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System harmonisation framework for water resources planning in peri-urban catchments

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Sustainable water resources management has become a pressing issue in Australia. In this study, water redistribution will be assessed based on the "System Harmonisation" framework, addressing social, hydrological, and economic impacts arising from alternative planning and management decisions in Western Sydney's South Creek Catchment. The main aim of this research is to develop and validate a dynamic tool for integrated water resources planning and strategy development in complex landscapes adaptable across Australia and beyond.

Specific to this environmentally degraded catchment, population and industrial growth is expected, resulting in an increase in demand for water in the next twenty five years. Concerns relate to the appropriate, most effective allocation of scarce water resources, especially to maintain agricultural productivity and environmental requirements. Within the System Harmonization framework, A Block-wise TOPMODEL with Muskingum-Cunge flow routing method (BTOPMC) hydrologic model was used to synthesise catchment supply and stream flows, a network resource allocation model Resource Allocation Model (REALM) was used to analyse level of water security under different demand regimes with current and future scenarios. And lastly, allocation modelling output underwent Social Cost-Benefit Analyses, using inductively estimated values for water used in different sectors for various pursuits, whereby multiple scenarios could be compared against one another.

At present, there are numerous urban development plans for the catchment; population is expected to increase from about 390,000 to 1 Million by 2030. In addition, potential climatic changes in the catchment can be expected, whereby hydrology for the system was modelled using CSIRO climate change prediction models output for the region, where overall supply in the system was found to decrease due to decrease in precipitation and increase in evapotranspiration. Scenario development for anticipated future changes in demand and available supply within the catchment is well underway through extensive stakeholder consultation, with consideration being given to projected changes.

The hydrological and economic impacts of these processes were assessed and preliminary results are presented in this paper. With expected high stresses relating to water shortage, it was found that assessing effects of water redistribution from a multi-disciplinary perspective could be extremely useful to policy-makers in the South Creek Catchment. System Harmonisation has proven capable of critiquing potential scenarios in terms of quantifying economic potential given the resource allocation of a particular scheme.

Keywords: *System Harmonisation, Peri-Urban Catchment, South Creek, Urbanization, Climate Change, Water Resources Modelling*

1. INTRODUCTION

In Australia, rivers are regulated to principally provide water for agriculture, as agriculture has long played an important role in the country. However, due to the recent downward trend in supply availability and an increase in demands across all sectors, there exists the challenge of more effective water resources management within catchments. Furthermore, recreational and environmental services have long-since been overlooked, and with rapid urbanization, domestic and industrial demands are increasing, highlighting the importance of more effective water resources planning and management tools for catchments.

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 is 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 and allocation options will be explored from a multi-disciplinary perspective through a tool known as 'System Harmonisation'. This approach aims at incorporating engineering and economic components of water resources management in addition to the inclusion of social, cultural, institutional and policy-making perspectives so as to maximize benefits across the system. Following a truly integrated and cooperative approach through will be the only means by which such a goal can be achieved.

Applications of integrated hydrologic-economic models in the field have been few because of the complex interrelationships that exist between environmental, socio-economic, and political developments within a catchment (Heinz et al.,2007). It has been identified that 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). There exists the necessity of conducting catchment management through an integrated approach, whereby a more realistic representation of the basin in the context of water markets can be developed (Rosegrant et al., 2000), but that as a minimum, a comprehensive explanation of the hydrology and economic situation within the catchment, and the inclusion of institutional rules and incentives in order to generate realistic scenarios (Heinz et al., 2007)

The main aim of this research is to develop and validate a dynamic tool for integrated water resources planning and strategy development in complex landscapes using water resources and economic principles assessed from a social perspective. Furthermore, that this tool remains generic in the sense that it can be used for integrated water resources planning and strategy development in any complex landscapes, adaptable across urban Australia and beyond. The South Creek Catchment is located in Western Sydney. What makes this area a peri-urban landscape is that it lies between suburban developments of the city, and the countryside beyond. The area has been scheduled for 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. BACKGROUND

The South Creek Catchment is a component of the Hawekesbury-Nepean Catchment. South Creek and East Creek are the two watercourses in this catchment; both are tributaries of the Hawkesbury River. 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.

Exiting population in the catchemnt, as of 2005, was approximately 390,000 people. With current urbanization plans, population is expected to reach 1M by 2030. In addition, greenfield development plans are well under way in the catchment and are expected to result in dramatic changes in land-use in the same time period (Rae, 2007). Planning in this catchment is mainly regulated at the LGA level. Parallels exist amongst LGAs in the realms of stormwater management, erosion control and sediment reduction, and the development of best practice guidelines for greener subdivisions (Rae, 2007). It is expected that greater planning alignment between councils in the future will be seen.

Many problems have been identified relating to the future of water resources in the South Creek Catchment. It is anticipated that these issues could have grave impacts on the catchment's environmental and hydrologic systems and its economy. Firstly, overall surface water quality in the catchment is considered poor, mainly due to urban and agricultural runoff, as well as sewage treatment plant discharge. Second, urban development, in addition to the trend towards intensification of agricultural industries that remain, increases the risk of exacerbating existing salinity problems. Third, vegetation loss throughout the catchment has resulted from clearing for agriculture and urbanization (Rae, 2007). Lastly, overall lack of environmental flows is affecting downstream users and overall catchment health. Restoration of natural flow regimes needs to be considered to ensure longevity of river health.

From a review of existing literature and past practice, there are many examples of water resources management research that deal with individual components under the System Harmonisation framework, but little has been done in the way of integrating these practices so that they can support and benefit one another in order to identify and assess more ideal solutions. These issues are all correlated, stressing the need for an integrated approach when developing and assessing potential solutions for the catchment's future. 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

System Harmonisation is a framework, developed 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.

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 in the study area. The main strength of this approach is that plausible scenarios, developed through extensive social research, are evaluated from a broad perspective. Output from the System Harmonisation approach can be used to strengthen the basis of arguments surrounding decisions with respect to water resources allocation and management within a catchment.

A robust modelling framework needs to be established in order to ensure that the aim of this study can be met. 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 resources. This model will strive for full integration, encompassing all system supplies and demands, all identified social components, and will be evaluated from an economic perspective.

In this study, models will be used to replicate existing catchment conditions. Furthermore, to simulate management and development scenarios for water resources with regards to supply and allocation, to assess potential benefits in economics, 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, and to help attain initial goals through the most appropriate and effective management approach.

3.1. Water Cycle Research – Hydrology

A main objective of a hydrologic study is to identify the source and quantity of available water resources as system supply. In order to properly model a hydrologic system, consideration need not only be given to surface water, but also to groundwater, soil, existing land and water use practice, nutrient cycles, as well as historical data concerning rainfall patterns. From this base, future water resource patterns can be projected.

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). In System Harmonisation, water cycle research consists of two simulation modelling tools: BTOPMC – a distributed hydrological model to capture the impact of land use changes over the catchment and to assesses available supply, and REALM – a water allocation model to link multiple sources and multiple users of water as constrained by water quality and specific legislation.

Modified BTOPMC (Block-wise TOPMODEL with Muskingum-Cunge flow routing method), a runoff simulation tool, is used in an attempt to discuss the influence of land-use 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 large watersheds (Nawarathna et al, 2001).

A thorough hydrological assessment will include all supply sources in the South Creek Catchment, which have been identified in Table 1 as (Rae, 2007):

Table **1.** Supply sources of the South Creek catchment

Source	**Amount in South Creek Catchment**	**Details**
Potable	33,162 ML/year ('04/'05)	From Sydney Water
Surface Water	8,729 ML/year ('04/'05)	Total extraction entitlement
Treated Wastewater	28,243 ML/year ('04/'05)	5 sewage treatment plants contributed to 95% of base flow in lower reaches of the catchment in dry weather.
Groundwater	200 ML/year ('04/'05)	89 Active extraction licences (31 monitoring, 4 test, 53 to extract for domestic or stock, 1 & 2 ML/year respectively)

Demands are incorporated into the study's framework during allocation modelling. 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, 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)

Demand in each of these zones has been split between various sectors based on use and anticipated differing value of resource. 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.. The following table displays baseline demands in the catchment:

Table **2.** Demand in the South Creek Catchment (2004)

ML/year	**Hawkesbury**	**Blacktown**	**Penrith**	**Liverpool**	**Camden**	**TOTAL**
Residential	2,103	15,451	6,362	482	357	**24,756**
Industrial	711	3,241	4,750	1,051	563	**10,316**
Agriculture	1,516	2,369	1,926	2,041	2,254	**10,105**
Rec – Parks	153	1,339	770	402	1,128	**3,791**
Rec – Golf	20	258	2,123	0	160	**2,561**
TOTAL	**4,503**	**22,658**	**15,930**	**3,975**	**4,463**	

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, to name a few. Modelling a catchment in terms of resource allocation is a means by which future system requirements can be forecasted.

REALM (Resource Allocation Model) is a software package, developed by Victoria University, the Victorian government, and various water authorities, that 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). REALM will help to equitably allocate and distribute water resources in the South Creek catchment based on scenario-specific supply and/or demand and on established operating rules. Once built, a REALM model will be used to undertake three major processes: input processing, simulation, and output processing (Perera et al., 2005). A schematic representation of the South Creek catchment, as built into the REALM model, is presented in figure 1

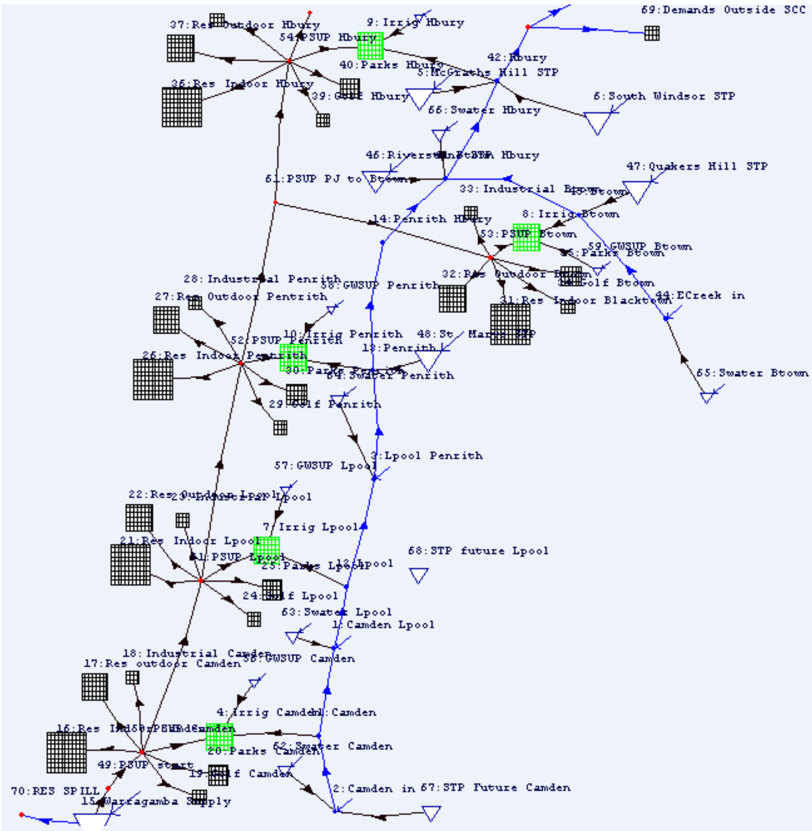

Figure 1. Schematic of the study region in REALM

3.2. Social, Cultural, Institutional and Policy Research - SCIP

The Social, Cultural, Institutional and Policy (SCIPs) program, the social research aspect of the framework, 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 through the process, and to mitigate any potential externalities that could arise without such an evaluation. Water resources are shared, and are essential to many sectors for various pursuits, thus the importance of this component in System Harmonisation.

Furthermore, research conducted and decisions made within this social research aspect of the framework, are directly linked with the other two main components of System Harmonisation in many ways. For example, decisions with respect to feasible and solutions for domestic, commercial, industrial and agricultural retrofits for demand reduction will be conducted in conjunction with the SCIPs research. Also, valuation of water for environmental services will be done in conjunction with the SCIPs research, as well as with direct consultation with and approval from project stakeholders.

3.3. Markets and Products Research – Economics

The markets and products component of System Harmonisation strives to determine the social value of water used by various sectors 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 over any prescribed time period – until 2030 in the case of the South Creek Catchment. The economic component of this framework, in conjunction with the hydrologic model and all findings from the SCIP assessment in the study area, assesses costs and benefits of reallocating water. Effects of simulated water allocation scenarios are assessed in terms of the net-present value (in dollars) of water from a social perspective; the outcome of all scenarios can then be compared against one another.

Thorough and impartial economic consideration should be a mainstay in water resources management, especially because of the growing demands for the resource and ever-increasing constrained supply. This component is necessary because any reallocation of water resources may change economic circumstances of individual users, which will affect benefits that society, as a whole, would derive from altering the allocation of water (Davidson and Hellegers, 2008). Information obtained from analyses using economic principles in an integrated context further assists in developing management and policy alternatives and can greatly aid policy-makers with catchment management.

The economic assessment will be grouped together within a Social Cost-Benefit Analysis to meet the aims of determining economic viability of certain management and development scenarios. Through various simulations, an economic assessment can help determine whether or not the implementation of particular management schemes will result in an overall net benefit (or loss) to society – in this case, the South Creek Catchment.

The first issue in assessing the economics of water as a resource is to ascribe a value to it. Valuing water is a complex task, as water is not generally freely traded on a market where prices are readily observed. However, given that water is only one input to produce outputs, it is necessary that only the value of water is measured, as opposed to the sum of all benefits. To determine the value of water, all additional costs, identified as operational, social, environmental, and opportunistic, must be evaluated and subtracted. In essence, the consumer surplus determines the value of the good in question. Ideally, when supply and demand reach a market-clearing price, the value of the good is determined by the area under the demand curve, but above this price; however, with no such market in existence, deductive valuation techniques have been applied.

In this study, the "correct" or "socially acceptable" price must be used. It is the cost of a good without tariffs or subsidies. These identified costs will accurately reflect the opportunity cost or marginal return for water resources. The price that consumers, from all sectors, actually pay for water often does *not* reflect cost of the provision of the resource or its value. It is the value of water resources that must be determined in order to properly assess the scenarios proposed for this system.

A basic approach for calculating the value of water in agriculture is to break down the total price of the crop into its aggregate components. An inductively deduced residual valuation method is employed, whereby all known prices and quantities for agriculture products are used to determine the remaining unknown value of water. This can be done by determining the net income received by the farmer per unit of water applied. It is this final value that needs to be disaggregated in order to determine only the water-sourced benefits.

For water used in urban and industrial centers, its value will be determined based on the price paid and established elasticities in order to evaluate the consumer surplus. Elasticity is an indication of how responsive the demand of a quantity of a good is to a change in its price. For this study, close to unitary elasticity has been used for industry (0.902). For urban use, water has been deemed near inelastic (0.17) (Grafton & Ward, 2007), because domestic water is irreplaceable. No matter what the price, it is expected that demand per person per day will not change.

Once the value of water to each sector in each region is determined for the baseline scenario, these values are then used to determine the Net Present Value (NPV) over a period of time by discounting future values to present day worth. This can be adequately done using a Social Cost-Benefit Analysis (SCBA), which involves understanding the benefits and costs of a good over time. A Cost-Benefit Analysis is a well established and accepted method used to assess the relative desirability of competing alternatives to society by their economic worth. It attempts to put all costs and benefits arising from a project into monetary terms, in order to enable sensible comparisons between alternate scenarios.

The overall idea behind conducting an SCBA is to add up all benefits that will be seen from a project, subtract all costs (using shadow prices and including all externalities), and account for timing over the prescribed life of the project. An SCBA must be conducted from the present day status and project forward. This is needed as any investment that changes the allocation of water is usually very high and the costs are borne early on in the process while its benefits are realized over many subsequent years (Davidson and Hellegers, 2008).

4. SCENARIO DEVELOPMENT

Scenario development for anticipated future changes in demand and available supply within the catchment is well underway through extensive stakeholder consultation and through the SCIP component of the System Harmonisation framework. 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, thus developing scenarios to maintain demands being met equitably across all sectors will play an important role.

Present-day conditions form the baseline for this research study. This scenario accommodates existing residential (both indoor and outdoor), commercial, industrial, agricultural and environmental demands as they exist today within the catchment. It is this baseline scenario that will be used as the foundation for comparative purposes to evaluate impacts of change within the catchment.

Scenario was developed to assess impacts from population growth and climate change. At present, there are numerous urban development plans for the catchment; population is expected to increase from about 390,000 to 1 Million by 2030. This scenario was evaluated to assess expected changes in urban demand. Hydrology for the South Creek Catchment was modelled using output from CSIRO climate change prediction models for the region, where overall supply in the system was found to decrease due to decrease in precipitation and increase in evapotranspiration. Impacts on system users were evaluated given these projected changes. Different water management strategies were suggested through stakeholder consultation and those scenarios will be tested using the water substitution model.

6. DISCUSSION AND CONCLUSIONS

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 base physical, economic and social position of the catchment identifies the key biophysical, economic, social, environmental, or institutional pressure points in the system and 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, allocation, with the aim of assessing effects of water redistribution from an economic perspective.

In this study, scenarios to address potential landuse 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 in terms of net present value, as well as quantifying the changes in value of water in each sector arising from each hypothesized allocation

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