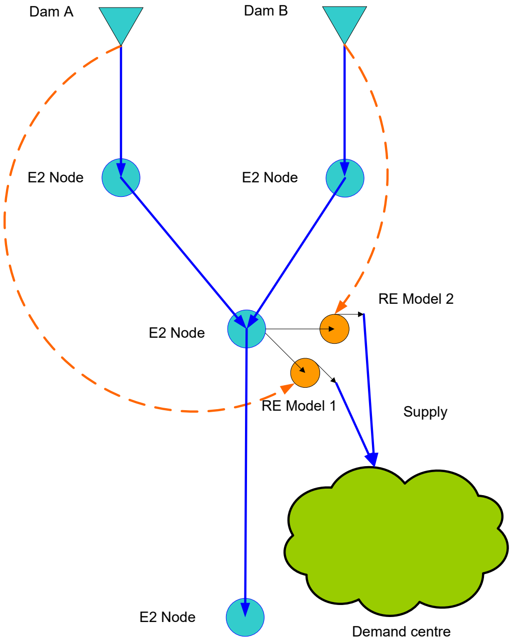


Figure 4.1 Quasi-MSP method allows supplying water from two sources using "Regulated Extraction (RE) Model" (Source: Maheepala *et al.*, 2009b).

The use of NetLP optimisation for releasing water from sources, however, did not require the concept of local buckets; instead, the NetLP solver could tell the sources how much water to release. Releases could then be extracted when they arrived at the extraction point.

Therefore, in order to implement the NetLP method in HydroPlanner, the local buckets at the extraction points needed to be able to change their behaviour – acting as buckets when NetLP optimisation was turned off by the user, and acting as extraction points for the demand when it was turned on.

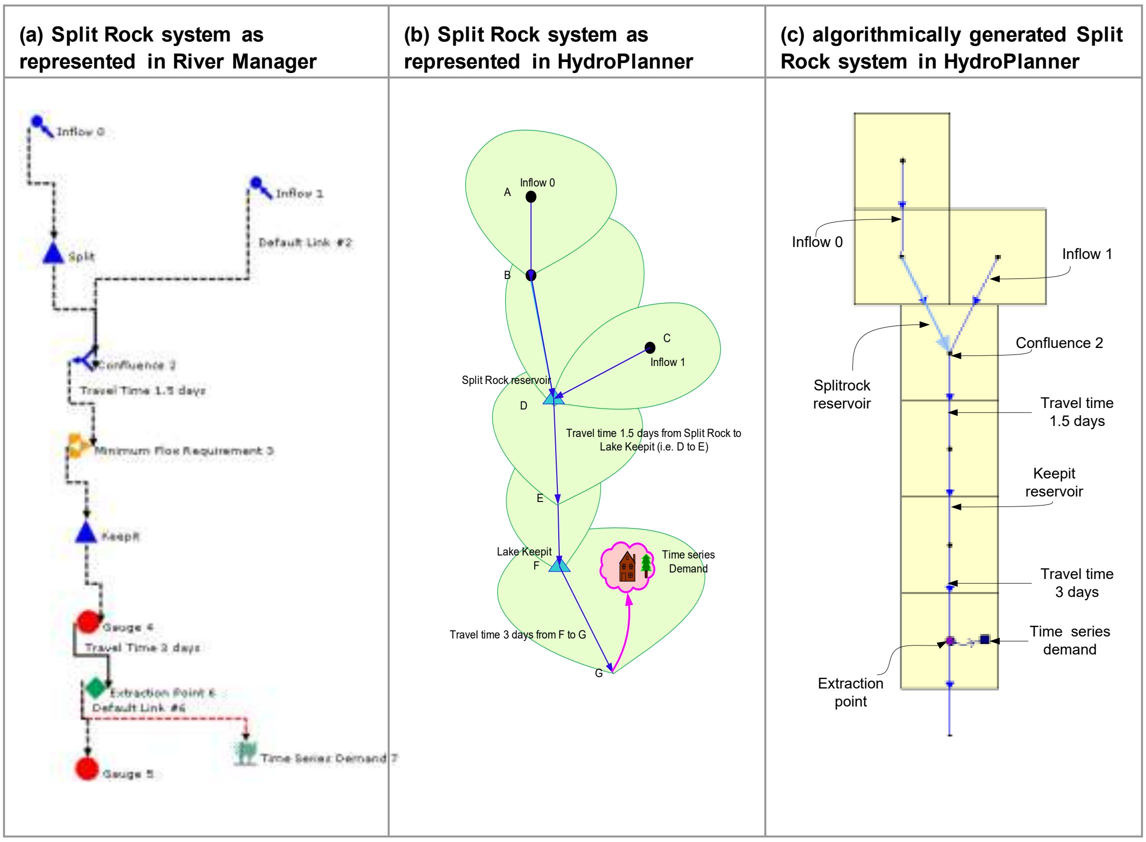
Due to the way the local buckets worked, travel time did not need to be considered. As long as the buckets were sized sufficiently, they would not run dry due to lag related issues (they could only run dry due to a general lack of available water). Because of this, the demand only needed to extract the requested water on the given simulation day. However, the demand needed to pass its requirements to the optimiser ahead of time so it could generate the required releases from storages and give them time to arrive.

After making these changes to the HydroPlanner prototype, the simulation results needed to be tested to make sure that the NetLP method worked equivalently to the River Manager software in terms of releases from storages to satisfy demands.

4.3.3 Testing of NetLP Method in HydroPlanner

It was decided to use an example problem created to illustrate the NetLP method in River Manager (Penton, 2009), to test the same method in HydroPlanner. The example problem was called the "Split Rock system" and its representation in Source Integrated Modelling System (IMS) is shown in Figure 4.2. It consisted of two storages: Split Rock reservoir and Lake Keepit and a demand located downstream of the Lake Keepit. Both regulated releases and spills from the Split Rock reservoir flow to the Lake Keepit. Details of this example problem are given in Penton (2009).

To test the implementation of the NetLP method in the HydroPlanner prototype, first, we created an equivalent of the Split Rock system in HydroPlanner (see Figure 4.2, in which (a) represented the Split Rock system in River Manager and (b) represented the same in HydroPlanner). While both River Manager and HydroPlanner used node-link networks, the River Manager node-link network showed a schematic view whereas HydroPlanner's network was shown on a spatially explicit catchment map. Both representations were then passed through the same NetLP solver and simulation was performed by focussing on water balance aspects. Results were compared numerically.


(a) Split Rock system as represented in River Manager

(b) Split Rock system as represented in HydroPlanner

(c) algorithmically generated Split Rock system in HydroPlanner

Figure 4.2 Representation of Split Rock system in (a) River Manager and (b) and (c) HydroPlanner.

The HydroPlanner representation was also generated algorithmically in order to make it resemble the river manager network as closely as possible (see Figure 4.2 (c)). This produced a rather unnatural looking set of square catchments that were required nonetheless.

The model was then populated with the exact features of the Split Rock system including inflows, storage details, travel times and minimum flow requirements. The one area where the two problems differed was in the demand model itself. HydroPlanner demands were different from Source IMS ones in the following ways:

- HydroPlanner demands could be supplied from multiple sources when not running the NetLP solver using the quasi-MSP method of Regulated Extraction node models placed at extraction points
- HydroPlanner demands were associated with land uses, which were located in sub-catchments. The sub-catchments were spatially explicit
- HydroPlanner demands generated wastewater which could be treated in a recycling plant
- HydroPlanner demands could be supplied with treated water from a wastewater recycling plant
- HydroPlanner demands considered the user supplied time-series as a series of extractions which needed to be ordered in advance (due to travel time). Source IMS considered demands as a series of orders from the storages which later needed to be extracted when they arrived.

The last point required that the two time-series supplied to each problem was different in order for the demand's extractions to happen on the same simulation day. To accommodate this, HydroPlanner's demand time-series was manually offset by the maximum travel time of the system. The results of the simulation runs were then checked to see that this was happening correctly. To ensure that the MSP functionality was equivalent in both scenarios, the simulation was run and the following values compared:

- Inflows
- Demand requested
- Demand supplied
- Split Rock dam storage level
- Keepit dam storage level
- System outflow

A new visualisation tool was also built due to the difficulty of comparing the two scenarios. At each time step, the HydroPlanner and River Manager networks needed to be "translated" into a network that the NetLP solver could process. In order for the results to match, these translated networks needed to be equivalent. Evaluating this proved to be difficult without a way to visualise the networks themselves. Software was written to achieve this: an example visualisation can be seen in Figure 4.3 below.

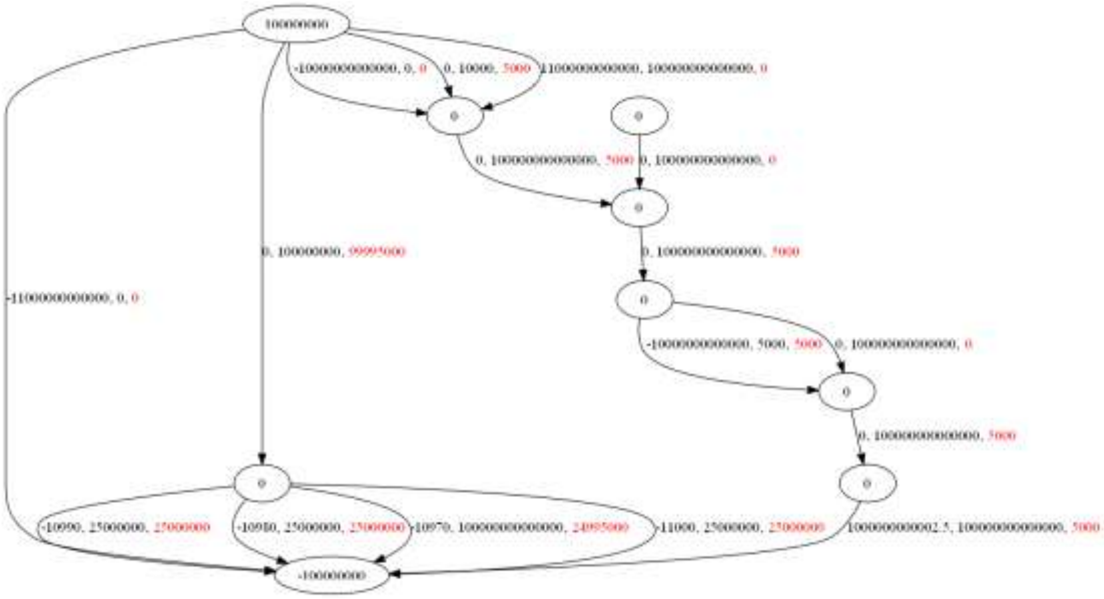


Figure 4.3 An example visualisation of NetLP network in a particular time step.

4.4. Off-Stream Surface Water Storages

The Logan-Albert catchment had an off-stream storage (OSS) at Bromelton. The Bromelton OSS had the following characteristics:

- It did not have a catchment of its own
- It supplied water to irrigation demands directly from the storage
- Inflow to the OSS was extracted downstream of the Bromelton Weir
- The amount of water that can be extracted depended on: (1) a defined threshold volume in the Logan River at two specified locations, one at the extraction point (upstream of the Bromelton OSS) and another downstream of Cedar Grove Weir (and Bromelton OSS); (2) pump capacity; and (3) volume of empty storage in the OSS. (Note: Most of the input data of Regional Urban Tool's SEQ application were sourced from the IQQM model developed to support the Water Resource Plan (WRP) of the Logan basin. In the WRP, threshold volume for Bromelton OSS

was defined as 300 ML/year, i.e. water could be pumped up to capacity of the pump if the amount of water in the river at the two specified locations was greater than 300 ML/year.)

- Spills from the OSS returned to the Logan River
- As per the WRP of Logan basin, there were no controlled releases from the OSS to the Logan River to improve low flows in the Logan River

The modelling method involved representing an OSS as a surface water storage, but without a catchment of its own. This is illustrated in Figure 4.4. A new functionality 'off-stream storage splitter' was developed to divert water from the river to fill an off-stream storage. Demand could access the stored water using the Regulated Extraction node model, placed at the downstream node of the off-stream storage link (see Figure 4.4). The off-stream splitter upstream of the OSS directed flow down a link that feeds this storage. The split was governed by rules relating to river flow at the node.

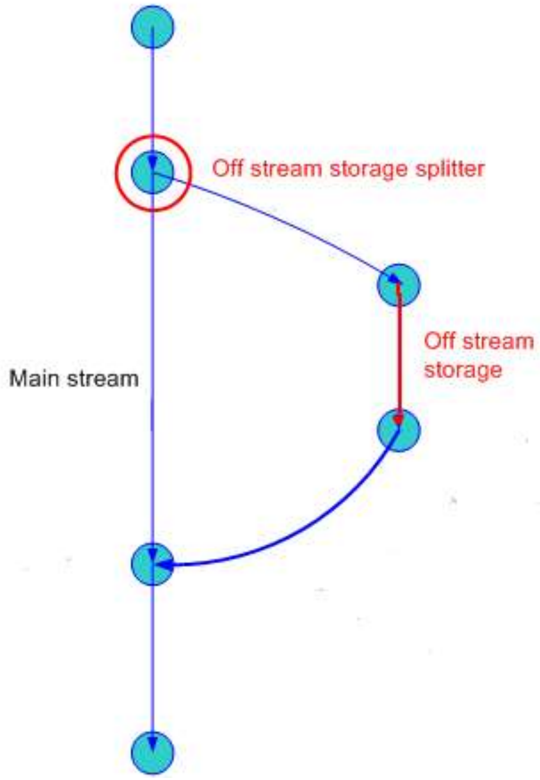


Figure 4.4 **Representation of OSS splitter in the prototype SEQ IUWM modelling tool.**

For an OSS, the storage at the end of time t is given by:

$$S_{t+1} = S_t + DI_t - D_t - surface\_evaporation_t - seepage_t + surface\_inflow_t$$

If $S_{t+1} > S_{max}$; $Spill_t = S_{t+1} - S_{max}$ and $S_{t+1} = S_{max}$

Where,

D_t is the demand supplied from the OSS at time t;

DI_t is the diverted inflow at time t;

$surface\_evaporation_t$ is evaporation loss from the surface of the OSS, which can be computed as:

$surface\_evaporation_t = evaporation \; X \; surface\_area_t$

The surface area is computed from a storage-surface area relationship, which must be specified by the user.

$surface\_inflow_t$ is inflow to OSS due to precipitation, computed as:

$surface\_inflow_t = rainfall \; X \; surface\_area_t$

$seepage_t$ is seepage loss at time t, which must be given by the user

$spill_t$ is spill at time t, which returns to the river via a return-link. Hence, flow in a return link at time t = $spill_t$.

4.4.1 Off-Stream Storage Splitter

Due to limitations with the way custom expressions were evaluated within the splitter functionality available through the E2 framework, a new functionality was required in the HydroPlanner.

The new functionality, off-stream storage splitter, diverted water from the main stream in order to resupply or "top up" and off stream storage. The amount of water diverted at an off-stream storage splitter depended on the following values:

- *Storage deficit*: the amount needed to fill the storage
- *Minimum flow*: a minimum flow level to be maintained
- *Inflow*: the amount of water flowing into the splitter
- *Pump Capacity*: the maximum capacity of the pump used to divert the water

The rate at which to divert water was then simply the minimum of:

- The rate needed to supply all of *Storage Deficit* over 24 hours.
- *Inflow* minus *Minimum flow* (only when *Inflow* > *Minimum flow*).
- *Pump Capacity.*

To illustrate this, a few examples are given in Table 4.1.

Table 4.1 Off-stream storage diversion examples.

Case	Inflow (ML/d)	Storage Deficit (ML)	Storage Deficit supply rate (ML/d)	Minimum Flow (ML/d)	Pump Capacity (ML/d)	Diversion (ML/d)
A	3	48	2	2.5	1	0.5
B	2	24	1	0	5	1
C	5	300	12.5	1	2	2
D	0	48	2	3	17	0

Limitations and Possible Improvements

The off-stream storage splitter was not aware of any lag between the point at which water was diverted and when that diverted water actually reached the storage. Therefore, the end user should ensure that the links between the off-stream storage splitter and the storage itself were configured to have zero lag or travel time.

The off-stream storage splitter was opportunistic, much like the flood harvest diversion node model (described below in the 'unsupplemented demand' section). This may create problems when water ordered by downstream demands was diverted to the off-stream storage instead. To counteract this, the off-stream storage splitter might need to be made aware of the orders and ownership of the water.

4.5. Wastewater Generation, Transportation, Treatment and Recycling

4.5.1 Wastewater Generation and Transportation

Urban demands consume water for both indoor and outdoor purposes. It was assumed that water used for indoor purposes fully converts into wastewater and the indoor water use could be any percentage (i.e. 0-100%) of the total demand satisfied. The *wastewater functional unit model* generated wastewater as per these assumptions as a daily time-series. Both demand and wastewater resided in the functional unit.

The wastewater functional unit model was executed after the demand model, which allowed the volume of demand satisfied to be passed from the corresponding demand model to the wastewater. If a wastewater treatment plant was configured, a percent of the satisfied demand was added to the treatment plant's storage.

The wastewater generated by the wastewater functional unit model was transported to a specified wastewater treatment plant, which was represented as a node model. Transportation occurred via pipes, which were not represented as links in the system. The transport phase was assumed to finish within a time-step of the modelling run.

4.5.2 Wastewater Treatment

The Wastewater Treatment Plant (WWTP) was represented using a node based model on the scheme shown in Figure 4.5.

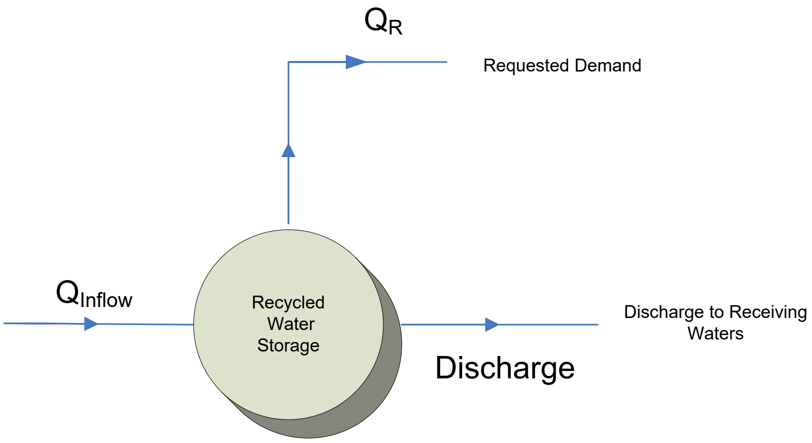


Figure 4.5. Schematic representation of a wastewater treatment plant.

The model considered the plant as a bucket with a defined maximum capacity S_{max} and initial volume S_i. Demand models that referred to this instance of the WWTP as a source could request to extract a volume of water from the model's storage if available. Inflow to the WWTP was added to the storage, after releasing water to satisfy the demand. Any water that could not be stored is discharged as outflow.

The quality of this storage was not defined, but the requester (demand model) was assumed to accept as fit for purpose. The modeller assigned a concentration that defined the fixed quality of the discharge stream, representing the quality of the plant discharge to receiving water according to the plant operational license.

The input parameters of the WWTP Model were as follows:

- S_i: Initial volume of water available for supply to a demand (i.e. treated water), ML/d
- S_{max}: maximum storage volume, ML/d
- C_{RW}: User defined nutrient concentration in the overflow, mg/l

The outputs produced by the model were as follows:

- Q_R: Flow supplied to meet water demand, ML/d
- Nutrient loads for each simulated constituent (if any) in the outlet stream, as a product of C_{RW} times the overflow volume, Kg/d

The current storage volume was augmented by the buffered inflow volume. If the new storage volume was greater than the storage capacity, the difference was passed to the discharge node.

Most of the water quality modelling capability of the HydroPlanner prototype was based on existing functionality offered by the E2 framework. Storages were considered to be fully mixed systems, so constituents entering a storage were instantaneously distributed through the storage. A detailed description of the water quality models was available (Argent *et al.*, 2008). The only additional source of constituents in the prototype was through discharges from a WWTP.

4.6. Supply System Performance Indicators

One of the key strengths offered by the prototype HydroPlanner was capability to quantify performance of the supply system under different urban water management strategies. Performance measures often considered included reliability, resilience and vulnerability (Loucks 1997). In addition, the Australian water industry often used system yield of surface water sources as a performance measure for planning purposes. This document describes functional specification for computing these performance measures in the prototype HydroPlanner.

4.6.1 Reliability

Reliability of the system measures the proportion of total time the system performs satisfactorily (Loucks 1997). Reliability (say, R) was defined as:

$$R(\%) = 100\left(1 - \frac{f}{T}\right)$$

Where, T is the total number of simulation periods and f is the number of unsatisfactory simulation periods.

For water supply systems, an unsatisfactory simulation period was a time period during which any of the demands was not met satisfactorily (i.e. the amount of water supplied to meet any demand was less than the requested or actual demand). The number of unsatisfactory simulation periods (i.e. f) could be computed by using a time-series of total demand shortfall. A demand shortfall at any time t was the difference between total requested demand at time t and the total supplied demand at time t.

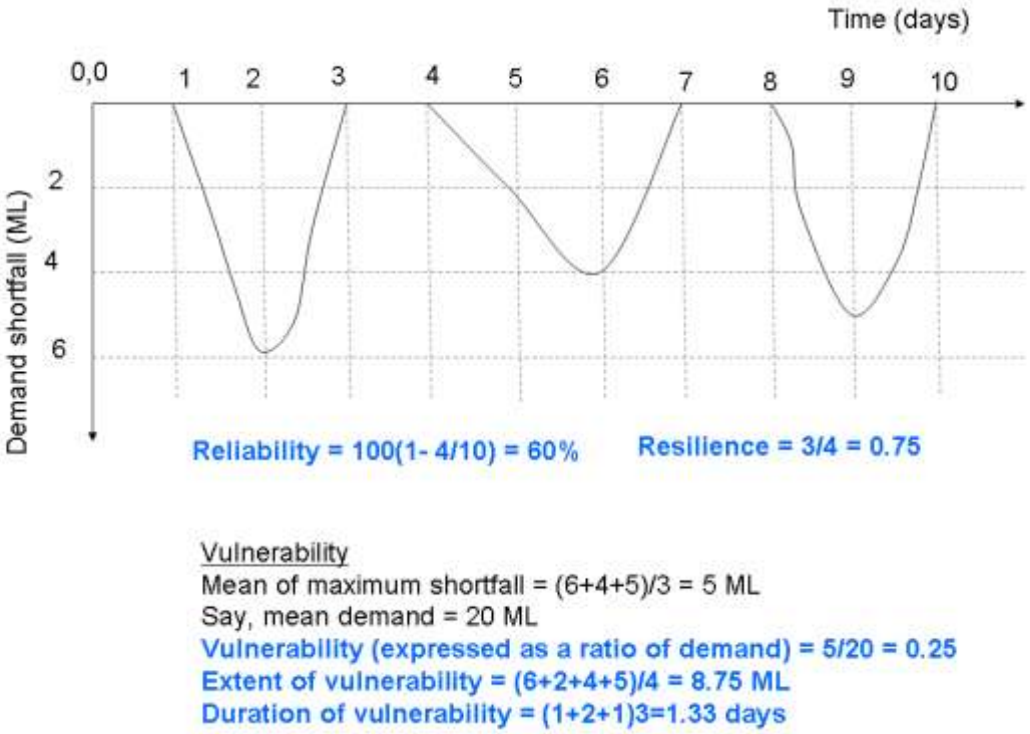
An example for computation of reliability is given in Figure 4.6. In this example, the total number of simulation periods = 10; failures (i.e. demand shortfalls) occur on time periods 2, 5, 6 and 9, i.e. number of unsatisfactory periods = 4. Hence, reliability = 100(1-4/10) = 60%.

4.6.2 Resilience

Resilience is an indicator of the speed of recovery from an unsatisfactory condition. It was defined as the probability that a satisfactory value follows an unsatisfactory (or failure) value (Loucks 1997; Montaseri and Adeloye 2002). It could be computed as follows:

$$\beta = f_c / f$$

Where f_c is the number of continuous failure sequences. The example in Figure 4.6 has three continuous failure sequences and four unsatisfactory simulation periods. Hence, resilience = ¾ = 0.75.



Reliability = 100(1- 4/10) = 60%

Resilience = 3/4 = 0.75

Vulnerability

Mean of maximum shortfall = (6+4+5)/3 = 5 ML

Say, mean demand = 20 ML

Vulnerability (expressed as a ratio of demand) = 5/20 = 0.25

Extent of vulnerability = (6+2+4+5)/4 = 8.75 ML

Duration of vulnerability = (1+2+1)3=1.33 days

Figure 4.6 An illustration of deriving reliability, resilience and vulnerability.

4.6.3 Vulnerability

Vulnerability measures the magnitude of water shortage. It could be computed as a ratio of the mean demand over the simulation period, as follows (Montaseri and Adeloye 2002):

$$\eta = \left. \frac{\sum_{k=1}^{f_c} \delta_k}{f_c} \right/ D$$

Where, η is the vulnerability, D average demand over the simulation period and δ_k is the maximum shortage in continuous failure sequence k.

The example in Figure 4.6 has three continues failure sequences and the maximum extent of shortages corresponding to the three failure sequences are: 6, 4 and 5. The mean of the maximum shortfalls = (6+4+5)/3 = 5. If the average demand over the simulation period is 20, vulnerability = 5/20 = 0.25.

Vulnerability can also be expressed as extent and/or duration of failure (Loucks 1997), as follows:

$$Extent\ of\ vulnerability = sum\ of\ all\ failure\ values / f$$

$$Duration\ of\ vulnerability = sum\ of\ failure\ sequences / f_c$$

Figure 4.6 shows the computation of both the extent of vulnerability and the duration of vulnerability.

4.6.4 System Yield

The system yield of a supply system is the average annual volume that can be supplied by a water supply system at the adopted level of service (LOS) objective (Erlanger and Neal 2005). The LOS objective is the desirable maximum frequency, duration and severity of water restrictions expected by the community.

The system yield depends on such aspects of a water supply system as physical configuration of the supply system, capacities of reservoirs, storages of alternative sources such as stormwater ponds and treated wastewater holding ponds, pipelines and pumping stations, characteristics of stream inflows and evaporations and operating rules of the system.

Computation of system yield generally requires demands to be increased until the LOS objective is no longer valid. There are two methods available for computing the system yield (Erlanger and Neal 2005):

Method 1: Uses a constant average annual demand over the whole simulation, which is increased uniformly to represent future demand scenarios. To estimate the yield, average annual demand is varied iteratively until the LOS objective is no longer valid. The result represents the maximum average annual demand that can be supplied from the system without breaching the LOS objective. It can be interpreted as the amount of water that can be safely supplied per year on an average basis over the whole simulation period (or planning period).

Method 2: Uses an increasing level of average annual demand corresponding to the estimated population growth over the simulation period (or planning period). To estimate the yield, the LOS objective is assessed for each simulation year. The year in which the LOS objective is no longer valid is considered as a potential augmentation time. The average annual demand corresponding to that year is taken as the system yield.

Both methods are used by water companies in Australia for system yield assessment. Method 1 has an advantage of including the potential impact of successive years of drought condition on the LOS objective. On the other hand, method 2 has an advantage of providing timing for supply augmentations.

Method 1 was implemented in the HydroPlanner.

The LOS objectives specified in the SEQ Water Strategy was:

- to ensure that medium level restrictions:
    1. will not occur more than once in every 25 years on average;
    2. will last longer than six months (say, 2a) no more than once every 50 years on average (say, 2b); and
    3. need only achieve a targeted reduction in consumption of 15% below the total consumption volume in normal operations.

To capture this LOS objective, the following input parameters were defined:

A. **Severity of restrictions**: the users of the HydroPlanner prototype were required to specify this input parameter as a percentage value. It represented the targeted reduction in consumption below the total consumption volume under normal operations. This input parameter represented component #3 of the LOS;

B. **Frequency of restrictions**: the users of the HydroPlanner prototype were required to specify this input parameter as a percentage value. It represented the acceptable time reliability of the system, i.e. (1-acceptable probability of system failure). This input parameter represented component #1 of the LOS; and

C. **Duration of restrictions**: the users of the HydroPlanner prototype were required to specify this as two input parameters:

    C.1 **Allowable duration of restrictions,** in months. This input parameter represented component #2a of the LOS; and

C.2 **Allowable frequency of the allowable duration of restrictions** in terms of once in xx years on average (i.e. user to specify a value for xx). This input parameter represented component #2b of the LOS.

The following steps should be followed to evaluate the LOS criteria. The evaluation method used parameters A, B, C.1 and C.2:

(i) Compute total system demand shortfall daily time-series

(ii) Compute allowable daily system demand shortfall using input parameter A, say α

(iii) Deduct α from each of the data point in total system demand shortfall daily time-series, computed in step i. The resulting time-series represents *non-acceptable demand shortfalls* that are below the targeted reduction in consumption

(iv) Count the number of days with *non-acceptable demand shortfalls,* say X

(v) Compute the allowable number of days with restrictions (say, Y), using input parameter B as follows:

$$Y = \frac{365}{100(1-B)}N$$, where N is the number of years used for simulation.

Note: assumed 365 days per year.

If $X \leq Y$, LOS criteria A and B are satisfied

(vi) Compute the number of failure sequences with duration = $30(C.1)$; (note: assumed 30 days per month). Say, there are Z number of failure sequences

(vii) Compute the frequency of duration of failure sequences (say, β) as follows:

$$\beta = \frac{Z}{N}$$

If $\beta \leq \frac{1}{C.2}$, LOS criteria A and C are satisfied

System yield can be displayed as a graph, as shown in Figure 4.7.

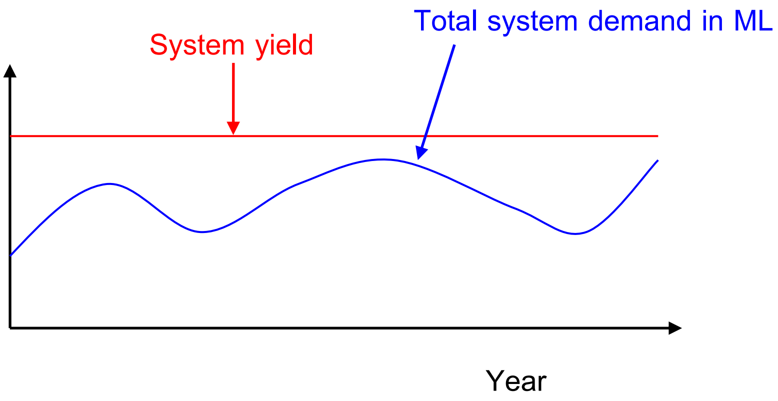


Figure 4.7 System yield graph.

4.7. System Output Reporting

All results could be viewed on the screen as graphs, tables and with relevant statistics. The user could choose to write all or subsets of the results to various output formats.

The program could report on system performance indicators such as:

- Total demand requested;
- Total demand deficit;
- Reliability of supply;
- Total system storage;
- Storage levels and volumes of individual storages;
- Inflows and outflows from subcatchments, links and nodes; and
- Constituent loads and concentrations for inflows and outflows.

See Appendix A for full list of recordable outputs.

5. TEST APPLICATION

5.1. Objective

The primary objective behind the case study was to test the applicability of the HydroPlanner prototype to a typical regional catchment in SEQ and its ability to quantify potential impacts of alternative urban water management options on both supply system dynamics (e.g. system yield, storage levels, demand shortfall and reliability) and receiving water quantity and quality. The key modelling questions of the test case study are given in section 3.1

5.2. Test Case Study Location

The test case application was undertaken for the Logan-Albert Basin in SEQ (Figure 5.1) (hereinafter called the Logan Basin or the Logan test case). This basin, south of Brisbane, includes the Logan and Albert Rivers, and overlaps the council areas of Scenic Rim, Logan City, and parts of Gold Coast City, Redland City and Brisbane City councils.

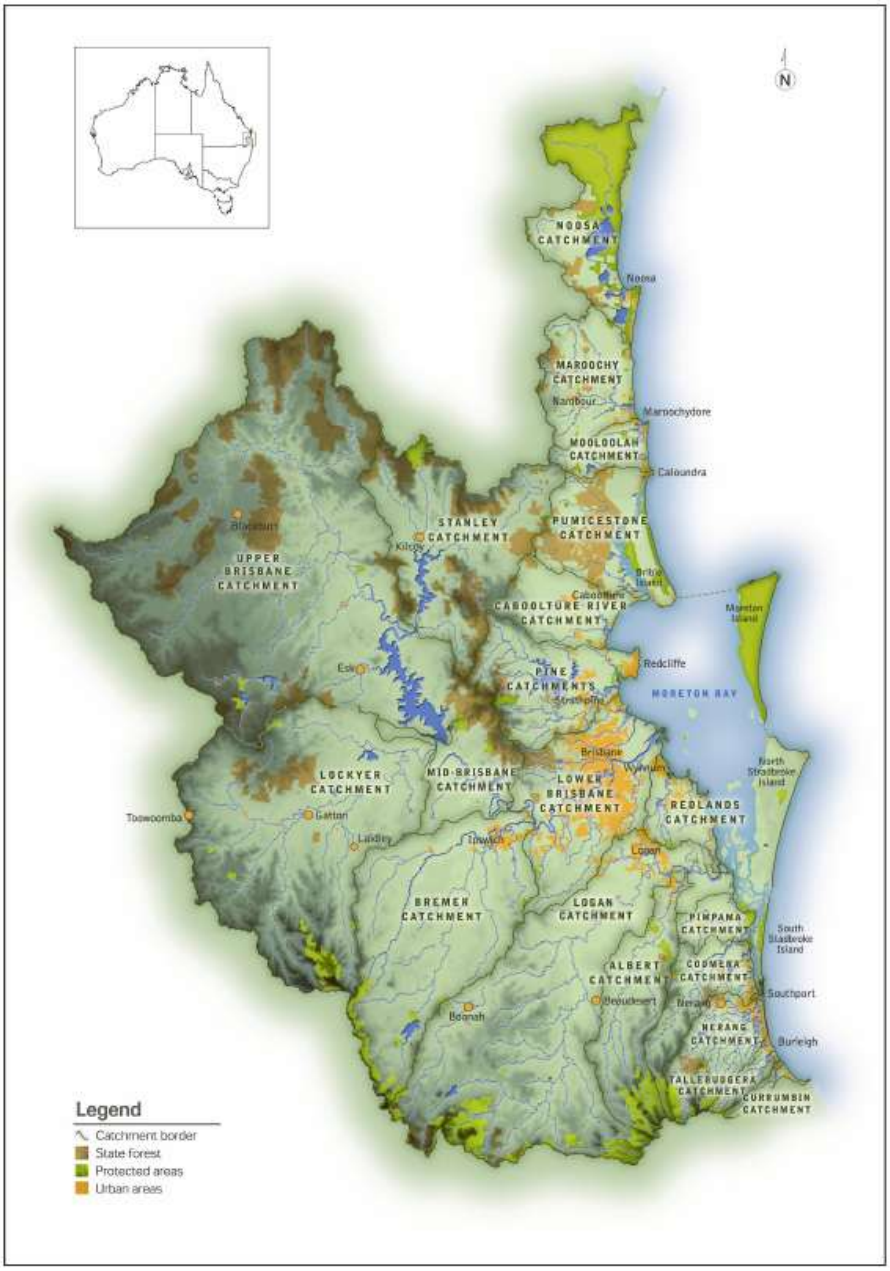


Figure 5.1 Test case study: Logan-Albert catchment in SEQ (Healthy Waterways 2007).

5.3. Key Modelling Assumptions and Constraints

The Logan Basin was considered as a closed catchment, i.e. demands located geographically within the catchment. Supplies from sources external to the basin were excluded. This hydrological rather than geographical approach is the same as that taken for the IQQM model of the region. This assumption excludes any discharges of wastewater from these demands to the basin's waterways, but eliminates the need to extend the catchment boundary or model imports/exports of water. For calibration and validation of flows, time-series outputs from external catchments could be input as supplies or wastewater discharges.

Even though catchment features identified in the Logan Basin influenced the focus for software development, software development or data constraints prevented inclusion of some features, such as:

- Unsupplemented (unregulated) demands, which extract water according to flow volumes available in the waterway. These may be irrigation or fixed rural/residential demands. The ordering functionality to ensure that unregulated demands do not capture water belonging to regulated orders is not yet available within the E2 framework
- Rainwater tanks or fully parameterised regional stormwater harvesting
- External supplies, e.g to towns such as Logan City

Note that the scenarios and assumptions are based on information that, to the best of our knowledge, represents an (albeit simplified) depiction of to Logan Basin, sufficient for proof-of-concept application of capabilities of available model components. Data used mostly matches that currently for regional scale models of the basin, and any additional data that was readily available at the time of development. Any expansion of demand and wastewater representation, for example, will require integration of more detailed data.

5.4. Scenarios

A number of scenarios have been developed, which allow comparison between different growth or development conditions and urban water management plans. These are as follows:

- Scenario A: Base case. This includes present day infrastructure, land use, demand and climate
- Scenario B: Base case wastewater recycling. Same as Scenario A, but with reuse of wastewater from treatment plants for urban and irrigation demands
- Scenario C: Base case stormwater harvesting. Same as Scenario A, but with capture and reuse of runoff on tributaries in urban areas
- Scenario D: Future business-as-usual case. Same as Scenario A, but with future (around 2026) land use changes, demand growth and additional storage (Wyaralong Dam)
- Scenario E: Future case wastewater recycling. Same as Scenario D, but with point and diffuse source constituent reduction schemes and reuse of wastewater for urban demands

5.5. Data and Model Features

The Logan test case was mostly parameterised with data sourced from existing models, namely: the Logan Water Resource Planning (WRP) (Office of the Queensland Parliamentary Counsel 2008) Integrated Quantity and Quantity Model (IQQM) (NSW Department of Land and Water Conservation 1999) scenario s180c (obtained from DERM); and the current Logan WaterCAST quantity and quality catchment model (Argent, *et al.* 2008) developed by WBM for the Healthy Waterways Partnership.

5.5.1 Catchments and Streams Network

The subcatchment map used for the Logan Basin is the same as that in the Logan WaterCAST model, derived from a 25m Digital Elevation Model, but the node-link network was revised by mapping nodes on to subcatchment boundaries. Additional catchments and nodes were also identified, corresponding to the locations of Bromelton Weir, Bromelton Off-Stream Storage, Wyaralong Dam and Luscombe Weir. Straight-through routing is used on most links; lagged flow routing (daily time-step) is employed on reaches as indicated in the supply source to demand lag information of the Logan WRP IQQM model.

Land use areas, defined by in the model as Functional Units, were also taken from the WaterCAST model; these functional units are connected to rainfall-runoff, constituent generation, demand and wastewater generation models. The functional units used are:

- Green space
- Grazing
- Broad acre agriculture
- Intensive agriculture
- Rural residential
- Suburban
- Dense urban
- Water

These areas correspond to scenarios for the period around 2002- 2008.

Future land use was based on a percentage change applied to each catchment according to predicted changes for SEQ planning as outlined in Table 5.1. These values indicated, by 2026 a 22% increase in urban area (rural residential + suburban + dense urban), a 463% increase in dense urban area, and a 36% increase in intensive agriculture. This was accompanied by 3-4% decrease in green space and grazing areas. In the model, these changes were implemented on a functional unit rather than a basin-wide basis to approximate these trends whilst keeping the area balanced to 100%.

Table 5.1 Extent of land use in 2004 and predicted land use in 2026 (Healthy Waterways 2007).

Land Use Class	2004		2026		Change
	Area (km^2)	*Area (%)*	*Area (km^2)*	*Area (%)*	*Area (%)*
Green Space	1790	46.4	1721	44.6	-4
Grazing	1481	38.4	1435	37.2	-3
Broad acre Agriculture	144	3.7	156	4.1	8
Intensive Agriculture	37.9	1	51.5	1.3	36
Rural Residential	217.5	5.6	214.9	5.6	-1
Suburban	155.5	4	143	3.7	-8
Dense Urban	22	0.6	123.9	3.3	463
Water	12.7	0.3	12.7	0.3	0

5.5.2 Rainfall-Runoff Modelling

Climate (rainfall and evaporation) inputs were obtained as ASCII 5km grid format from SILO (Queensland Department of Natural Resources 2004).

The rainfall-runoff (RR) modelling procedure outlined below was suggested by Department of Environment and Resource Management (DERM) Staff (Mahmutovic 2009) to align with rainfall-runoff modelling performed as part of the development of the IQQM model of the Logan-Albert catchment. The Logan-Albert IQQM model uses the Sacramento RR model (Burnash, Ferral and McGuire 1973) and consequently this model was chosen for the HydroPlanner prototype. RR modelling of the catchment involved calibration to:

- Pre-development conditions – achieved by determining the parameters which fit the runoff characteristics of pre-development conditions in the subcatchments. The model will then describe the behaviour of the sub-catchments in natural conditions.

- Developed conditions – achieved by subtracting known and estimated water extractions from the pre-development runoff volumes to approximate the present day hydrology and the observed gauge data throughout the catchment.

Further details about the calibration procedure are provided below.

Pre-Development Conditions

The Logan WRP IQQM model included inflow from a calibrated Sacramento RR model, which estimated pre-development conditions by adding known and estimated water extractions to observed gauge data. The calibrated Sacramento (Burnash, *et al.* 1973) parameters used for modelling of pre-development conditions, and the estimated pre-development runoff volumes, were provided to the HydroPlanner development team.

However, the input data sets used by the HydroPlanner development team differed slightly to those used by DERM. For example, although the climate data used by both DERM and the HydroPlanner development team were sourced from the SILO database, refinement of the underlying algorithms used to interpolate SILO climate data resulted in slightly different data sets being supplied. Additionally, the sub-catchment areas differed slightly as the HydroPlanner subcatchment areas were derived from a 25m Digital Elevation Model (DEM) while DERM areas were estimated by field staff. Therefore, in order to achieve more accurate model results the parameters initially supplied by DERM were adjusted using eWater CRC's Rainfall Runoff Library (RRL) (Podger, 2004).

For headwater reaches, DERM staff advised that minimal water extraction had occurred and the historical observed gauge data would be representative of pre-development conditions (see Appendix B, Figure B1 for a Logan-Albert reach map). For residual reaches (those reaches receiving inflows from upstream subcatchments), the pre-development IQQM model runoff volumes were the best available estimate of pre-development hydrology. Therefore, when adjusting the Sacramento parameters supplied by DERM, observed gauge data was used for headwater reaches and pre-development IQQM flows were used for residual reaches.

Exceptions to the above occurred for some reaches. For the headwater reach which contains Maroon Dam, IQQM pre-development runoff volumes were used as the influence of the dam would have been reflected in the gauge data. For the bottom reaches of the Logan and the Albert Rivers no gauge data is available, and therefore no estimate of pre-development flows was possible. Flows for these reaches were approximated by scaling by area the pre-development IQQM flows from the directly upstream reaches.

DERM staff advised that in the Logan-Albert catchment, water extraction was minimal for most subcatchments prior to 1986. The modelling period was therefore broken up into a calibration period from 1966 to 1985 and a verification period from 1986 to 2008. For headwater reaches, which were calibrated against gauge data, this division was adhered to if gauge data extended over this period. For residual reaches, which were calibrated against pre-development IQQM flows, the calibration and verification period selected reflected the original periods used in the creation of the IQQM model (see Appendix B Table B1 for a list of calibration and verification periods for each reach).

For all reaches, calibration proceeded as follows:

- Data was assembled for reach calibration. This included: reach areas from the model subcatchment map (derived from a 25m DEM); runoff generated from the reach in question only; and rainfall and PET (Morton's potential evapotranspiration) data from SILO (Jones, Wang and Fawcett 2009) which was provided in ASCII grid format for the period 1950-2008. This data was provided in daily rainfall and PET 5 km grids, which were interpolated from point climate measurements. These daily grids were interrogated to produce a continuous time-series of data for each reach for the modelling period. The above data was entered into the RRL with the Sacramento parameters supplied by DERM.

- To improve the fit of the model's predicted flow to either the gauge data or the pre-developed flows supplied by DERM, first the lower zone tension water storage was adjusted (the Lztwm parameter) then the upper zone tension water storage was adjusted (the Uztwm parameter). These parameters were optimised using the Rosenbrock Multi-Start Optimiser with the Nash-Sutcliffe criterion (Nash and Sutcliffe 1970) as the primary objective and percentage runoff difference as the secondary objective.
- If either Nash-Sutcliffe efficiency values, absolute and relative differences, or fit between observed and predicted flow duration curves were unsatisfactory, a manual calibration was performed to improve results.
- Channel loss curves were taken from the IQQM model of the catchment and incorporated into the RR component of HydroPlanner.

Calibration results for each reach in the Logan-Albert catchment are presented in Appendix B, Table B1 and Table B2. For all reaches, the relative difference between predicted and observed (or IQQM pre-development flow) data was kept to under approximately 10% for the calibration and verification period. Exceptions to this occurred for reaches 8, 13 and 14. It is unclear why the verification period for reach 8 had an approximate 25% relative difference. However DERM field staff suggested that changes in the method used to derive rating curves between the pre- and post-1985 periods may account for some of this difference. The poor results of reaches 13 and 14 are most likely a reflection of the additional assumptions needed when estimating flows in these reaches due to lack of gauge data.

In general the monthly Nash-Sutcliffe E values were higher for the calibration periods compared to the verification periods, although there were some exceptions. This was expected given the assumption outlined above that the majority of water extraction occurred post 1985. The daily Nash-Sutcliffe E values were far more variable however. These daily E values were the best possible while trying to simultaneously minimise relative differences and match flow duration curves as closely as possible.

A good fit was able to be achieved for calibration period flow duration curves for all reaches. The match was generally only possible for the high flows however as matching the entire length of the flow duration curve led to significant consequences in terms of reduced Nash-Sutcliffe values and increased relative differences. Similarly to the Nash-Sutcliffe values, the flow duration curves were a better match in the calibration periods rather than the verification periods.

Developed Conditions

To simulate developed conditions, information on known and estimated extractions is required. Accounting for water extractions can be complex as they can be either:

- Supplemented: meaning that the user can always extract their licensed amount of water, and if there is insufficient flow to accommodate this amount more water can be ordered from upstream storages. This type of extraction covers town water supplies, irrigation and water harvesting; or
- Unsupplemented: the user can only extract their licensed amount in certain conditions, for example when flow passes a critical threshold. This type of extraction covers irrigation, water harvesting, and other unsupplemented uses such as stock and domestic.

Calibration to developed conditions was not possible for this deliverable as complete extraction information was not received from DERM.

5.5.3 Constituent Generation and Transport

Each land use in the model generates constituents based on event mean and dry weather concentration factors (EMC and DWC). These were taken from the WBM WaterCAST catchment model; constituents included were suspended solids, total nitrogen, and total phosphorus. Table 5.2 gives the parameter values for each land use in the catchment. Filtering of generated constituents in transport to streams, or in-stream processing of constituents has not been included.

Table 5.2 Constituent generation parameters for Functional Units (land uses).

	Total Suspended Solids		Total Nitrogen		Total Phosphorus	
	DWC (mg/L)	*EMC (mg/L)*	*DWC (mg/L)*	*EMC (mg/L)*	*DWC (mg/L)*	*EMC (mg/L)*
Green Space	7	20	0.4	1.5	0.03	0.06
Grazing	10	260	0.7	2.08	0.07	0.3
Broad acre Agriculture	10	300	0.7	1.95	0.07	0.321
Intensive Agriculture	10	550	0.7	5.2	0.07	0.449
Rural Residential	10	130	0.7	1.6	0.07	0.28
Suburban	7	130	1.5	1.6	0.11	0.28
Dense Urban	7	130	1.5	1.6	0.11	0.28
Water	0	10	0	0.5	0	0.04

For the future scenarios, these constituent generation rates were reduced, according to the SEQ Healthy Waterways Strategy management outcomes for Logan for 2026 (Healthy Waterways 2007). These management outcomes included a reduction of loads in urban areas based on adoption of best management standards for Water Sensitive Urban Design (Healthy Waterways 2006), which for SEQ were:

- 80% reduction in total suspended solids load;
- 60% reduction in total phosphorus load; and
- 45% reduction in total nitrogen load.

These load reduction targets were applied to the suburban and dense urban functional units. For all other functional units, the Strategy's management outcome for non-urban diffuse source pollutant load reduction of 50% by 2026 has been applied. As the runoff quantity in future scenarios of the model was similar to the base case, these load reductions were applied to the constituent generation concentrations for future scenarios as shown in Table 5.3.

Table 5.3 Future (2026) action plan constituent generation parameters for Functional Units (land uses).

	Total Suspended Solids		Total Nitrogen		Total Phosphorus	
	DWC (mg/L)	*EMC (mg/L)*	*DWC (mg/L)*	*EMC (mg/L)*	*DWC (mg/L)*	*EMC (mg/L)*
Green Space	3.5	10	0.2	0.75	0.015	0.03
Grazing	5	130	0.35	1.04	0.035	0.15
Broad acre Agriculture	5	150	0.35	0.975	0.035	0.1605
Intensive Agriculture	5	275	0.35	2.6	0.035	0.2245
Rural Residential	5	65	0.35	0.8	0.035	0.14
Suburban	1.4	26	0.825	0.88	0.044	0.112
Dense Urban	1.4	26	0.825	0.88	0.044	0.112
Water	0	5	0	0.25	0	0.02

5.5.4 Surface Water Storages

Storage curves, initial volumes and releases for surface water storages were taken from the Logan WRP IQQM model. In the case of Bromelton Off-Stream storage, this also included thresholds of extraction from the river, based on flow at the extraction point, limited to pump capacity and the capacity of the storage.

Initial concentrations of constituents for all storages are given in Table 5.4. These were obtained from the WBM WaterCAST catchment model. Evaporation and rainfall on storages were obtained from the SILO data used in the rainfall runoff generation models.

Table 5.4 Initial concentrations of constituents in storages.

Constituent	Concentration (mg/L)
Total Nitrogen	1
Total Phosphorus	0.1
Total Suspended Solids	5

Environmental and flood releases were implemented for Maroon Dam, Bromelton Weir and Wyaralong Dam, based on information in the Logan WRP IQQM model. Flood releases were applied using a culvert, based on storage levels in the dam. Environmental flows used a minimum flow node, which looked at maintaining minimum flow downstream of the dam, based on its inflow. These volumes were implemented based on the output of the previous time-step, so may be lagged by one time-step.

Currently there was not explicit software capability for storages to pass orders upstream, nor order to fill dead storages. However these mechanisms were simulated through the use of a minimum flow node. These included orders from Bromelton Weir, Cedar Grove Weir, and South Maclean Weir to upstream storages to maintain dead storage volume and to satisfy downstream orders (storage volume – order deficit). This imitated the capability to pass orders between storages as represented in the IQQM Logan WRP model, allowing better distribution of the water available in headwater storages. A minimum flow node placed above the weir would order flows to attempt to maintain dead storage and average daily demand volume in the weir. Again, a feature of the minimum flow node expression was that it would be implemented based on output of variables from the previous time-step, and would also incorporate any lag present in the stream network.

5.5.5 Demands

The Logan Basin application included all supplemented (regulated) irrigation and urban water demands represented in the Logan WRP IQQM model. Supplemented irrigation and town water demands were mapped to five categories of Functional Units (FUs):

- ***Broad acre/Intensive Agriculture*** – for supplemented irrigation diversions.
- ***Rural Residential/Suburban/Dense Urban*** – for urban or industrial urban water demands.

Details of these demands, for future and base case scenarios, are given in Table 5.5. Demand was based on that for the year 2003.

Table 5.5 Supplemented demands in test case.

Demand Name	Base Case Average Daily Demand (ML)	Future Case Average Daily Demand (ML)	Functional Unit (Land Use)	Order Reservoir	Wastewater Discharge Plant	Recycled Water Source	Stormwater Harvesting Source
Urban Demand 007	0.03	0.06	Suburban	Maroon Dam	None	None	None
Supp Irr 009	0.09	0.2	Broad acre Agriculture	Maroon Dam	None	None	None
Supp Irr 012	3.9	7.3	Broad acre Agriculture	Maroon Dam	None	None	None
Supp Irr 023	0.7	1.3	Broad acre Agriculture	Maroon Dam	None	None	None
Urban Demand Rathdowney 032	0.2	0.4	Suburban	Maroon Dam	None	None	None
Supp Irr 046	7.6	14.2	Broad acre Agriculture	Maroon Dam	None	None	None
Urban Demand Kooralbyn 066	1.3	2.4	Suburban	Maroon Dam	Kooralbyn WWTP	Kooralbyn WWTP	None
Supp Irr 068	2.8	5.2	Broad acre Agriculture	Maroon Dam	None	Kooralbyn WWTP	None
Supp Irr 079	2.3	4.3	Broad acre Agriculture	Maroon Dam	None	None	None
BOSS Demand 393	42.4	79.1	Broad acre Agriculture	Bromelton OSS	None	None	None
Urban Demand 088	1.5	2.8	Rural Residential	Bromelton Weir	Beaudesert WWTP	Beaudesert WWTP	Beaudesert Stormwater Pond
Urban Demand Sunwater 089	5.2	9.7	Dense Urban	Bromelton Weir	Beaudesert WWTP	Beaudesert WWTP	Beaudesert Stormwater Pond
Supp Irr 091	2.3	4.3	Broad acre Agriculture	Bromelton Weir	None	Beaudesert WWTP	None
Urban Industrial Demand 093	1	1.9	Dense Urban	Bromelton Weir	Beaudesert WWTP	Beaudesert WWTP	Beaudesert Stormwater Pond
Urban Demand Beaudesert 100	3.6	6.7	Suburban	Bromelton Weir	Beaudesert WWTP	Beaudesert WWTP	Beaudesert Stormwater Pond
Urban Demand 109	0.03	0.06	Suburban	Bromelton Weir	Beaudesert WWTP	Beaudesert WWTP	None
Supp Irr 111	8.9	16.6	Broad acre Agriculture	Bromelton Weir	None	None	None
Supp Irr 128	n/a	3.5	Broad acre Agriculture	Wyaralong Dam	None	None	None
Supp Irr 133	0.7	1.3	Broad acre Agriculture	Bromelton Weir	None	None	None
Urban Demand Sunwater 136	4.2	7.8	Dense Urban	Bromelton Weir	None	None	None
Urban Demand 370	11.6	21.6	Suburban	Cedar Grove Weir	Jimboomba WWTP	Jimboomba WWTP	Jimboomba Stormwater Pond
Urban Demand 137	3.3	6.2	Rural Residential	Cedar Grove Weir	Jimboomba WWTP	Jimboomba WWTP	Jimboomba Stormwater Pond
Supp Irr 333	0.09	0.2	Broad acre Agriculture	Cedar Grove Weir	None	None	None
Supp Irr 147	1.9	3.5	Broad acre Agriculture	Cedar Grove Weir	None	Jimboomba WWTP	None
Urban Demand South Maclean 157	6.8	12.7	Suburban	South Maclean Weir	None	None	None
Supp Irr 160	0.4	0.7	Broad acre Agriculture	South Maclean Weir	None	None	None
Urban Demand Beaudesert 277	1.4	2.6	Suburban	Luscombe Weir	None	None	None

Locations of demands were mapped where possible, and location and land use inferred from the IQQM source data. However, many demands (e.g. irrigation) were lumped at the subcatchment level. Assumptions made for location were primarily illustrative and would not alter the modelling results, as the extraction order remained the same. Regulated extraction capacities were sized based on pump capacity or maximum daily demand, and lag time as reported in the Logan WRP IQQM model.

Priority for alternative sources of water for demands were set as highest priority to recycled wastewater, followed by stormwater and surface water storages. It was assumed wastewater would be sufficient quality to supply only a portion of demand:

- 28% (outdoor portion) of urban demand;
- 80% of industrial demand; and
- 100% of irrigation demand.

As stormwater ponds were currently in the same source category as other surface water storages, they would also supply 100% of a linked demand. Wastewater recycling was included for nearest urban (same as that supplying the wastewater plants) and irrigation demands as outlined in Table 5.5. Stormwater pond water was reused for urban demands within the same area.

Urban demands were increased by 86.5% for future case to simulate 2026 demand, based on the SEQ Regional Plan 2005-2026 forecast for Beaudesert Shire (within which all the currently populated urban demands occur), as was adopted for Healthy Waterways modelling of the Logan-Albert Basin from the Regional Plan (Office of Urban Management 2005).

5.5.6 Wastewater

Wastewater in the model was generated from all urban and industrial demands within treatment plant sewersheds, obtained from Scenic Rim Regional Council (Ravels and Maddalena 2009). It was assumed that 72% of urban demand will go to a treatment plant (based on the target of 65 out of 230 kL to be outdoor consumption (Queensland Water Commission, 2008) and 90% of industrial demand to a treatment plant, with the remainder assumed to be for outdoor use. Treatment plants were currently sized based on amalgamation of regulated extraction capacities of contributing demands. This allowed for 2-3 days of peak wastewater quantity to be held.

Only wastewater treatment plants supplied from demands represented in the model were included. Thus, this excluded treatment plants supplied from un-supplemented demands only (e.g. Canungra) or from externally supplied demands (e.g. Logan City).

Constituent outputs for Beaudesert, Kooralbyn and Jimboomba were obtained from EPA monitoring data (Antcliff, 2009; Garnett, 2009). The median values were used for constituent outputs of Total Nitrogen, Total Phosphorus and Total Suspended Solids as outlined in Table 5.6.

Table 5.6 Wastewater treatment plant outputs.

Treatment Plant	Total Suspended Solids (mg/L)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)
Beaudesert	6.8	19.6	8.6
Kooralbyn	0.4	17.7	5.4
Jimboomba	3.5	17.4	8.25

The SEQ Healthy Waterways Strategy management outcomes for the Logan-Albert Basin by 2026 (Healthy Waterways 2007), stipulated removal of 100% of nutrient loads from point sources such as wastewater plants from receiving waters. This could be achieved through recycling, however the treatment plant output concentrations for Scenario E (future constituent reduction) were also reduced to zero accordingly, assuming that technologies were implemented to achieve this outcome.

5.5.7 Stormwater

The capacity for stormwater harvesting was simulated by applying the surface water storage model to small tributaries. This can simulate the capture, storage and harvesting of stormwater in a pond within urbanised catchments. It must be noted that the ponds included in the test application were as proof of concept only, and not based on any existing ponds.

Ponds were located in Beaudesert and Jimboomba urban areas, on tributary drains to the Logan River. They were sized approximately for typical water quality treatment requirements, not for reliability or cost. This includes a surface area of 2% of the catchment, based on Australian Runoff Quality (Wong, 2006) recommendations, and a nominal 2m depth, with 1m draw down. Detention or routing time was not included, with water stored until demanded or spilled.

5.6. Calibration and Testing

Calibration and testing of the entire model results against existing models and all existing data was not undertaken with the exception of the rainfall-runoff models which were calibrated and validated. However, basic mass balance testing was undertaken at component model and system levels, both at the software development and application stage. Water and constituents were conserved appropriately.

Future work could include calibration and testing of the model against existing model outputs, as well as gauge data and water quality monitoring points on the network. These were expected to differ to some degree, as the aim was not to replicate these models exactly.

5.7. Results

As previously discussed, extensive calibration was undertaken only for the rainfall-runoff models, and as such, no definitive conclusions could be drawn from the results. The results presented here instead provided a qualitative comparison between the modelled scenarios and demonstrate some of the prototype capabilities. Results for evaluation of different options could be produced once calibration and verification of the model outcomes is completed.

5.7.1 Storage Levels

Figure 5.2 and Figure 5.3 show the total surface water storage for the Logan-Albert system, including stormwater ponds for stormwater harvesting but excluding wastewater recycle storages, on a daily time-step. The total storage for the future case scenarios was almost double the total storages for the base case due to the inclusion of the Wyaralong Dam. As expected, inclusion of augmentation options increases the overall system storage.

Figure 5.2 shows the influence of wastewater recycling and stormwater harvesting on the base case scenario. Both options increased the storage levels, with highest total storage in the stormwater case. This storage volume was a result of the additional pond storage not present in the wastewater case, as well as changes to drawdown of existing storages due to increased supply. It was also of note that when the dam levels were very high, there was virtually no difference in the total storage between the base case and the recycling case since water was discharged from the dam via the spillway or culverts. However, as the volumes dropped, the differences between storage volumes in the wastewater reuse and base cases steadily increased over time. This can be clearly seen in Figure 5.4, which shows the storage volumes in Maroon Dam over a longer time period and the difference caused by augmentation schemes. The same effect is also seen in Figure 5.3, but is less pronounced since Wyaralong Dam greatly increases the overall system storage.

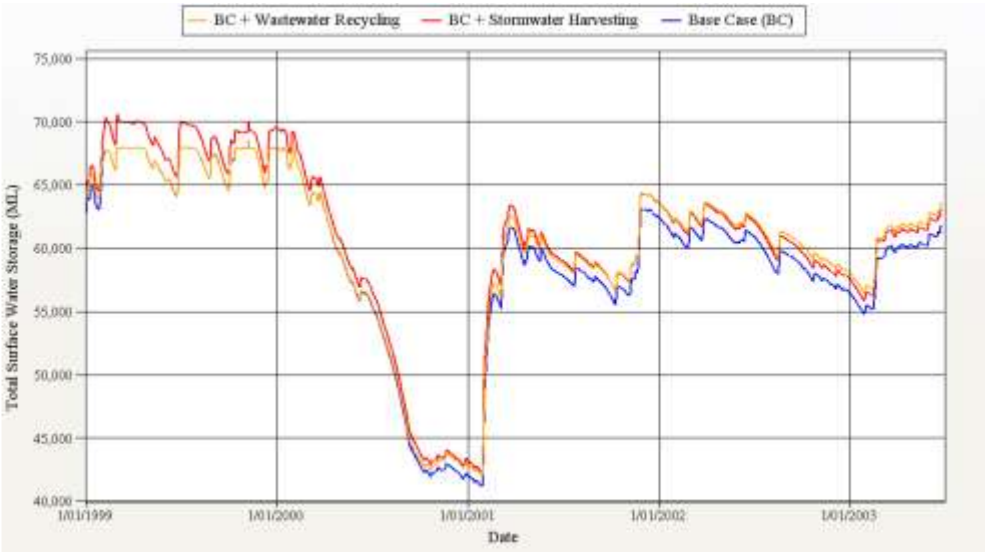


Figure 5.2 Total surface water storages for the base case scenario and augmentation options with wastewater recycling and stormwater harvesting.

Figure 5.3 Total surface water storages for the future case scenario and augmenting with wastewater recycling.

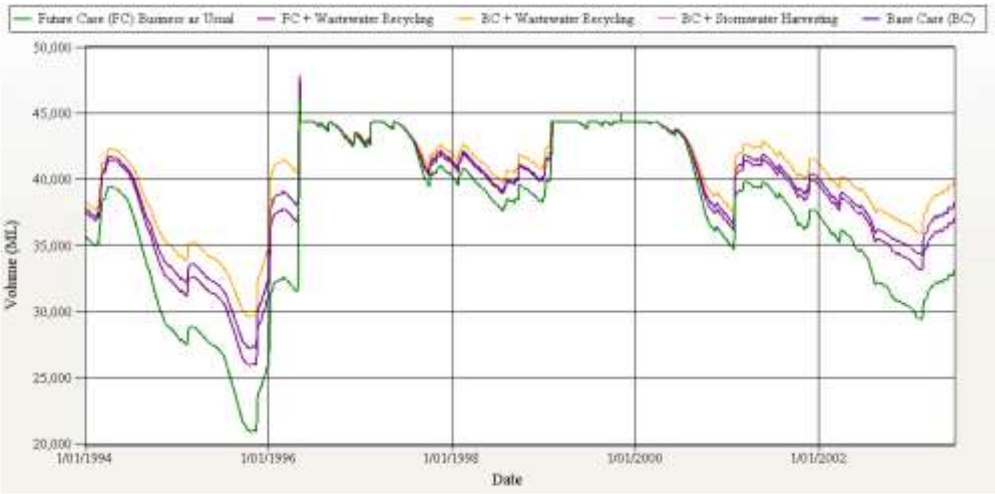


Figure 5.4 Water storage at Maroon dam for all scenarios.

5.7.2 System Yield and Demand Deficit

As indicated above, the impact of augmentation (or alternative supply) options on storages could be minimal for long periods of time, so other measures such as the system yield may give a better indication of the impact of these measures. Calculation of the system yield was based on the following level of service criteria from the SEQ Water Strategy (QWC 2010):

- Allowable reduction in demand (deficit threshold): 15%
- Allowable frequency of restrictions (temporal reliability): 1 out of 25 years (96%)
- Allowable duration of restrictions (persistent deficit threshold): 6 months
- Allowable frequency for duration (acceptable persistent deficits): 1 in 50 years

As expected and indicated in Table 5.7, augmentation options increased the average yearly yield when compared to the base case and the future case. It also demonstrated the impact of the construction of Wyaralong Dam, which increased the yield from an estimated 60496 ML in the base case to 77986 ML in the future case, both using business as usual approaches. This increased in yield occurred despite the future predicted 86% increase in urban demand in the Logan-Albert catchment.

Table 5.7 Average yearly yield for the different scenarios.

Scenario	Average Yield (ML/year)
Base Case (BC)	60496
BC + Stormwater Harvesting	60686
BC + Wastewater Recycling	65068
Future Case (FC) Business as Usual	77986
FC + Wastewater Recycling	81480

However, even though the construction of Wyaralong Dam increased the system yield, the increase in demand resulted in other problems in comparison to the base case, such as the increase in the demand deficit such as shown in Figure 5.5. The increase in demand resulted in larger daily deficit demands during certain periods, but once more, the alternative supply options reduced the severity and duration of the deficit.

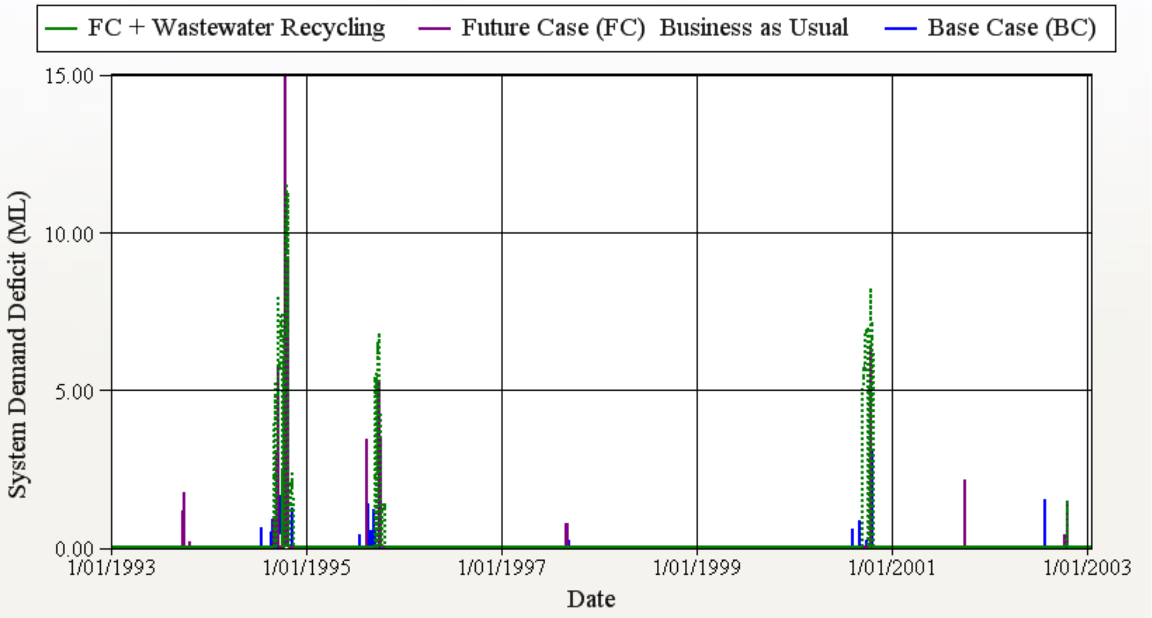


Figure 5.5 System deficit demand for the base case and future case scenarios.

5.7.3 Water Quality

In terms of water quality, the prototype produced outputs that were very similar to WaterCAST (Argent, *et al.* 2008) in terms of output variables, such as those demonstrated in Figure 5.6 and Figure 5.7. However, the HydroPlanner prototype used the demand actually supplied to calculate the wastewater plant outflow, also taking into account any use of wastewater for supply augmentation. In this instance, the modeller did not need to supply the model with time-series of plant discharges.

Figure 5.6 shows the estimated nitrogen concentrations at the model outlet for the different scenarios. It was possible to infer the contribution of wastewater discharges to the nitrogen exports, with the adoption of stormwater harvesting showing a lower benefit compared to the base case than wastewater reuse. However, these results could change once wastewater outflows were calibrated and all demands were included in the model. Hence the results reported in this report should be treated as indicative only.

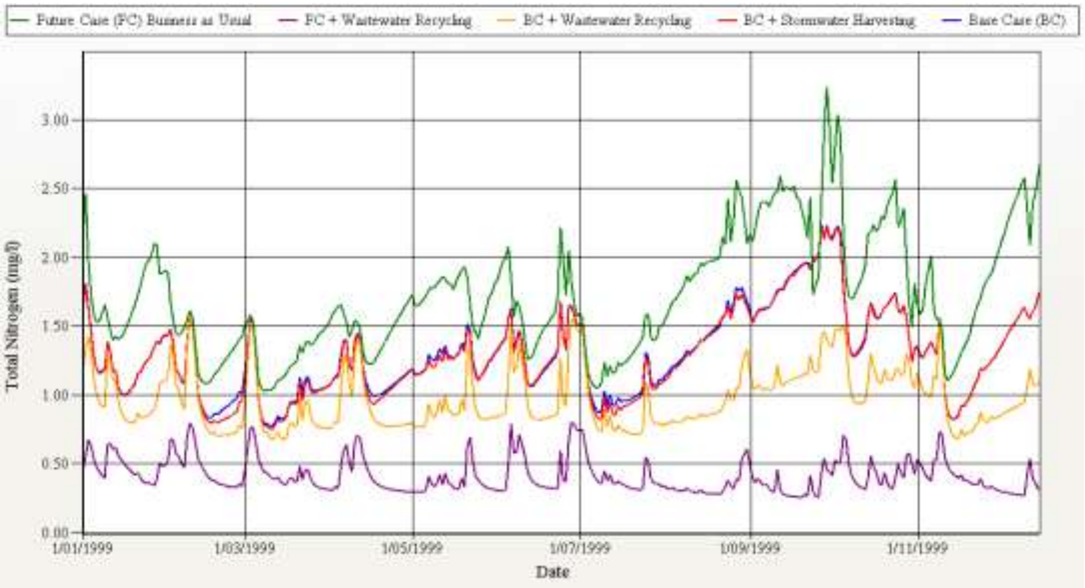


Figure 5.6 Total nitrogen concentration at the basin outlet for the different scenarios.

Nonetheless, it was clear that the proposed SEQ strategy of 100% reduction of nutrient loads from point sources such as wastewater plants (Healthy Waterways 2007) could have a large beneficial impact as shown by the comparison between nitrogen concentrations for the future case and for the future case with wastewater recycling in Figure 5.6. A similar result was observed if the predicted average annual loads were compared, as in Figure 5.7.

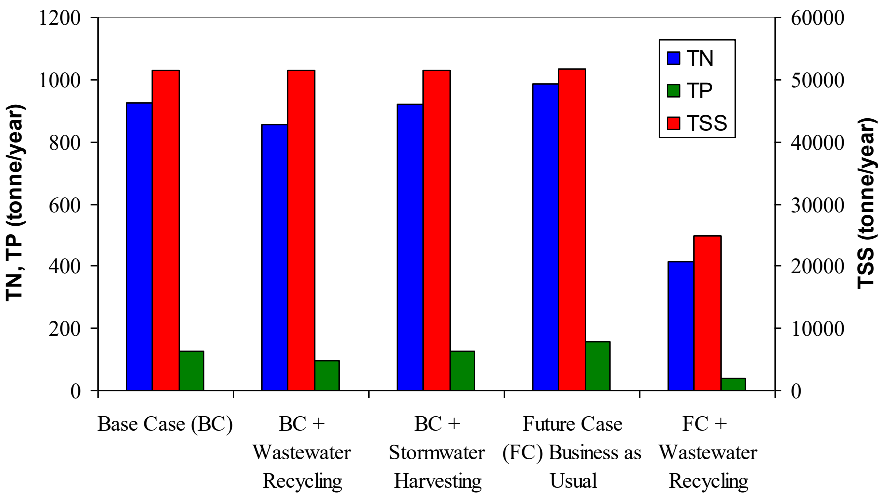


Figure 5.7 Average yearly export of constituents for the different scenarios.

6. CONCLUSIONS AND FUTURE DIRECTION

6.1. Conclusions

The HydroPlanner prototype showed the ability of the tool to undertake total water cycle modelling in a typical, urbanised, local government scale catchment in SEQ. The modelling framework had the flexibility to include a choice of various component models and parameters, and to provide multiple quantity and quality interactions or exchanges between these components. Overall indicators of system performance could be generated from the complex interactions and feedbacks of various regional land use, climate and planning changes and management scenarios.

Even though extensive calibration of the prototype was not undertaken, and hence no definite conclusions could be drawn from the results, the results demonstrated that it was possible to model a large system and draw conclusions about water security and water quality aspects in receiving waters to aid the development of total water cycle management plans at a local government scale. The prototype was capable of evaluating various augmentation options, as well as variations in land use and demands. It could also analyse effects of climate change by varying the input climate conditions (although this was not presented in Chapter 5). Model outputs in terms of storage, demand deficit, system yield and constituent export were helpful in modelling and assessing the impacts of truly integrated urban water management.

The software development of the prototype was challenging but successful. The negatives of working in a small team had been offset by using a large existing code base and modifying it as necessary. Because of this, most of the functionality required to model the Logan Basin was implemented in the prototype. These features were also tested and shown to meet their requirements.

Additional features not represented in this prototype, but presented within the Logan Basin (and other catchments of SEQ), were identified for research into future development in order to better address modelling questions and enhance the ability to calibrate and validate the tool against reality.

6.2. Future Direction

Merits of developing the HydroPlanner prototype as a full-scale integrated urban water system model were assessed against the emerging modelling capabilities of eWater CRC's Source integrated modelling platform, which was also built on the E2 modelling framework. Given that the Queensland State Government was a partner to the development of eWater CRC's Source modelling platform, it was decided not to go ahead with transforming the prototype into a full-scale model. Instead, it was decided to port learning from the prototype exercise, including the functionalities developed as part of the prototype, to eWater CRC's Source integrated modelling platform.

Accordingly, many of the concepts tested and functionalities developed as part of the HydroPlanner prototype were ported to the eWater CRC's Source modelling platform. Our concepts and functionalities were then further developed under the umbrella of the Source integrated modelling platform, in particular, as part of urban water related functionalities of the Source Integrated Modelling System.

Development of the Source Integrated Modelling System model as part of the eWater CRC was completed in July 2012. The Source Integrated Modelling System is now available from eWater Limited (http://www.ewater.com.au/products/ewater-source/).

APPENDIX A: Recording Outputs for Whole Scenario

‘Miscellaneous’ Sub-Tree

Type: Demand Deficit
Attribute Recorded: *Scenario Demand Deficit*

Type: Demand Requested
Attribute Recorded: *Scenario Demand Requested*

Type: Mass Balance
Attribute Recorded: *Scenario Mass Balance*
[Note: Prototype functionality does not yet handle recycled wastewater re-entering the system, so mass balance *reporting* is not accurate when considering wastewater re-use, even though the mass balance for wastewater is accurate.]

Type: Multiple Supply Manager
Attribute Recorded: *Multiple Supply Path*
[Note: Functionality of this is not yet complete in the prototype]

Type: Piecewise Linear Functions
Attribute Recorded: *Last Value*
[Note: Functionality of this is not yet complete in the prototype]

Type: System Storage [aka Total Surface Water Storage]
Attribute Recorded: *Scenario System Storage*

Type: System Yield
Attribute Recorded: *Scenario System Yield*
[Note: When performing a ‘System Yield Calculation’ analysis, it returns the System Yield. However, in Single Run mode, it returns no data.]

Multiple Recording Outputs - for each object that exists of each type

Items listed as recording ‘Constituents’ will record Total Nitrogen, Total Phosphorus and Total Suspended Solids

‘Catchment’ Sub-Tree

Type: [For each Functional Unit eg:] Broad acre Agriculture, Suburban etc
Name example: SC #1
Attributes Recorded:
Area
Demand Deficit of Supply
Demand Satisfied by Alternate
Demand Satisfied by Primary
Demand Satisfied Overall
Quick Flow *[includes Constituents and Flow]*
Slow Flow *[includes Constituents and Flow]*
Total Flow *[includes Constituents and Flow]*

Type: Total [Incorporates all Functional Units]
Name example: SC #1
Attributes Recorded:
Outflow *[includes Constituents and Flow]*
Quick Flow *[includes Constituents and Flow]*
Slow Flow *[includes Constituents and Flow]*

‘Link’ Sub-Tree

Type: Lagged Flow Routing
Name example: link for catchment SC #84
Attributes Recorded:

Catchment Inflow	*[includes Constituents and Flow]*
Inflow	*[includes Constituents and Flow]*
Inflow Volume	
Lag	
Lateral Flow	*[includes Constituents and Flow]*
Lateral Inflow Volume	
Link Travel Time	
Mass Balance	
Outflow	*[includes Constituents and Flow]*
Outflow Volume	
Storage Volume	

Type: Straight-Through Routing
Name example: link for catchment SC #1
Attributes Recorded:

Catchment Inflow	*[includes Constituents and Flow]*
Inflow	*[includes Constituents and Flow]*
Inflow Volume	
Lateral Flow	*[includes Constituents and Flow]*
Lateral Inflow Volume	
Link Travel Time	
Mass Balance	
Outflow	*[includes Constituents and Flow]*
Outflow Volume	
Storage Volume	

‘Node’ Sub-Tree

Type: Regulated Extraction
Name example: Node on catchment SC #100
Attributes Recorded:

Cumulated Extracted Volume	
Extracted Volume	
Gains Allocated	
Gains Received	
Inflow	*[includes Constituents and Flow]*
Inflow Volume	
Mass Balance	
Order	
Order Volume	
Outflow	*[includes Constituents and Flow]*
Outflow Volume	
Storage capacity	
Storage Volume [Unused in prototype. Please use Storage Volume instead]	
Storage Volume	
Travel Time	
Volume of Order Allocated	
Volume Ordered	

Type: Wastewater Overflow Node
Name example: Node on catchment SC #18
Attributes Recorded:

Inflow	*[includes Constituents and Flow]*
Inflow Volume	
Mass Balance	
Outflow	*[includes Constituents and Flow]*
Outflow Volume	
Storage Volume	

Type: Wastewater Treatment Plant
Name example: Beaudesert WWTP
Attributes Recorded:

Discharge volume	
Inflow	*[includes Constituents and Flow]*
Inflow Volume	
Inflow Wastewater volume	
Initial Volume	
Mass Balance	
Outflow	*[includes Constituents and Flow]*
Outflow Volume	

Storage capacity
Storage Volume [Unused in prototype. Please use Storage Volume instead]
Storage Volume

Type: Confluence
Name example: Node on catchment SC #1
Attributes Recorded:
Inflow *[includes Constituents and Flow]*
Inflow Volume
Mass Balance
Outflow *[includes Constituents and Flow]*
Outflow Volume
Storage Volume

Type: Minimum Flow Requirement
Name example: Node on catchment SC #106
Attributes Recorded:
Inflow *[includes Constituents and Flow]*
Inflow Volume
Last Order
Mass Balance
Order Time
Orders
Outflow *[includes Constituents and Flow]*
Outflow Volume
Required Water
Storage Volume

Type: Storage
Name example: Bromelton Off-Stream Storage
Attributes Recorded:
Catchment Inflow *[includes Constituents and Flow]*
Dead Storage Volume
Evaporation Volume
Full Supply Volume
Infiltration Volume
Inflow *[includes Constituents and Flow]*
Inflow Volume
Lateral Flow *[includes Constituents and Flow]*
Lateral Inflow Volume
Link Travel Time
Mass Balance
Maximum Release Rate
Minimum Release Rate
Outflow *[includes Constituents and Flow]*
Outflow Volume
Rainfall Volume
Requested Flow Rate
Required Release Volume
Required Storage Level
Storage Level
Storage Volume

APPENDIX B: Logan-Albert Calibration Reaches, Sacramento Calibration Parameters and Results

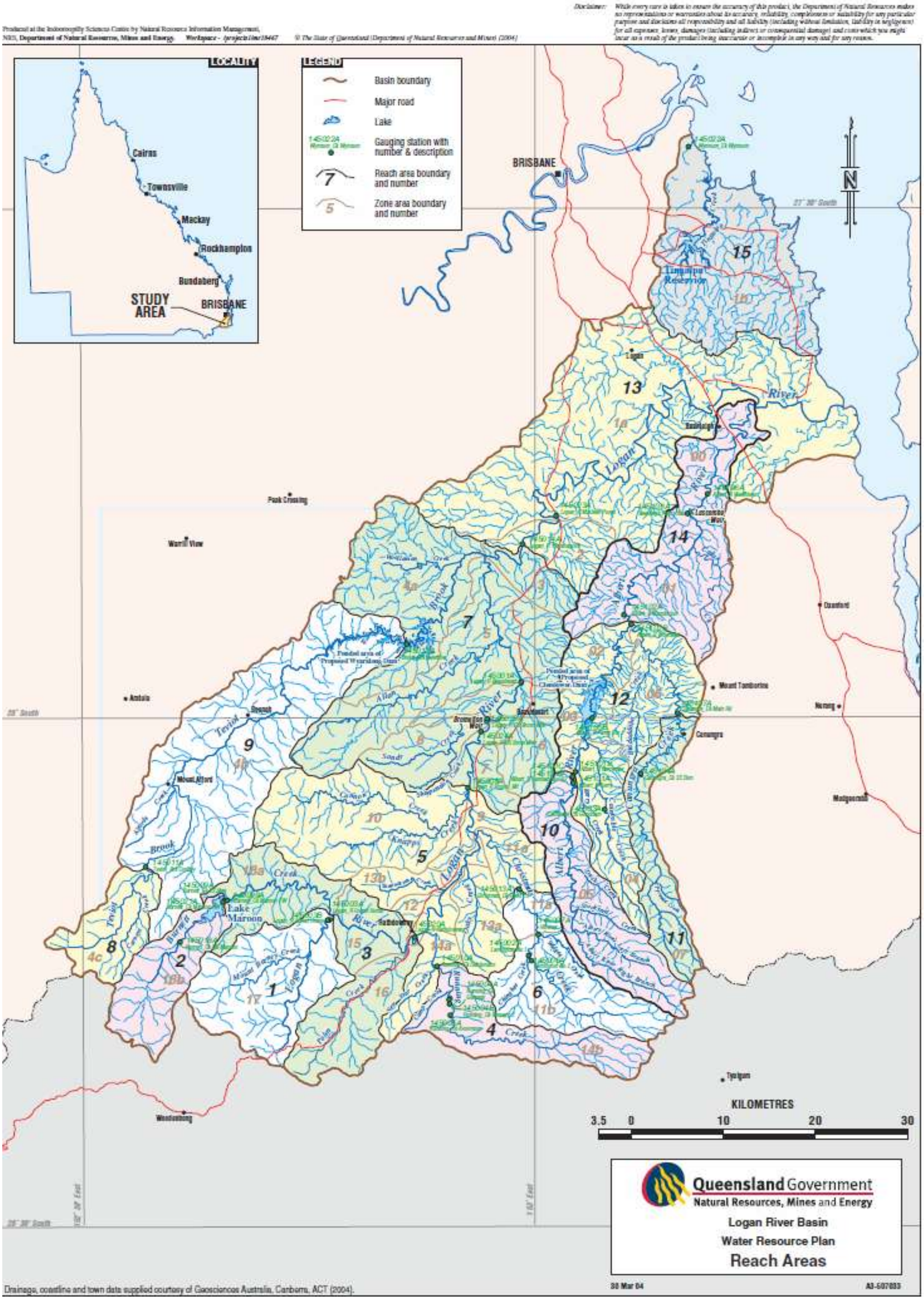


Figure B1. Logan-Albert calibration reaches.

Table B1. Sacramento Calibration Results.

Reach	Area (km^2)		Time Period	Relative Difference (%)	Absolute Difference (mm)	Correlation Coefficient	Nash-Sutcliffe E - Daily	Nash-Sutcliffe E - Monthly
1	173.34708032	Calibration	1/1/1966 - 31/12/1985	-7.913%	-495.055	0.481	0.116	0.844
		Verification	1/1/1986 - 21/12/2008	1.138%	53.455	0.438	0.142	0.801
2	103.2471552	Calibration	4/1/1977 – 30/6/2003	-3.333%	-136.158	0.83	0.675	0.753
		Verification	NA					
3	252.077364	Calibration	1/7/1973 - 31/12/1985	2.331%	24.954	0.75	0.205	0.79
		Verification	1/1/1986 - 30/6/2003	-1.792%	-24.6	0.693	0.4	0.684
4	127.090688	Calibration	1/1/1966 to 31/12/1985	-1.687%	-130.73	0.677	0.326	0.906
		Verification	1/1/1986 to 31/12/2008	2.573%	154.293	0.544	0.056	0.855
5	442.22909976	Calibration	1/1/1974 - 31/5/1988	-5.944%	-60.87	0.328	-0.111	0.817
		Verification	NA					
6	156.75691668	Calibration	21/10/1967 - 31/12/1985	-3.891%	-185.534	0.768	0.564	0.88
		Verification	NA					
7	649.21031144	Calibration	23/1/1969 - 31/12/1985	-0.914%	-29.233	0.577	0.267	0.88
		Verification	1/1/1986 - 30/6/2003	7.199%	166.866	0.415	-0.295	0.723
8	80.0625	Calibration	9/2/1966 to 31/12/1985	-4.633%	-229.08	0.484	0.05	0.871
		Verification	1/1/1986 to 31/12/2008	23.986%	564.85	0.522	0.058	0.884
9	414.73802672	Calibration	1/4/1966 - 31/12/1985	3.550%	75.093	0.842	0.686	0.879
		Verification	1/1/1986 - 30/6/2003	1.135%	17.239	0.824	0.676	0.951
10	164.736	Calibration	1/1/1966 to 31/12/1985	-3.196%	-215.982	0.813	0.652	0.939
		Verification	1/1/1986 to 31/12/2008	-4.297%	-238.963	0.712	0.46	0.943
11	95.664816	Calibration	26/1/1973 - 31/12/1985	-4.345%	-564.92	0.768	0.544	0.94
		Verification	1/1/1986 - 31/12/2008	-10.281%	-822.221	0.729	0.501	0.939
12	277.5790084	Calibration	25/1/1973 - 31/12/1985	-0.202%	-4.616	0.845	0.714	0.922
		Verification	1/1/1986 - 30/6/2003	3.474%	106.644	0.904	0.807	0.965
13	551.8196326	Calibration	1/1/1966 - 31/12/1985	-9.369%	-323.993	0.591	0.324	0.78
		Verification	1/1/1986 - 30/6/2003	-27.218%	-594.524	0.433	0.169	0.646
14	238.8244818	Calibration	1/1/1966 - 31/12/1985	-1.764%	-65.612	0.786	0.564	0.795
		Verification	1/1/1986 - 30/6/2003	-38.502%	-1171.561	0.836	0.685	0.845

Table B2. Calibrated Parameters for the Sacramento model.

Reach	Adimp	Lzfpm	Lzfsm	Lzpk	Lzsk	Lztwm	Pctim	Pfree	Rexp	Rserv	Sarva	Side	Ssout	UH1	UH2	UH3	Uzfwm	Uzk	Uztwm	Zperc
1	0.36	50	23	0.102	0.99	363.92	0.01	0.42	2.89	0.3	0	0	0	0.99	0.01	0	80	0.88	17.0747	85
2	0.13	54	24	0.03	0.67	256	0	0.37	1.07	0.28	0	0.57	0	0.01	0.98	0.01	64	0.88	100	77
3	0.1	75	42	0.03	0.3	70	0	0.35	2.71	0.3	0	0	0	0.99	0.01	0	39	0.7	100	23
4	0.275	50	55	0.0155	0.067	121.6187	0.015	0.4	1	0.3	0	0	0	0.7	0.2	0.1	35	0.3	19.9049	35
5	0.008	79	16	0.015	0.35	131	0.009	0.205	2.5	0.3	0.006	0	0.025	0.9	0.1	0	27	0.6	54	33
6	0.01	132	77	0.0078	0.045	162	0.0042	0.174	2.1	0.3	0.0005	0	0.012	0.7	0.2	0.1	55.8	0.65	27.3	115
7	0.2	48	24	0.01	0.3	31	0.02	0.38	2.88	0.3	0.01	0	0.06	0.99	0.01	0	15	0.49	48	32
8	0.05	25	15	0.0085	0.187	60	0.015	0.3	0.25	0.3	0.0035	0.0025	0.0015	0.99	0.01	0	26.5	0.8	99.99	30
9	0	9	48	0.01	0.29	75	0.01	0.32	1.03	0.3	0	0	0	0.9	0.1	0	28	0.99	96	28
10	0.03	58	31.5	0.012	0.2	20.3606	0.0305	0.73	1.1	0.3	0.005	0.0008	0.003	0.99	0.01	0	80	0.69	98	77
11	0.015	68	105	0.005	0.03	51.893	0.005	0.25	2	0.3	0	0	0	0.7	0.2	0.1	55	0.25	100	65
12	0.01	59	2	0.02	0.04	72	0	0.17	2.31	0.3	0	0	0.02	0.3	0.7	0	15	0.32	61	44
13	0.42	13	17	0.04	0.4	350	0.01	1	0.97	0.3	0	0	0.01	0.99	0.01	0	31	0.49	100	62
14	0.07	50	48	0.12	0.05	388	0	0.11	2.94	0.3	0	0.31	0	0.3	0.7	0	5	0.22	71	42

GLOSSARY

Component model	A method that does run at every time-step of simulation
FU	Functional Unit, a geographically undefined area of a subcatchment with a common response or behaviour, typically corresponding to land use
Functional Unit models	Component models associated with functional units
Functionality	A method that does not run at every time-step of simulation
IUWM	Integrated Urban Water Management
IQQM	Integrated Quantity Quality Model
Link	Link allows flow in 1 direction between 2 nodes.
Link models	Component models associated with links
Local government scale	Application of HydroPlanner to sub-regions such as Logan basin in South East Queensland scale
Node	Point where flow is combined and/or separated and must mass balance each time step
Node models	Component models associated with nodes
RR model	Rainfall-runoff model
RRL	Rainfall-runoff Library
Region scale	Application of HydroPlanner at South East Queensland scale
SEQ	South East Queensland
TWCM	Total Water Cycle Management
User	The person using the HydroPlanner software
WSUD	Water Sensitive Urban Design - includes urban design features designed to attenuate peak stormwater flows and improve stormwater quality

REFERENCES

Antcliff, J., 2009, Personal Communication, Scenic Rim Regional Council.

Argent, R., G. Podger, R. Grayson, K. Fowler and N. Murray, 2006, E2 catchment modelling software - User Guide, eWater CRC, Canberra, Australia.

Argent, R. M., J.-M. Perraud, G. M. Podger and N. Murray, 2008, WaterCAST Component Model Reference Manual, eWater CRC, Canberra, Australia.

Ashbolt S., Maheepala S., Mirza F., Neumann L., Kinsman D. and Coultas E, (2010). "HydroPlanner: Towards a regional integrated urban water modelling Tool", Ozwater'10 8-10 March 2010, Brisbane

Bertsekas, D.P., (1991). Linear Network Optimisation: Algorithms and Codes. MIT Press, Cambridge, MA.

Burn, S., Maheepala, S. and Sharma, A. K., 2012, Utilising integrated urban water management to assess the viability of decentralised water solutions, Journal of Water Science and Technology, 66.1, International Water Association.

Burnash, R. J. C., R. L. Ferral and R. A. McGuire, 1973, A generalised streamflow simulation system - conceptual modeling for digital computers, US Department of Commerce, National Weather Service and State of California, Department of Water Resources.

Butler, D. and M. Schütze, 2005, Integrating simulation models with a view to optimal control of urban wastewater systems, *Environmental Modelling & Software,* 20(4): 415-426.

Clark, R., D. Pezzaniti and D. Cresswell, 2002, Watercress - Community Resource Evaluation and Simulation System - A tool for innovative urban water system planning and design, *Hydrology and Water Resources Symposium*, Melbourne, Australia.

Coombes, P. J., Kuczera, G., Kalma, J. D. and Argue, J. R. 2002, An evaluation of the benefits of source control measures at the regional scale, Urban Water 4: pp 307-320.

Erlanger, P. and B. Neal, 2005, Framework for Urban Water Resource Planning, Sinclair Knight Merz for Water Services Association of Australia.

Fletcher, T. D., V. G. Mitchell, A. Deletic, T. R. Ladson and A. Séven, 2007, Is stormwater harvesting beneficial to urban waterway environmental flows?, *Water Science & Technology,* 55(4): 265-272.

Garnett, C., 2009, Personal communication, Queensland Department of Environment and Resource Management.

Grant, A., S. Maheepala, F. Mirza, B. Leighton, M. Rahilly, J. Rahman, J.-M. Perraud and A. Sharma, 2006, HydroPlanner: providing an improved process for assessing urban water supply-demand balance. *30th Hydrology and Water Resources Symposium*, Launceston, Australia.

Hall, M., J. West, J. Lane, D. de Haas and B. Sherman, 2009, Energy and Greenhouse Gas Emissions for the SEQ Water Strategy. *Urban Water Security Research Alliance Technical Report No. 14,* SEQ Urban Water Security Research Alliance, Brisbane.

Healthy Waterways, 2006, Water Sensitive Urban Design Technical Design Guidelines for South East Queensland, South East Queensland Healthy Waterways Partnership, Brisbane.

Healthy Waterways, 2007, Logan-Albert Catchments Action Plan. *South East Queensland Healthy Waterways Strategy 2007-2012*, South East Queensland Healthy Waterways Partnership.

Jones, D. A., W. Wang and R. Fawcett, 2009, High-quality Spatial Climate Data Sets for Australia, *Australian Meteorological and Oceanographic Journal,* (In press).

Kuczera, G., 1992, Water supply headworks simulation using network linear programming. Advances in Engineering Software. 14, 55-60.

Kuczera, G., 2008, "Urban water supply drought security: a comparative analysis of complimentary centralised and decentralised storage systems", Conference proceedings of Water Down Under April 2008, Adelaide, South Australia.

Loucks, D. P., 1997, Quantifying trends in system sustainability, *Hydrological Sciences,* 42(4): 513-530.

Maheepala, S. and J. Blackmore, 2008, Integrated Urban Water Management for Cities, *Transition*, P. Newton, Ed., CSIRO Publishing: 463-479.

Maheepala, S., J. Blackmore, C. Diaper and M. Moglia, 2009, Integrated Water Management Manual, Water Research Foundation. Denver, Colorado, USA.

Maheepala, S., A. Grant, F. Mirza, B. Leighton, M. Rahilly, J. Rahman, J.-M. Perraud and A. Sharma, 2007, Hydro Planner for assessing water quantity and quality aspects of integrated and diversified urban water systems. *OzWater Conference*, Australian Water Association, Sydney, Australia.

Maheepala, S., A. Grant, H. Schandl, R. Oliver, J. Blackmore, W. Proctor, S. Ashbolt, T. Baynes, J. Gilles, N. Grigg, W. Habla, K. Hoskin, T. Measham, F. Mirza, E. Qureshi and A. Sharma, 2009, Canberra Integrated Waterways: Feasibility Study. *Report for Australian Capital Territory and Municipal Services*, CSIRO and Water for a Healthy Country National Flagship, Black Mountain, Canberra, Australia.

Maheepala, S., B. Leighton, F. Mirza, M. Rahilly and J. Rahman, 2005, Hydro Planner - a linked modelling system for water quantity and quality simulation of total water cycle, *MODSIM05 International Conference on Modelling and Simulation Society of Australia and New Zealand*, Melbourne, Australia.

Maheepala, S, Mirza, F, Ashbolt, S, Neumann, L, McMahon, J, Hardy, M.J., Ogden, R, Rahman, J, Kinsman, D, Rahilly, M, Lane, B, (2009). Prototype Modelling Tool to Aid Development of Integrated Urban Water Management Strategies, SEQ Urban Water Security Research Alliance (UWSRA) Science Forum, August 2009, Brisbane Australia.

Maheepala, S., Coultas, E. and Neumann, L. (2013). *Quantification of Regional Scale Water Quantity and Quality Implications of Rainwater Tanks in South East Queensland*. Urban Water Security Research Alliance Technical Report No. 104.

Mahmutovic, A., 2009, Personal communication.

Mitchell, V. G. and C. Diaper, 2005, UVQ: a tool for assessing the water and contaminant balance impacts of urban development scenarios, *Water Science and Technology (IWA),* 52(12): 91-98.

Mitchell, V. G., M. Inman, M. Rahilly, J. Stewart, A. Vieritz, P. Holt, A. Grant, T. D. Fletcher, J. Coleman, S. Maheepala, A. Sharma, A. Deletic and P. Breen, 2007, State of the art in integrated urban water modelling. *NOVATECH 2007, 6th International Conference on Sustainable Techniques and Strategies in Urban Water Management*, Lyon, France.

Mitchell, V. G., R. G. Mein and T. A. McMahon, 2001, Modelling the urban water cycle, *Journal of Environmental Modelling and Software,* 16(7): 615-629.

Mitchell V.G., Siriwardene N., Duncan H. and Rahilly M., 2008, "Impact of temporal and spatial lumping on rainwater tank system modelling", Conference proceedings of Water Down Under April 2008, Adelaide, South Australia, pp 54-65.

Montaseri, M. and A. J. Adeloye, 2002, Effects of Integrated Planning on Capacity-Yield-Performance Functions, *Journal of Water Resources Planning and Management,* 128(6): 456-461.

Nash, J. E. and J. V. Sutcliffe, 1970, River forecasting using conceptual models, 1. A discussion of principles, *Journal of Hydrology,* 10(1970): 282-290.

Neumann, L. and Maheepala, S. (2013). *Impact of Spatial Lumping on Modelling of Stormwater Harvesting Systems: Scoping Study.* Urban Water Security Research Alliance Technical Report No. 107.

NSW Department of Land and Water Conservation, 1999, IQQM: Integrated Quantity and Quality Model, Centre for Natural Resources, NSW Department of Land and Water Conservation.

Office of the Queensland Parliamentary Counsel, 2008, Water Resource (Logan Basin) Plan 2007, Queensland Government.

Office of Urban Management, 2005, South East Queensland Regional Plan 2005-2026, Queensland Government Office of Urban Management, Department of Local Government, Planning, Sport and Recreation.

Penton, D. 2009. The NetLP Ordering Component Guide and Introduction. eWater CRC.

Perera, B.J.C. and James. B. A. 2003, Generalised Water Supply Simulation Computer Software package, Hydrology Journal, Institution of Engineers (India), 26/1-2, 67-83.

Podger, G., 2004, Rainfall Runoff Library User Guide, CRC for Catchment Hydrology, Australia.

Queensland Department of Natural Resources, 2004, The SILO Data Drill, Department of Natural Resource Management.

Queensland Water Commission, 2010, South East Queensland Water Strategy, Queensland Water Commission, Brisbane, Queensland, Australia.

Rahman, J., S. P. Seaton, J.-M. Perraud, H. Hotham, D. I. Verelli and J. R. Coleman, 2003, It's TIME for a new Environmental Modelling Framework, *MODSIM 2004 International Congress on Modelling and Simulation*, Modelling and Simulation Society of Australia and New Zealand, Townsville, Australia.

Ravels, C. V. and R. Maddalena, 2009, Personal communication, Scenic Rim Regional Council.

Schmitt, T. G. and W. C. Huber, 2005, The scope of integrated modeling - system boundaries, sub-systems, scales and disciplines. *10th International Conference on Urban Drainage*, Copenhagen, Denmark.

Smith, T., P. Jordan and J. Rahman, 2009, Flood Harvesting Diversion Node Model Specification, eWater CRC and CSIRO.

Spiller, D., 2008, Policy Forum: Urban Water Pricing and Supply.

Water for Today, Water for Tomorrow: Establishment and Operation of the SEQ Water Grid, *The Australian Economic Review,* 41(4): 420-427.

Victoria University and Department of Sustainability and Environment, 2005, REALM: Getting Started Manual V5.

Water Services Association of Australia, 2006, End Use Model User Guide Version 4.1, Water Services Association of Australia.

WBM, 2008, Urban Water Management Modelling Needs Assessment - Scoping Report, T. McAlister.

Wong, T.H.F., Ed. 2006, Australian Runoff Quality: A Guide to Water Sensitive Urban Design. Engineers Australia.

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