INTEGRATED LAND USE AND MULTIPLE WATER SUPPLY-DEMAND MODELLING FRAMEWORK: A PERI-URBAN CASE STUDY

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Abstract: The South Creek catchment with an area 620 km^2 confronts increased competition between potable water, irrigation and environmental flows. Peri-urban areas also generate a large volume of effluent and stormwater and can often meet some or all the irrigation and industrial water needs provided adequate infrastructure is available. An adequate harmonisation of these multiple supplies and land use using a total system analysis approach leads to a better understanding and evaluation of the limitation and opportunities to enhance the overall performance of the system. This paper descriers the developed modelling framework to simulate water supplies and forecast future demands and integrate supplies and demands in finding water allocations with different climate change and land use scenarios. The integrated model is applied to the South Creek catchment to plan future land use and water supply in an environment of water scarcity under system harmonisation water resources management concept.

Keywords: System Harmonisation, Peri-Urban Catchment, South Creek catchment, Water Resources Modelling

1 Introduction

Research and development in water resources management usually involves separate investigations into technical, institutional, environmental, and social spheres; however, with a primary focus on technical aspects. Hard-engineering solutions were implemented without focusing on overall economic and environmental impacts, or the social implications associated with these projects (Spingate-Baginski et al., 2003). With increasing sustainability discourse, there is a realization that the technical aspects of water resources management need to be addressed with the immediate understanding of environmental and social interactions for successful development and application of potential solutions.

Through this research, an attempt has been made to develop an alternative to past approaches for achieving more effective, equitable and efficient water resources management in heavily stressed catchments such as Western Sydney's South Creek Catchment. Different demand management options were explored from a multi-disciplinary perspective through a concept known as 'System Harmonisation'. System Harmonisation involves addressing the hydrological and economic impacts arising from alternative planning and management decisions, as well as identifying and including all affected social, cultural, institutional and policy issues to maximise benefits across the system.

Development and management of catchments require the utmost cooperation between all stakeholders involved, be it a single urban dweller, a farmer, government, corporate or academic (Prato & Gamini, 2007). The main aim of this research is to develop a dynamic generic tool for integrated water resources planning and strategy development in peri-urban landscapes using water resources and economic principles assessed from a social perspective. The tool is adaptable across peri -urban Australia and beyond. The study area has been scheduled for significant land use change due to future development, where a rapid and substantial increase in urbanized areas will be seen; however, maintenance of water supply for existing farmlands, industry, recreation, and environmental services has been highlighted as integral for sustainability of this catchment.

2 South Creek Catchment

The South Creek Catchment (Figure 1), located approximately 50 km west of the Sydney. It is a sub-basin of the Hawkesbury-Nepean Catchment. This catchment encompasses diversity with a mix between urban and agricultural uses, industrial, commercial and services-oriented land-use, as well as dedicated recreation areas and various other open spaces. It is approximately 620 km^2 and falls within portions of 8 Local Government Areas (LGAs) or councils: Baulkham Hills, Blacktown, Camden, Campbelltown, Fairfield, Hawkesbury, Liverpool, and Penrith.

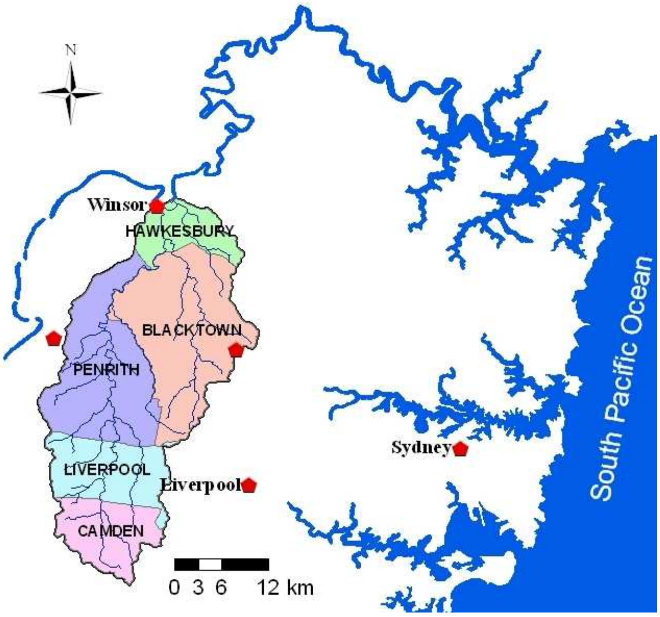

Figure 1: South Creek Catchment

Exiting population in the catchement, as of 2005, was approximately 390,000 people. With current urbanization plans, population is expected to reach one million 2030. In addition, greenfield development plans are expected to result in dramatic changes in land use (Rae, 2007). There exists the need for integrating water management approaches that considers system water supply, demands, economic impacts of change, as well as overall effects on social, cultural, institutional and political realms.

3 System Harmonisation

In response to an increasing need and support for a more integrated approach to sustainable use of land and water resources in Australia, the Cooperative Research Centre (CRC) for Irrigation Futures has developed a framework (Figure 2) that seeks to align the physical, economic, environmental and social components of water resources management. System Harmonisation is a framework described by Khan et. al. (2008), that seeks to align all components of water resources management to generate and evaluate more appropriate solutions in a transparent manner. It has been recognized that a multi-disciplinary approach is ideal for water resources management, whereby each component be assessed on its own but all elements come together in the overall system framework. The main strength of this approach is that plausible scenarios, developed through extensive stakeholder consultation and social research are evaluated and compared.

The South Creek Catchment will be modelled based on the System Harmonisation method to generate potential solutions for its future with respect to management and development of water and land resources. Furthermore, to simulate management and development scenarios for water resources with regards to supply and allocation, to assess potential economic benefits, as well as the social impacts of each, alternate scenarios can be compared against one another in order to help with the decision making process.

The Social, Cultural, Institutional and Policy component of the system harmonisation program seeks to assess all identifiable social facets that will effect or be affected by any change relating to water resources. It is important that these components be considered in order to maintain transparency throughout the process, and to mitigate any potential externalities that could arise without such an evaluation.

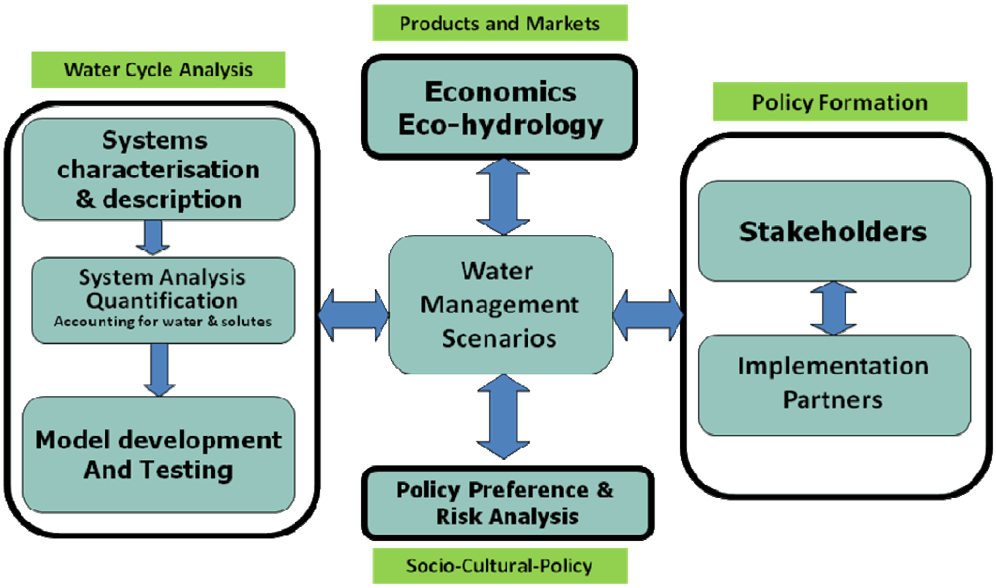

Figure 2: System harmonization concept

The products and markets component of System Harmonisation derives values for all uses of water in the system, drawing off outputs from both the water cycle and SCIP research. This method is a means by which impartial and comprehensive evaluation is conducted across a number of regions with a variety of uses of water over a lengthy time period. The costs and benefits of reallocating water are assessed from society's perspective, and are eventually used to evaluate scenarios developed by the catchment's stakeholders.

4 Water cycle modeling of the South Creek catchment

The water cycle research consists of three components designed to describe the physical system and its conceptual hydrologic modeling framework. First, the identification of the conceptual system forms the basis for the quantification of the water balance. Second, a critical water accounting process occurs that allows the key stocks and flows in the system to be identified and quantified and provides the data for calibration and validation of the various models. Third, models are developed and applied to evaluate alternative water strategies defined by the stakeholders. Following three main modules are the components related to South Creek water cycle modeling task.

(a) A distributed hydrologic model capable of reflecting the impacts of spatially distributed land use and climate changes on runoff ;
(b) A demand module to estimate water demand for multiple uses including primary production, public open spaces, industrial, domestic and environment; and
(c) A water allocation module that routes quality specific water supplies and demands based on agreed supply priorities.

In order to properly model a hydrologic system, consideration need not only be given to surface water, but also to groundwater, existing land and water use practice, as well as historical data concerning climate patterns. Future available water resource were projected using the expected change in land use and climate using the distributed hydrological model.

In the research, water cycle research consists of two simulation modelling tools: BTOPMC (Block-wise TOPMODEL with Muskingum-Cunge flow routing), a distributed hydrological model to capture the impact of land use and climate changes over the catchment and to assesses available supply, and REALM (Resource Allocation Model) – a water allocation model to link multiple sources and multiple users of water as constrained by water quality and specific legislation. Hydrologic modelling drives the overall modelling framework, as its exogenous changes in the allocation of water to different sectors and regions vary per year. The output of the hydrologic model is input to the economic model. Changes in flow of water govern the flow of net economic benefits (Davidson and Hellegers, 2008).

Modified BTOPMC, a rainfall-runoff simulation tool, is used in an attempt to discuss the influence of land use and climate changes with respect to water resources and discharge in the South Creek Catchment. Developed at the Yamanashi University (Japan), BTOPMC is a physically-based distributed hydrological model based on block-wise use of TOPMODEL with Muskingum-Cunge flow routing method that can be used for runoff simulations in different size of watersheds (Nawarathna et al, 2001).

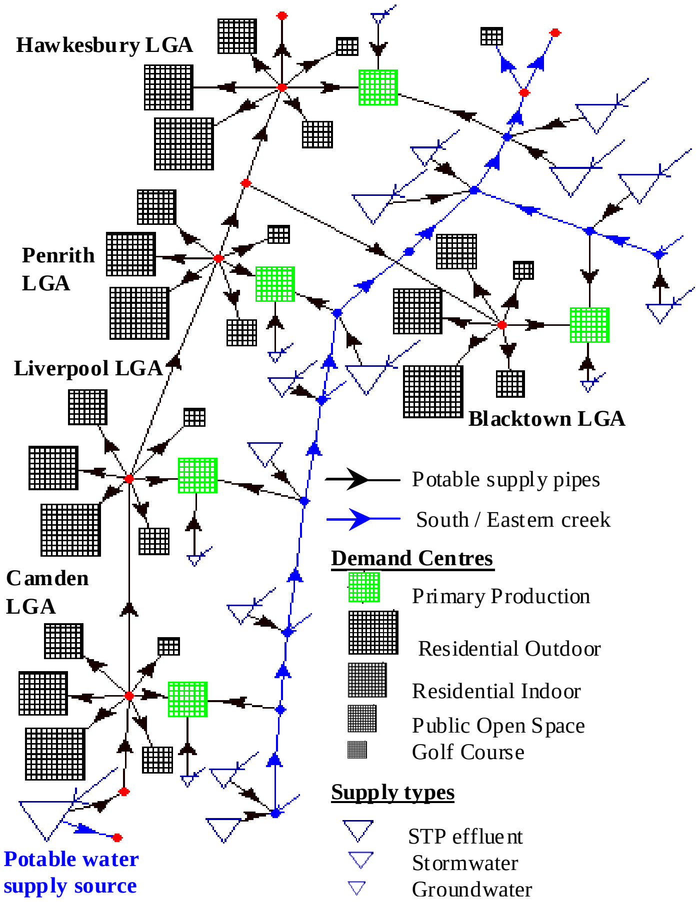

Figure 3: Schematic of the study region in REALM

The REALM package was developed and tested over many years by the Victorian Department of Sustainability and Environment in close conjunction with its major users. It simulates water resource distribution in a defined area. It incorporates harvesting and bulk distribution based on allocated supply and demands using mass-balance accounting at nodes in conjunction with a linear optimization algorithm. Furthermore, it operates on a set of user-defined penalties, which act as constraints to generate results leading to preferential resource use (Perera et al., 2005). Allocation modelling is a very valuable tool for planning in a catchment, whereby outcomes of alternate management scenarios are observed. REALM software can cater to environmental flows, issues relating to water entitlements and allocation, future growth in any or all sectors within the study area. Modelling a catchment in terms of resource allocation is a means by which future system requirements can be forecasted.

REALM equitably allocate and distribute water resources in the South Creek catchment based on scenario-specific supply and/or demand and on established operating rules developed through stakeholder consultation. A schematic representation of the South Creek catchment, as built into the REALM model, is presented in Figure 3.

The supply sources in the South Creek Catchment include potable water, surface water, groundwater, treated effluent and treated stormwater. Demands of residential indoor and outdoor, industrial, primary production, open space irrigation, golf and environmental flow are included. Demands were determined based on land-use details, population trends, domestic, commercial and industrial consumption records, as well as advice from the New South Wales Department of Primary Industries (NSW-DPI). Zoning of the system into demand centres, and determining water requirements of each must be determined prior to allocation modelling. Because each zone will have its unique supply and demand, and it will therefore have a unique allocation. What makes the South Creek catchment modelling exercise a unique one is that it has been zoned based on political boundaries, defined by LGAs. Five zones have been identified in the South Creek Catchment (three of the LGAs in the catchment have been included in the more prominent LGAs):

1. Camden (= Camden + Campbelltown)
2. Liverpool
3. Penrith
4. Blacktown (= Blacktown + Fairfield)
5. Hawkesbury (= Hawkesbury + Baulkham Hills)

5 Scenario development

The scenarios for the south creek catchment modeling as listed in the table 1 were developed through extensive stakeholder consultation. Developed scenarios are of interest to the stakeholders in the South Creek catchment and the policy makers at a wider level in the Western Sydney Region. These scenarios revolve around the need to assess future urban growth, the harvesting of stormwater, the treatment of effluent and the impacts of the Smart Farms program. Two main land use change scenario namely natural growth and growth centres are described below.

Table 1: Stakeholder driven scenarios of the study region

Land use	Smart farms	Effluent reuse	Stormwater harvesting		
			Public Open spaces	Industrial	Residential Outdoor
Natural Growth Growth predicted to remain constant in future	Increasing water use efficiency of irrigated agriculture across the Catchment	High quality effluent from wastewater treatment plants will be allocated for outdoor use, agriculture and open space irrigation	Use of stormwater to irrigate parks, golf courses, sporting fields and reserves	Use of stormwater to replace potable water for outdoor use	Use of stormwater to replace potable water in various industries
Growth Centre Two Growth centres are considered for future developed in addition to the natural growth					

5.1 The baseline scenario: Natural Growth

Initially, a baseline will be estimated that best represent the 'as is' conditions in the study area. This means that some idea of the conditions and urban growth rates over the next 25 years is required. Constructing this baseline scenario requires extensive data collection prior to model construction, which in turn is followed by an arduous process of calibration and validation to ensure its representativeness. As suggested above, the baseline scenario is arguably the most important scenario estimated; as it becomes the one upon which all other scenarios are compared to.

It is expected that the existing population of approximately 392,000 in 2005 will reach 1 million by 2030. Plans for urban development are well under way in the South Creek Catchment. For the baseline it is assumed that the number of dwellings will expand from 91,650 to 155000 in the catchment (see Table 2).

Most of this growth will occur in the already heavily populated region of Blacktown. Growth rate were calculated based on the derived land use map for natural growth 2030 and growth centres 2030. Of interest is the annual growth, and it is assumed that the growth occurs evenly over the period in question.

Table 2: Expected total Number of Dwelling and population in South Creek catchment by Local Government Area under natural growth

Region	Number of Dwelling		Population	
	2005	2030	2005	2030
Blacktown	55400	98100	204980	363000
Camden	1760	2900	6512	10800
Liverpool	2070	3900	7659	14500
Penrith	24850	37600	91945	139200
Hawkesbury	7570	12500	28009	46300
Total south Creek	91650	155000	339105	573800

5.2 The development of urban growth centres

The South Creek catchment has been identified as the region where Sydney's future growth urban development should occur. In this scenario it is estimated that the population will rise to just under a million people and have nearly 269800 dwellings (see Table 3). It is not only Blacktown that grows markedly, but also Camden and Liverpool. As with the previous scenario it is assumed that the population grows evenly over the 25 years in question.

Table 3: Population growth and the increase in the Number of Dwellings that May result from the Growth Centres Policies of the NSW Government in South Creek Catchment

Region	Number of Dwelling		Population	
	2005	2030	2005	2030
Blacktown	55400	113300	204980	419500
Camden	1760	57500	6512	213000
Liverpool	2070	40300	7659	149500
Penrith	24850	43400	91945	160500
Hawkesbury	7570	15300	28009	57000
Total south Creek	91650	269800	339105	999500

6 Results and Discussion

Through various simulations, a hydro-economic assessment can be useful in determining whether or not the implementation of particular management schemes will result in an overall net benefit (or loss) to society. In this section summary of the hydrological assessment results related to change in potable water supply demand and stream flow at the outlet of the south creek catchment in each scenarios are presented. The scenario results are compared with baseline scenario (one in which natural population growth is said to occur, but nothing else).

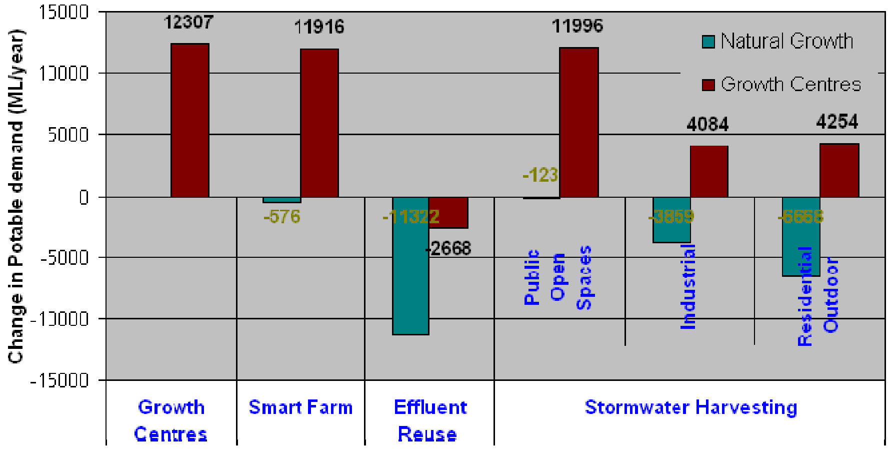

Figure 4: Average change of potable water demand with respect to baseline

Figure 4 shows the average potable water saving for the period between July 2009 to June 2030 by water management options like smart farms, effluent reuse and storm water harvesting in comparison to the baseline scenario. As the population increases, potable water demand is also expected increase significantly in the growth centres land use change scenario. Reusing the treated effluent to irrigate public open spaces, golf courses, agricultural lands and outdoor can save water on average 2.6 GL per year. In all the other water management scenarios the potable water demand is not decreasing with the introduction of growth centres. However a significant reduction of potable water demand can be achieved by using stormwater for industrial and residential outdoor. As the primary production demand is not significant compared to other demands, potable water saving by the reduction of primary production irrigation demand by 10% in the smart farm scenarios has not reduced the potable demand significantly. However it will reduce the surface and groundwater extractions from the catchment and increases the stream flows.

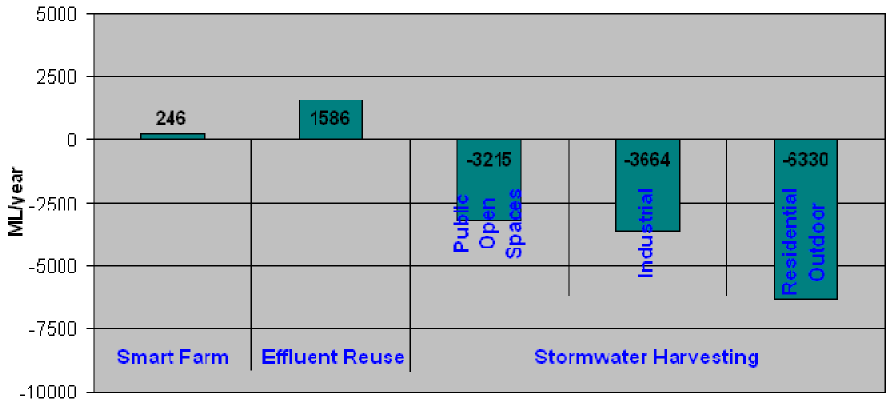

Figure 5: Average change of the South Creek outflow with respect to baseline

Figure 5 shows the average change in south creek outflow for the period from June 2009 to July 2030 for each scenario with respect to business as usual case of natural growth. Both in smart farm and effluent reuse water management scenario have increased the river discharge at the catchment outlet due to decrease in surface water extractions. However stormwater harvesting scenarios reduces out flows significantly. In the water allocation modeling monthly minimum flow requirement were set with highest priorities to maintain environmental flows of each LGA. Stormwater can be harvested only after releasing the sufficient volume water to meet minimum flow equipments at each river segments. Water allocation modeling was carried out in monthly time step. However, to consider environmental flow requirements, daily simulations are suggested using other water allocation tools such as Source Rivers.

The proposed modeling framework was used to simulate hydrologic and economic outcomes of different scenarios and compared with the business as usual scenario. But in this paper only hydrological results are discussed.

7 Conclusion

This paper discusses a system harmonisation modeling framework applicability for securing future water resources in a peri-urban catchment. The system harmonisation process establishes the physical, economic, and social position of the catchment identifies the key biophysical, economic, social, environmental, or institutional pressure points in the system as well as the system constraints. Changes in these key pressure points need to be assessed and acted upon, in a comprehensive and systematic way, to enhance the multifunctional productivity of a water resources system. With the continual trend of increasing demand and a finite supply, effective management of water resources will be needed to meet these needs in a sustainable manner. In this study, the South Creek catchment was modeled in terms of water resources availability, demand, and allocation with the aim of assessing effects of water redistribution from an economic perspective.

In this study, scenarios to address potential land use and population changes and changes in water management practices that could improve the allocation of water are discussed. A framework whereby integrating water allocation modelling and economic assessments can provide policy-makers with a tool that allows them to make more appropriate decisions with respect change of management and operations strategies. This framework was found to be capable of assessing each scenario relative to the baseline, as well as quantifying the changes in value of water in each sector arising from each hypothesized allocation

Acknowledgment

The authors are grateful for the funding support provided by the Cooperative Research Centre for Irrigation Futures to carry out this research. The authors gratefully acknowledge the considerable assistance from the members of the WISER project team.

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