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The hydrological and economic impacts of changing water allocation in political regions within the peri-urban South Creek catchment in Western Sydney I: Model development

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SUMMARY

In this paper an integrated model of the hydrological and economic impacts of deploying water within the political divisions in the South Creek catchment of the 'peri-urban' region of Western Sydney is presented. This model enables an assessment of the hydrological and economic merits of different water allocation-substitution strategies, both over the whole catchment and in each political region and jurisdiction within it, to be undertaken. Not only are the differences in the water allocated to each region and use revealed, but also the net present values associated with each use within each region. In addition, it is possible to determine measures of equity in water distribution using this approach. It was found that over a period from 2008 to 2031 the South Creek catchment in total would on average use approximately 50,600 ML of potable water a year, the vast majority of this is used in the two urban regions of Penrith and Blacktown. Agricultural water use was also greatest in these two regions. Over this period the allocation system was estimated to have a small net present value of approximately $A301 million and the Benefit-Cost ratio was estimated to be 1.06. The urban regions of Penrith and Blacktown and the rural region of Hawkesbury were estimated to have returned a net positive benefit of $A76 million, $A246 million and $A39 million (respectively), while water to Liverpool and Camden was delivered at a loss of $A7 million and $A52 million over the period assessed. It was found that across the catchment a fair degree of both physical and economic equity occurred between regions, with the exception of Liverpool, which was over endowed with water and paid a high cost for it.

1. Introduction

Research and development in water resources management usually involves separate investigations of the technical, institutional, environmental and social spheres on how to allocate limited supplies of water to those who would appear to have an unlimited demand for it. Spingate-Baginski et al. (2003) argue that 'hard-engineering' solutions to water resource problems have been implemented without any consideration of the overall economic and environmental impacts that might result, or of the social implications associated with these projects. With the increasing discourse on sustainability issues that have arisen in recent decades, there is a realization that if any solutions are considered to be a success, technical aspects of water resources management need to be addressed within an immediate understanding of the environmental, economic and social interactions of the catchment. Increasingly, studies of hydrological problems have included economic and environmental aspects in them (Pittock and Lankford, 2010). However, considerations regarding the allocation of water in a catchment also have a political element to them that has not been captured by current hydro-economic modelling efforts. Prior to modelling the political processes that underlie decision making in a catchment, it is necessary to evaluate whether the impacts of decisions on water allocation can be captured on a political jurisdiction basis. If these jurisdictional impacts cannot be measured, then modelling the political process is not possible either.

The aim in this paper is to measure the hydrological and economic impacts of water allocation decisions on different political jurisdictions within a single catchment; South Creek in Western Sydney. The single element that needs to be present throughout this multidisciplinary approach, and which binds the various other elements together, is the purely physical and hydrological activity

Abbreviations: KL, kilolitre (1.0 m^3); ML, megalitre (1000 m^3); IPART, Independent Pricing and Regulatory Tribunal; BAU, business as usual; $A, Australian dollar currency units (exchange rate on 6 July 2012 $US1: $A0.97).

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of allocating collected and controllable supplies of water to its various end uses, within some well defined geographic region. Where this model differs from others is that it is segregated internally within the catchment on political frontiers, while accounting for the hydrological limits imposed by topography and the whole-of-catchment. The modelling approach also accounts for the economic impacts of making changes to the resources in that catchment and depicts them according to the political regions within which they occur in the catchment. Within the model six different uses of water are identified in five distinct Local Government Areas (LGAs)[1]. The model can be used to analyse the hydrologic and economic impacts different water allocations have on different political regions within the catchment and on the catchment as a whole.

The premise underlying the development of this model is that decisions regarding the spatial, temporal and geographic allocation of water are based principally on the assumption that water security in the South Creek Catchment is an integral consideration to the issue of land use policy. In this catchment, decisions that need to be made on meeting water demand have arisen from the desire of the State Government to settle an additional one million people in the catchment in the next 30 years (see NSW Department of Planning, 2007a, 2007b and Davidson et al., forthcoming for more details on the policies and developments planned for the catchment). This model will be used to assess the hydrological and economic impacts of this policy on the political jurisdictions within the catchment. The complexity facing policy makers in each jurisdiction is immense. Not only is there the possibility of settling one million people in the catchment, but numerous suggestions and policies are in play to supply those people with water, including stormwater harvesting, effluent recycling and improving the efficiency of water use in the agricultural sector. Further adding to the complexity is that combinations of the policies and nuances within them are being suggested and these will affect people in different ways depending on how they use water and where they are located. All these scenarios are assessed in the companion paper to this study (Davidson et al., forthcoming).

2. The modelling framework

The modelling framework used in this study is based on the principles enunciated within the System Harmonisation framework developed in Davidson et al. (2007), Khan et al. (2008); and Malano and Davidson (2009) and a subsequent coupled hydro-economic modelling approach presented in George et al. (2010a and 2010b). In this approach the individual hydrological and economic components of the model and the factors that link them together are specified. The capability of the proposed modelling framework must be adequate to represent the complex nature of problem and issues confronting it, one that not only accounts for the catchment's hydrology and the economic components, but also reveals what the impact may be on its different political entities.

The hydro-economic modelling approach employed in this study is depicted in Fig. 1. The inputs into each modelling component are specified in the left hand side of the diagram, while the outputs from each modelled component are specified on the right hand side. The individual components that need to be modelled are specified in the middle section of Fig. 1. In addition, in the middle component of Fig. 1 the mechanism through which this model can be simulated is shown. The arrows in Fig. 1 represent the flows of information that exist in this integrated model. They originate from the physical features of the catchment, which are required for the hydrological model. The outputs from the hydrological model (principally surface water flows and stormwater) are combined with a range of water supply and demand factors to estimate a water allocation and substitution model. The outputs from the water allocation and substitution model are the quantities of water allocated to each sector within each LGA. These water allocations are combined with a range of economic variables to become the inputs into the economic component of the model. This integrative approach yields a range of hydrological and economic information, on a sector and regional basis, which can be used by policy makers to determine the impacts of a range of policy innovations on the catchment. Thus, this framework is designed to represent the key bio-physical and economic processes involved in the evaluation of water security and the economic performance of alternative water allocation and substitution strategies.

There are three main modules to the modelling framework. First, a distributed hydrologic module which reflects the impacts of spatially distributed land use and climate changes on runoff. The model is used to estimate stream flows and storm water runoff (Nawarathna et al., 2006).

Second, a water allocation-substitution module that balances quality specific water supplies and demands based on agreed supply priorities. This module links multiple water sources with its multiple users on a "fit-for-purpose" basis. This component of the model is the tool that is manipulated to reflect the desires of policy makers and stakeholders regarding constraints, preferences and priorities where supplies are sourced and where they are used. The framework used to estimate the water allocation–substitution model in this study is REALM (Perera et al., 2005). The outputs from this module become the water quantity inputs in the economic component of the model. In addition the water security, which in this paper is defined as the amount of water available at a particular point in the system with an associated level of probability of supply, is derived as an output of interest to policy makers.

Third, an economic model, based on Davidson et al. (2007) is used to evaluate the economic cost and benefits for different water allocation and substitution scenarios. This component of the framework measures the economic outcomes of allocating water of different quality to different uses in each LGA. In this model, the outputs from this economic component are the net present values and Benefit-Cost ratios over a lengthy period of time. These are derived by taking the gross benefits derived from using water from each use away from the total costs of supplying water to each use. In addition, these regional costs and benefits are divided by the number of households in each, in order to determine the degree of equity across the catchment.

3. The South Creek catchment-water supply and demand

The South Creek catchment (Fig. 2) is located approximately 50 km west of the City of Sydney. This catchment is a smaller component of the much larger Hawkesbury-Nepean Catchment, which surrounds Sydney, entering into the South Pacific Ocean (to the north of Sydney).

The South Creek catchment contains portions of eight LGAs. Five of these political entities (Blacktown, Camden, Hawkesbury, Liverpool and Penrith) account for a significant proportion of the catchment. In addition, all five extend well beyond the boundaries of the catchment. Conversely, the remaining three LGA's (Baulkham Hills, Fairfield and Campbelltown) fall only slightly within the physical boundaries of the catchment. For all practical purposes, these remaining three LGAs can be ignored from the analysis and their small contribution merged with the adjoining LGAs.

[1] LGA: Local Government Area – The smallest unit of elected government in Australia, constituted under State Government statures and responsible for local land and water planning issues, minor roads, rubbish collection, collection of property rates, etc. There are five such entities in this catchment which are analysed in this study: Hawkesbury, Penrith, Blacktown, Liverpool and Camden.

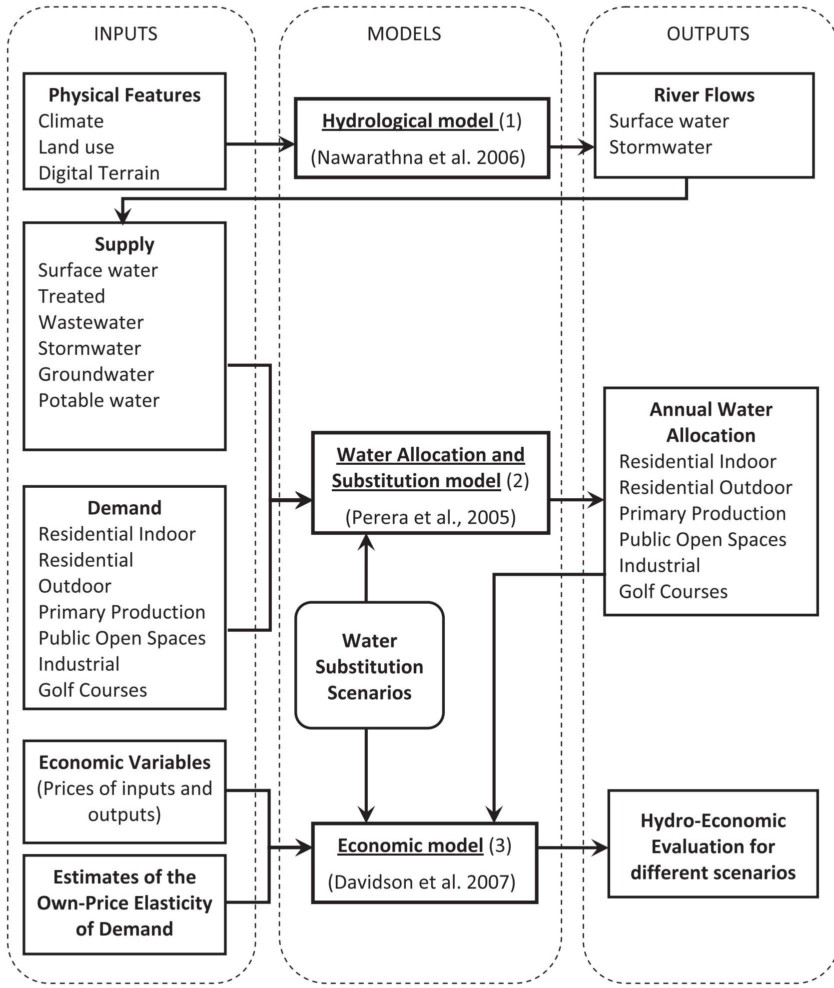

Fig. 1. The modelling framework.

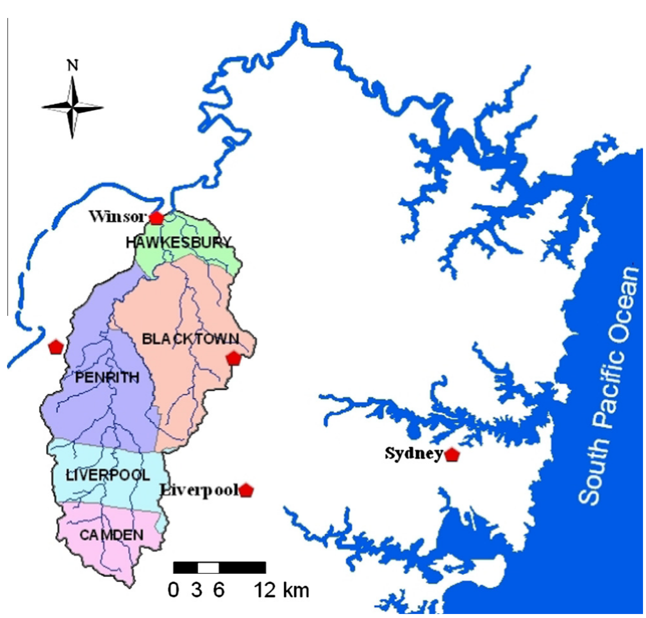

Fig. 2. The South-Creek catchment and its political divisions.

The South Creek catchment covers approximately 620 km^2. This climate is sub-tropical, with an average annual rainfall of approximately 800 mm, which varies slightly over the area. The temperature varies from a low of around 2 to 5 °C in July to a high of around 28–30 °C in January. The FAO56 Reference Evapotranspiration (ET_o) (Allen et al., 1998), has been estimated to be consistently higher than the rainfall in almost every month (Singh et al., 2009). It is expected that future climatic conditions are likely to be warmer and drier, resulting in a reduction in the rainfall and an alteration in the pattern in which it falls (CSIRO, 2007a).

The surface water and groundwater in the catchment, to be used in the allocation-substitution modelling, were determined from the bulk entitlements in the catchment. Most of the water supplied to households and industry in the catchment is sourced from Warragamba Dam and is potable. Quantities of potable water supplied to each LGA for each use are reported in Singh et al. (2009). To determine the maximum possible surface water and groundwater extraction for agriculture and public open spaces a share of the annual usage entitlement was apportioned to each month based on the average crop water requirement. The priorities assigned to each use were based on the priority rights of households' first, then industry, agriculture and finally open spaces. These quantities determine the constraints to resource use in each activity in the allocation-substitution modelling.

Demand in each LGA has been split one of five categories based on its use – residential, industrial and commercial, agriculture, parks and golf courses (Table 1) using a procedure outlined in Rae (2007). Monthly residential demand in each LGA was calculated from the Australian Bureau of Statistics (2005) estimates of the population in each LGA and the average urban (residential)

Table 1
Population and water supply and use by LGA and activity in the South Creek catchment (ML/yr) July 2004–June 2005. *Source*: Modeled estimates, with input from NSW Dept. of Primary Industries (*pers com.* Peter Regan Research Leader, Water in Primary Industries, NSW Trade and Investment, Orange) and Rae, D 2007, 'Water Management in South Creek Catchment: Current state, issues, and challenges', in *CRC for Irrigation Futures Technical Report* 12/07, UWS, Richmond NSW.

	Camden	Liverpool	Penrith	Blacktown	Hawkesbury	Total
Population	5660	7640	100,750	244,680	33,300	392,030
Potable supply (ML/year)	789	2116	9758	23,987	3165	39,815
Total water supply (ML/year)						
Residential	490	500	8724	21,181	2884	33,779
Industrial	4	6	641	2238	263	3152
Agriculture	283	1557	158	89	0	2087
Parks	9	53	169	453	18	702
Golf	3	0	66	26	0	95

demand in the catchment that occurred in 2004–2005 (Rae 2007). The daily water consumption varies between 209 and 265 L/Day/head. Measured valued were used to determine the ratio between indoor and outdoor water usage. In the model it is assumed that this *per capita* consumption does not differ across each individual LGA's in the catchment. The other uses, industrial and commercial, agriculture, parks and golf course activities were identified and classified from land-use maps developed in the year 2000 and reported in Rae (2007). With agricultural use 10 different activities were identified and quantified (dairy pastures, market gardens, greenhouses, hydroponics, turf, mushrooms, nurseries, orchards, vineyards and other). Irrigation requirements for each of these agricultural activities and the other non residential categories were derived from the NSW Department of Industry and Investment (2008) and modified after extensive discussion with Departmental staff. A more rigorous irrigation regime was assumed for gardens, parks and golf courses, of 5 ML/ha/year, but with varying monthly amounts according to relative potential evapotranspiration demand.

Given that water supply and demand need to be forecasted well into the future, in this paper it is assumed that no change in periurban development policies will occur, apart from an increase in population over the period from 2008 until 2031. Thus, it is assumed that future population growth will continue as it has in the past and that the number of dwellings will expand from 91,650 to 155,000 in the catchment (Table 2). Most of this growth is assumed to occur in the already heavily populated region of Blacktown.

4. Modelling development

The modelling framework is bound together by the flow of both regulated and unregulated water from its sources to its uses, as it passes through the various LGA's within the catchment. It is this process of collecting and distributing the water according to political jurisdictions (LGA's) that makes this model unique. The broad processes involved are the capture and collection of water represented by the hydrological module BTOPMC (Nawarathna et al., 2006), which is combined with other sources inside and outside the catchment, and subsequently distributed using the resource allocation model REALM (Perera et al., 2005) to different uses located in each LGA. The hydrologic and water allocation outputs of interest to policy makers and stakeholders are derived directly from these models and are then valued in the economic component of the model (Davidson et al., 2007).

Table 2
Expected total number of dwelling and population in South Creek catchment by local government area. *Source*: Rae, 2007 'water management in South Creek catchment: current state, issues, and challenges', CRC for irrigation futures technical report 12/07, UWS, Richmond, NSW.

Region	Number of dwelling		Population	
	2005	2030	2005	2030
Blacktown	55,400	98,100	204,980	363,000
Camden	1760	2900	6512	10,800
Liverpool	2070	3900	7659	14,500
Penrith	24,850	37,600	91,945	139,200
Hawkesbury	7570	12,500	28,009	46,300
Total south Creek	91,650	155,000	339,105	573,800

4.1. Calibration and evaluation of hydrologic model

A semi-distributed model (BTOPMC) was employed to describe the surface hydrology of the catchment. This is a grid wise physically-based distributed hydrological model that simulates surface and subsurface hydrological processes. The model is based on the block-wise use of TOPMODEL, with Muskingum–Cunge flow routing method at a daily time step (Nawarathna et al., 2006). The grid-wise generated surface runoff and base flows are aggregated within each LGA to estimate the available surface water. That provides the required detail for the subsequent input of runoff generation into the water allocation-substitution module.

Four model parameters (lateral transmissivity under saturated conditions, base flow decay factor of lateral transmissivity with respect to saturation deficit, maximum root zone storage and flood plain Manning's coefficient) are assigned to each land use (Nawarathna et al., 2001). The land use distribution generated in the year 2000 was used to calibrate the model. Land use types were categorized into six classes to account for the relationships between the dominant hydrological processes.

Some data over a select period is used to make the model (the process of calibration) and then the same data over a different period is used to assess how well the model works (validation). The model was calibrated using observed discharge on South Creek at Great Western Highway (250 km^2), Mulgoa road (88 km^2) and Riverstone (92 km^2) for the period from 1992 to 1997. The model was then evaluated using the discharge data from 1998 to 2005. The monthly runoff calibration and validation at Mulgoa road gauging station results between 1992 and 2006 are shown in Fig. 3. The model's monthly calibration results were found to be a reasonable match for the observed values at this gauging station. The model also accurately accounts for the mosaic of pervious and impervious areas in the catchment. A summary of calibration and validation Nash–Sutcliffe Coefficients of Efficiency (E) are presented in Table 3. Nash Sutcliffe efficiency coefficients of greater than 0.60 are generally considered satisfactory and values greater than 0.8 are considered to be good (Chiew and McMahon, 1993). The performance of the calibrated watershed model at three gauging stations is considered to be satisfactory for water resources assessment purposes. Further, in all cases the difference between calibration and validation Nash Sutcliffe coefficients the difference

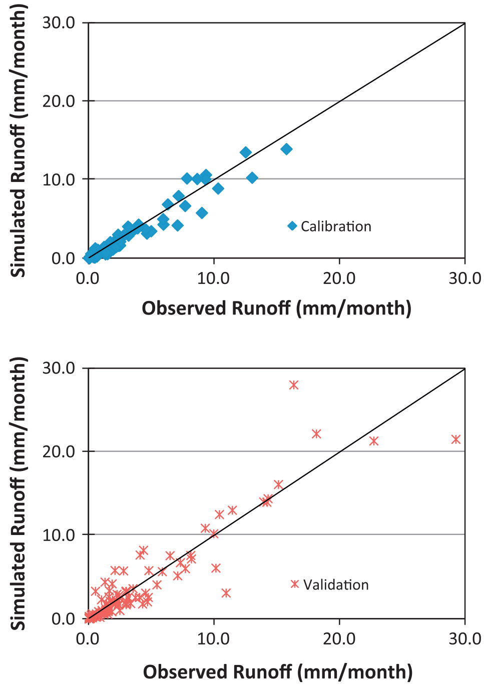

Fig. 3. Hydrological model calibration (a) and validation (b) results for Mulgoa Road Station.

Table 3
BTOPMC model calibration and Validation results (monthly time step).

Station	Nash–Sutcliffe coefficient	
	Calibration period	Validation period
Mulgoa road	0.82	0.76
Great western highway	0.67	0.74
Riverstone	0.78	0.67

is not significant, suggesting that the performance of the model with independent forcings is satisfactory.

4.2. Calibration and evaluation of resource allocation-substitution model

Allocation modelling is needed to evaluate the security of supply for the alternative water substitution and management scenarios. The output from the allocation model is also required in the economic components of this study, as it is the quantities supplied to different end uses that are valued. The REALM model was developed and tested to assess allocation policy in Victorian catchments (Perera et al., 2005). In REALM water resource distribution first incorporates supplies and demands using mass-balance accounting at nodal points and then simulates the distribution or allocation of water with a linear optimization algorithm. A set of user-defined penalties are used to act as constraints to generate results, leading to the preferred allocation of the resource. The REALM software can also cater for both environmental flows and quality constraints as it has a water 'fit-for-purpose' criterion built into it.

REALM is used in this study to allocate and distribute water resources in the South Creek catchment based on scenario-specific combinations of supply and/or demand and on established operating rules developed through a consultation process with stakeholders. The contemporary water supply sources include potable water, surface water and groundwater. Surface water and groundwater pumped from the creeks and deep aquifers in accordance with entitlement based allocation primarily to irrigate parks and agricultural lands. Potable water is supplied from Warragamba dam, which is located outside the catchment. Additionally, this study considered treated wastewater and stormwater in addition to the existing sources in scenario modelling which is described in Davidson et al. (forthcoming). Potable water is the main source of water supply in the catchment.

The validation and evaluation of the South Creek resource allocation model was carried out using the recorded potable supply data. The model calibration approach involves adjusting priorities and penalties parameters until the model reproduces these observed values. To calibrate the model the simulated potable water allocation to residential, industrial and public open spaces was compared with observed data over a period from 1993 to 1999. Then to validate the model, the observed potable water supply from Warragamba Dam was compared to that obtained from the model over the period from 2000 to 2007. The observed and modelled data for the calibration and evaluation periods are shown in Fig. 4. It was found that the Nash–Sutcliffe coefficients for both calibration and validation (at 0.73 and 0.62, respectively) were greater than the accepted value of 0.6 suggested by Chiew and McMahon (1993). It should be noted that the model could not be tested against river flows exiting the catchment (considered to be a more ideal measure), due to lack stream gauging at the end of the catchment. Nevertheless, surface water diversions represent a minor component of the contemporary water use in the catchment.

4.3. Economic modelling

The objectives of the economic modelling process in this paper are to first value the water demanded by each use and then to combine these values together in order to evaluate the changes

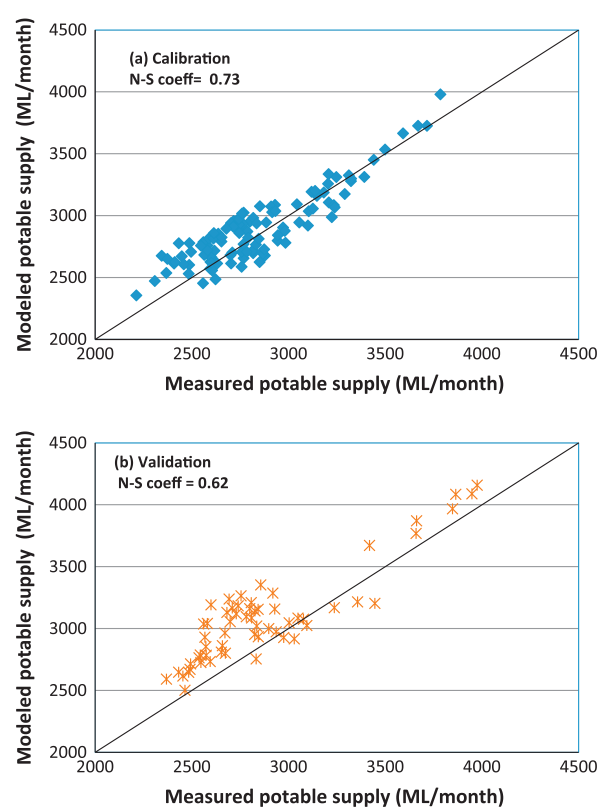

Fig. 4. Hydrological calibration (a) and validation (b) results for the REALM model of potable water supply at Warragamba Dam.

in allocating water over the whole catchment and within different LGAs in the catchment, over the simulation period from 2008 to 2031. The rationale underlying the economic components of this model is outlined in Davidson et al. (2007). The techniques used to estimate the values of different uses are presented in Young (2005) and an example of the links with the hydrological components is presented in George et al. (2011a). A Benefit Cost analysis can be used to complete the task of combining the different values together, but that requires quantification of the benefits (the value of water to different users) and the costs of providing it, over time. To estimate the value of water to users three approaches are employed:

1. The residual method for water used in agriculture.
2. A contingent valuation technique for estimating the value of environmental flows, and
3. A benefit function transfer for the other uses (Young 2005). The costs of providing water include *per* unit costs of providing water to the existing system and any future expansion of it.

The marginal value product of water estimated for various agricultural crops produced in South Creek is presented in Table 4, along with an average value weighted by the volume of water used in each crop type. The estimation approach relied heavily on the work of Hellegers and Davidson (2010), which is used to derive the agricultural input demand (Davidson and Hellegers, 2011). Data used in this procedure was derived from estimates of the gross margins budgets for each crop, produced by the NSW Department of Industry and Investment (2008) and NSW Agriculture (2003). A number of elements need to be highlighted regarding these estimated values of water used in primary production. Firstly, they vary widely, from a high of $A81.71/KL for hydroponics to a loss of $A6.08/KL for mushrooms. Secondly, the average value over all crops weighted by the amount of water used is $A1.06/KL which appears to be relatively high, because high value crops are produced. However, given the types of high value crops grown and the water saving techniques employed, especially for hydroponics, this relatively high estimate is to be expected.

Environmental flows fall into the category of being non-market use and as a consequence are more difficult to value. One well used method of calculating environmental values is Contingent Valuation. Garrans (1994, quoted in a review study by Morrison and Kingsford, 1997) found that the average household was willing to pay $A33.00/household to preserve a wetland. To obtain an estimate of the environmental worth of flows in South Creek, Garrens' value was doubled to account for inflation and the perceived greater awareness households have of the environment 14 years after his original study. The RBA (2009) estimates that inflation in Australia rose by 48% between 1994 and 2008. To account for the greater awareness the ABS (2009) has estimated that the proportion households spent on recreation and culture (which includes the environment) increased by approximately 50% over the period (from 7.8% to 11.3%). Summing the two influences together resulted in a 'doubling' of the estimate to $A66.00 per household. By multiplying this figure by the number of households in the catchment and then dividing it by the amount of water estimated to be the environmental flow, a value for environmental flows was estimated to be $A0.07/KL.

Residential industrial and recreational consumers receive a range of services from water, including the supply of clean water and the discharge of effluent. Consumers pay the rate determined by the local water authority, which is a single price which is approximately equal to the average cost of supply for domestic use. In other words, what consumers pay per unit is certainly the price of water, and may well equal the cost of water; but it does not equate to the value consumers derive from the water supplied. Value is equal to the difference between what a consumer is willing to pay for the product and what they actually pay for it. The only way to measure the value of water to the individual consumer is through estimating the area under the demand function for each use and above the price they pay over the quantity supplied (i.e. what economists' term, the Consumers Surplus). To calculate the demand function for each of these uses requires an estimate of the elasticity, the quantity deployed and the price in any particular year. In this study the elasticities and quantities used in 2008 were chosen because it coincides with both the start of the estimation period and with the pricing data from the Independent Pricing and Regulatory Tribunal (IPART). These are presented in Table 5 together with the sources of these data.

To determine the price of water on a per unit basis, it was necessary to assume that it would be equivalent to the cost of providing the last unit of water. The costs of raw water and its treatment are set in NSW by IPART, who are required to cover the full costs provision (Sydney Water 2008). Potable water prices consist of a fixed and variable charge to consumers. In 2008 the variable charge was $A1.61/KL and the fixed charge was $A75.70 per household. Rae (2007) estimated that there were 104,900 properties in the catchment in 2005 and the total consumption was 33,162 ML. This implies that every household on average consumed 326.00 KL per annum. This translates into a fixed charge equivalent to $A0.23/KL. The authority also charges households a fixed charge of $A480 a year for sewerage services, which represents an annual charge equivalent to a volumetric charge of $A1.47/KL. Adding both the volumetric fixed and the sewerage charges to the variable charges yields a cost of water to households on a volumetric basis alone, of $A3.32/KL of water used indoor. If the water was to be segregated into indoor and outdoor charges, then the volumetric sewerage charge could be taken away from this, to yield an outside use cost of $A1.48/KL.

The value of water used in residential indoor use was estimated to be $A9.75/KL. This is the perceived value derived by consumers from every kilolitre of water consumed in addition to the $A3.32/KL that they had to pay for it. With industrial use the value was estimated to be $A1.75/KL, whereas agriculture was estimated to return $A1.06/KL in value. The costs of existing infrastructure are excluded from the Cost-Benefit analysis, as they are considered to be sunk. However, the same exclusion does not apply for the future expansion of the system. The cost of bulk water from rivers is set by IPART (2006 and 2010) to be $A0.003/KL and from groundwater to be $A0.00226/KL. Besides the costs of the raw water itself, there is the cost of connecting the new dwellings to the grid. Anderson (2006) estimated the costs of connecting a household to the grid in Sydney to be $A2640 per dwelling, of which $A690 per dwelling was the cost of installing the mains. Given that this infrastructure will last well beyond the life of the current study,

Table 4
The marginal value of water employed in producing various crops in the South Creek catchment ($A/KL).

Crops	Camden	Liverpool	Penrith	Blacktown	Hawkesbury
Dairy/pastures	0.10	−1.11	−0.34	−0.32	0.26
Agri (other)	0.05	−1.16	−0.38	−0.37	0.21
Market gardens	0.38	−0.82	−0.05	−0.03	0.55
Greenhouse	10.79	9.59	10.36	10.37	10.96
Hydroponics	81.54	80.34	81.11	81.13	81.71
Turf farm	0.62	−0.58	0.19	0.20	0.79
Mushroom farm	−4.87	−6.08	−5.30	−5.29	−4.71
Nursery	4.17	2.96	3.74	3.75	4.33
Orchard	−0.38	−1.58	−0.81	−0.80	−0.22
Vineyard	0.22	−0.99	−0.21	−0.20	0.38
Average	0.87	2.08	0.79	0.65	1.19

Table 5
Total value, marginal value of water and elasticities used in South Creek catchment (2008) and their source.

Use (Units)	Total value ($A millions)	Marginal value product ($A/KL)	Total water (ml)	Elasticity –	Source
Residential indoor	298.65	9.75	30,631	−0.17	Grafton and Ward (2008)
Residential outdoor	1.12	2.88	389	−0.32	Brennan et al. (2007)
Primary production	5.27	1.06	4963	n.a.	
Industrial	1.12	1.75	640	−0.56	Grafton and Kompas (2007)
Public open spaces	2.67	2.68	999	−0.32	Brennan et al. (2007)
Golf	0.02	2.49	8	−0.37	Brennan et al. (2007)
Environmental USE	6.60	0.07	89,756	n.a.	
Total	315.45	2.47	127,386		

it was assumed to have a salvage value of 80% of its cost in 2030. The costs of potable water were specified above.

The economic desirability of operating a system over a long period of time was evaluated with a Benefit-Cost analysis, in which the costs are taken from the benefits in each particular year in which they occur to derive the 'net benefits'. These were calculated for the whole system and for each of the LGAs in the catchment. The sum of net benefits in each year was discounted at an assumed rate of 7% per annum, (in accordance with the rates established by Infrastructure Australia (Australia, 2008; Harrison, 2007), over the period from 2008 to 2030 to obtain the 'net present values' over the whole period. The Benefit-Cost ratios and the net present values were then used to compare the economic impacts between sectors and political jurisdictions.

5. Model application

The combined water allocation-substitution model and economic model were applied to the South Creek catchment assuming that the population continues to grow at the natural rate (of 3% or approximately 2750 households per annum). The modelling results comprising the average annual volume of water allocated to each use and to each LGA and its economic value over the period from 2008 to 2030 are presented in Table 6. Climate change data are obtained using OzClim climate generator (http://www.csiro.au/ozclim/home.do CSIRO, 2007b; Page and Jones 2001) which generates climate change scenarios based on pre-defined emission scenarios and climate sensitivities. In this study, the degree of climate change will be based on A1b emission scenarios with based on CSIRO's MK3.0 model.

It was found that different regions have, to varying degrees, either benefited from or paid for the scheme. The water allocation system in the catchment as a whole over the period from 2008 to 2031 is estimated to have a net present value of $A301.29 million (Table 6). However, given the scale of the operation the Benefit-Cost ratio was found to be 1.06, which can be used to suggest that there is a relatively thin margin between costs and benefits. In some way, this result is consistent with the efforts of IPART, 2006 in which they strived to set prices in such a way that the costs of running the system equate to the prices paid.

From a purely water resource perspective the allocation system is dominated by the supply of potable water (54,100 ML/year) from outside the catchment. Catchment's surface and groundwater supplies on average only account for less than 9% of the total regulated supplies of 59,298 ML/year. Potable supplies are used mainly in the high population LGAs of Blacktown (32,281 ML/year) and Penrith (12,629 ML/year), most of which is for residential indoor use. In addition, the largest user of water in Hawkesbury LGA is also residential indoor use at 2960 ML/year. In the other two LGA's – Camden and Liverpool – the largest user of regulated supplies is primary production. These latter two LGAs use on average 1155 ML/year and 2732 ML/year of water in primary production and earn off that allocation a net present benefit over the period of $A13.26 million and $A31.03 million, respectively. These benefits, while large, are much lower than the benefits received from residential indoor use in these two rural LGAs of $A58.66 million and $A79.17 million, respectively. Despite the economic importance and significance of regulated flows in this assessment, by far the largest flows are 'end-of-system-flows' which amount to 147,532 ML/yr representing 71% of the catchment flows (Table 6).

Table 6
LGA average annual water allocation (ML/yr) and its total net present value ($Am) from 2008/09 to 2029/30.

	Camden		Liverpool		Penrith		Blacktown		Hawkesbury		Total catchment	
(Units)	(ML)	($Am)	(ML)	($Am)	(ML)	($Am)	(ML)	($Am)	(ML)	($Am)	(ML)	($Am)
Supply/costs												
Potable	1413	49.53	3765	129.52	12,629	461.11	32,281	1128.11	4011	140.56	54,100	1908.83
Surface	844	0.02	479	0.02	1477	0.05	1530	0.05	633	0.02	4964	0.16
Ground	30	0.00	26	0.00	102	0.00	18	0.00	58	0.00	234	0.01
End flow	8771	–	21,563	–	20,659	–	46,996	–	59,072	–	147532	–
Connection cost	–	68.44	–	82.69	–	830.20	–	1948.01	–	266.66	–	3196.00
Total	11,059	117.99	25,833	212.23	34,867	1291.36	80,825	3076.17	63,774	407.24	206830	5105.00
Use/benefits												
Indoor	583	58.66	787	79.17	8955	937.84	22,475	2332.25	2960	310.01	35,760	3717.93
Outdoor	112	3.32	151	4.48	1709	52.83	4289	131.38	565	17.48	6826	209.50
Primary	1155	13.26	2732	31.03	1880	22.18	1971	22.85	597	6.80	8336	96.11
Industrial	122	3.40	153	2.27	840	25.98	2842	80.31	386	12.20	4342	124.15
Open space	224	5.76	492	12.68	760	21.04	1937	52.93	91	2.52	3503	94.92
Golf	24	0.57	0	0.00	343	8.41	64	1.71	4	0.10	435	10.79
End flows	8771	–	21,563	–	20,659	–	46,996	–	59,072	–	147532	117.12
Salvage	–	25.59	–	30.71	–	299.17	–	700.62	–	96.78	–	1152.88
Total	10,991	110.56	25,878	160.34	35,144	1367.46	80,573	3322.05	63,675	445.89	206734	5406.29
Net present value (exc. end flows)	–	−7.44	–	−51.89	–	76.09	–	245.88	–	38.64	–	301.29
Benefit cost ratio	–	0.94	–	0.76	–	1.06	–	1.08	–	1.09	–	1.06

Table 7
Measures of equity in South Creek catchment.

LGA	Physical equity (KL/year/household)	Economic equity of benefit ($A/year/household)	Economic equity of cost ($A/year/household)
Camden	937.53	2004.63	2197.82
Liverpool	1458.11	2414.04	3294.28
Penrith	498.06	2025.42	2057.68
Blacktown	506.39	2095.35	2093.03
Hawkesbury	509.54	2044.02	2005.88
Total catchment	539.41	2127.80	2110.87

Table 8
the impact of increasing and decreasing exogenous variables in the economic model of South Creek by 50% on the net present value ($A million).

Variable (with the baseline value)	The change in NPV arising from a 50% increase in the baseline value	The change in NPV arising from a 50% decrease in the baseline value
Discount rate (7%)	−71.35	577.64
Elasticity		
Residential indoor (−0.17)	−391.70	1174.78
Residential outdoor (−0.32)	−24.74	73.88
Industrial (−0.56)	−14.24	30.98
Public open golf (−0.37)	−1.30	3.58
Price of water		
Potable ($A3.32/KL)	−332.16	332.00
Ground water ($A0.00226/KL)	−0.08	0.08
Costs of provision		
Installation of pipes and mains ($A2640 per dwelling)	−397.45	397.29

Notes: The base line value of the NPV, calculated over the period from 2009 to 2031 is $A301.29 million, with a BCA ratio of 1.01. The discount rate at the baseline scenario is 7%, with an increase tested at 10% and a decrease at 4%.

Some interesting regional factors are that the net present value in Blacktown, a centre dominated by residential indoor use, is positive and high at $A245.88 million, whereas in Penrith and Hawkesbury it is relatively lower at $A76.09 million and $A38.64 million, respectively. The system operates at a significant loss in Camden and Liverpool of $A7.44 million and $A51.89 million, respectively. The greatest loss is made in the more rural LGA of Liverpool, where primary production dominates water use. The Benefit-Cost ratios in each LGA range from 0.76 in Liverpool to 1.09 in Hawkesbury, with both large using LGAs (Penrith and Blacktown) experiencing relatively high Benefit-Cost ratios of 1.06 and 1.08, respectively.

The results presented above do not account for the values placed on environmental flows. If these values were accounted for, they would result in a much larger net present value, of $A418.41 million and yield a Benefit-Cost ratio of 1.08. To avoid a double count, environmental flows have been valued only at the end of the system at $A117.12 million. They are not included as the overall benefits of environmental end flows accrue to those further down the Hawkesbury River, not to residents in the South Creek catchment itself.

From a political perspective it is possible to analyse the degree of equity that exists in the system. It should be noted that equity in this case refers to the differences that exist between the LGA's, and that no moral judgements can be placed on these differences. They are just the product of what occurs as water is allocated throughout the catchment. In this study three differences are reported: the physical supply per household, the economic present benefit per household and present cost per household (see Table 7). It can be observed that the Liverpool region provides the starkest example of inequity. The physical quantity of water supplied per household is approximately 1458 KL/year/household, greater (by approximately 900 KL/year/household) than in all other LGA's with the exception of Camden. This inequality translates into households receiving approximately $A200/year or more in net present benefits above households in other LGAs, but also paying $A1100/year more than households in any other LGA in extra in costs. In all other LGA's the benefits accrued are similar to the costs incurred. In other words, in all other LGAs with the exception of Liverpool, each household receives between $A2060 and $A2260 in benefit and pays between $A2006 and $A2198 in costs.

To evaluate the economic components of this study a sensitivity analysis was undertaken to test the impacts exogenous elements within the model have on its outputs. Increasing and decreasing the parameters by a large amount (say 50%) is undertaken to ascertain what the models findings are sensitive to, not what their reaction path may be. So variables that are subjected to a change that results in a great change to the outputs are considered to be ones which are required to be considered with care and with greater detail in future research. In other words, sensitivity analysis is about model verification and is used to highlight the limitations that exist in all models from the use of exogenous factors. To discover the reaction path of the model requires simulating it with changes that result from the changes in the allocations of water, which are derived endogenously from the hydrological component of the model (a task that is undertaken in Davidson et al. forthcoming). The analysis involved increasing and decreasing the elasticity estimates for each water use, the costs of each source of water and the costs of connections by 50%. In addition, the discount rate used in the analysis (7%) was increased to 10% and decreased to 4%, in accordance with the practices established by Infrastructure Australia (Australia, 2008). In each case the impacts these changes had on the net present values from the system were assessed. Given that a 50% change was imposed, any change of net present value of more than 50% is of interest and concern. It was found that changing the costs of connections, the discount rate, the price of potable water and the elasticity of demand for indoor residential use had the greatest impact on the results (Table 8).

The model is sensitive to the selection of the own-price elasticity of demand, as decreasing the elasticity by 50% results in the net present value rising from to $A486.78 million, while reducing it by the same amount reduced the net present value to $A223.25 million, changes of 61% and 26%, respectively. Grafton and Ward (2008, S63) provide an extensive assessment of the impacts changes in the own-price elasticity of demand has on the value for residential water in Sydney and found it to be large and significant. The model was also found to be sensitive to changes in the price of potable water. A change in the price paid for potable water, up or down by 50%, reduces the net present value to a loss of $A653 million and a gain of $A1256 million, respectively. Raising the discount rate to 10% yields a loss in the net present value of $A70.10 million, while decreasing it to 4% yields a net present value of $A1083.84 million. While 50% changes in all three variables yield greater than 50% changes in the net present value of the system, by far the greatest changes result when the costs of connections to the system are assessed. Increasing or decreasing the costs of connections by 50% yield a corresponding change in the net present values of 317%. These findings did not come as a surprise and further work should be conducted on these variables where the change in the outputs is large. All other variables tested were found to have an insignificant impact on the net present value of the system (Table 8).

6. Conclusions

The aim in this paper is to present the development and the results of a combined hydro-economic model of the South Creek catchment in Western Sydney. This model has the capability to assess the water security and economic outcomes that arise from allocating water from multiple sources to multiple uses on a fit-for-use basis. In particular, the model provides policy makers and stakeholders in different jurisdictions within the catchment with information on the security of water allocation and the economic costs and benefits involved. The model is unique in that it is segregated along political boundaries, rather than the more conventional approach of using physical delineation points. Thus, questions of the physical and economic equity associated with distributing water across a catchment can be evaluated. It should be noted that it is to be expected that any act to increase the efficiency of water within a catchment is more than likely to affect the equity of use across that catchment. With this model policy makers and stakeholders from different political jurisdictions are in a position to have an informed debate on the impacts any water allocation innovation may have on the households they represent. The model was applied (in this paper) to a situation in which no population or development pressures exist, but can (and will) be used as the reference scenario for assessment and comparison with other stakeholder defined scenarios presented in the companion paper to this study (Davidson et al., forthcoming).

It was found that over a period from 2008 to 2031 the region in total would use on average approximately 50,600 ML of potable water a year, the vast majority of this used in the two urban regions of Penrith and Blacktown. Agricultural water use was also greatest in these two regions. Over this period the allocation system was estimated to return a net present value of approximately $A301 million. The Benefit-Cost ratio was estimated to be 1.06. The urban region of Blacktown was estimated to have returned a net positive benefit of $A246 million, while water to Liverpool was delivered at a loss of $A52 million over the period assessed. It is the valuation of the environmental flows (at $A117.12 million) that, while not counted in this analysis, also contributes to the positive economic outlook to the system.

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