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The hydrological and economic impacts of changing water allocations in political regions within the peri-urban South Creek catchment in Western Sydney II: Scenarios

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SUMMARY

The aim in this paper is to assess the hydrological and economic impacts of deploying water in the political jurisdictions of the peri-urban South Creek catchment of Western Sydney. This catchment has been identified as the region in which the city of Sydney will grow into in the future, with a plan to move an extra one million people into the catchment in the next 25–30 years. In conjunction with this expansion, a plan exists to augment the existing water supply by treating waste water effluent, harvesting stormwater and improving irrigation efficiency, along with a strategy for saving water on farms. Water in this catchment is operated by and in the interests of society, where decisions on its allocation have a political perspective to them. However, the growth within this catchment and the water augmentation strategies are not split evenly amongst the political entities within this catchment, namely the Local Government Authorities. An integrated hydro-economic model segregated according to the political entities in the catchment is used in this study to address a range of water saving scenarios raised by stakeholders. The trade-offs inherent in all water allocation decisions on a regional basis are made transparent in this model and its political ramifications, defined as the impacts on different political regions, are identified. In analysing the measures designed to save water across the catchment, none resulted in a positive Net Present Value. Even just expanding the system to accommodate one million extra people resulted in significant economic losses. In addition, the impact of each measure in each political region was markedly different. The purpose of this study is to provide stakeholders in individual local government regions with evidence of the costs and impacts of rational decisions to change the management of water resources in South Creek catchment.

1. Introduction

The South Creek catchment, which is part of the Hawkesbury Nepean river system to the west of Sydney, principally spans the five local government areas (LGAs) of Camden, Liverpool, Blacktown, Penrith and Hawkesbury. Water in the catchment is controlled by the Sydney Catchment Authority (2012), while the provision of potable water to users is controlled by Sydney Water (2012), both who are answerable to the New South Wales State Government. However, actions by the State Government on large scale land planning and development issues (for which they are also responsible), also have a major impact on the benefits and costs of allocating water in each individual LGA. Stakeholders, those who have an interest in the water scarcity issue, within each LGA in the catchment face a multitude of planning problems, as the region has been identified as one of the main sites for the expansion of Sydney. Urban growth is a major issue, which in turn means that water may well need to be directed away from traditional uses, like agriculture. In addition, any suggestions have been made with respect to improving the security of supply of water, such as improving agricultural water use efficiency, treating effluent and harvesting stormwater. However, these activities and policies are not evenly spread over the catchment, which means that the impacts of both urban growth and the measures designed to remedy a possible shortage in water, will not be the same in each LGA.

In this study, a linked hydrological and economic model of the South Creek catchment, based on LGA boundaries and specified in Davidson et al. (in press), is used to address the specific issues raised by the local stakeholders, who are represented by the Local Government Authorities. They lack the range of evidence required to assess both the impacts urban growth may have on water

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security, which in this study is defined as the amount of water available at a particular point in the system with an associated level of probability of supply, and the policies suggested alleviating the pressure on water resources. The evidence these stakeholders require is the combination of physical and economic information on the:

- amount of water required for each pattern of growth (be it what would naturally occur or what might result from an expansion of population),
- quantities of water saved by various proposals, and
- net benefits or costs of each proposal to save water at whatever population growth rate is decided upon.

The first two elements relate to physical water security in the catchment which in this study can be measured principally with the amounts and changes to potable water supplies. The last issue relates to the costs and benefits of each scenario considered and can be measured in terms of the actual and changes to Net Present Values (NPVs) and in Benefit–Cost ratios. In order to combine both the hydrological and the economic impacts of each scenario in each region, it is necessary to evaluate the costs or benefit (whichever it may be) per unit of potable water saved. Once all these measures are derived, they can be compared over the whole catchment and individually between each LGA.

The nature and requirements of understanding policy needs in a catchment are best undertaken using a transdisciplinary and quantitative "systems approach". System Harmonisation (Khan et al., 2008) is an approach that is centred on a catchment and is driven by the concerns stakeholders (in this case Local Government Authorities) have within the catchment. This approach highlights how the different elements within a system are isolated and linked with one another. The defining link in this analysis is the water resource management function of allocating water from different sources to different regions and different uses, over time. More importantly, this analysis can quantify the economic impacts on individual local government areas (LGAs) within a catchment arising from decisions on different allocations of water both temporally and spatially. In this paper a model presented in Davidson et al. (in press) is used to measure the water security and economic impacts of a range of policy measures across the local political spectrum within the South Creek catchment in the Western Sydney region in Australia.

2. The South Creek catchment and its future development

The South Creek catchment is located approximately 50 km west of the city of Sydney and sits to the east of the Hawkesbury Nepean River into which it flows. The catchment is approximately 20 km wide and 50 km from north to south. It falls within portions of eight LGAs, of which only five are significant: Camden, Liverpool, Blacktown, Penrith and Hawkesbury.

The population in the catchment in 2005 was estimated to be approximately 392,000 people, with around 60% of them residing in Blacktown. The other major centre of population is Penrith. In these two mainly urban LGA's the concerns over water lie in providing sufficient supplies for domestic and recreational uses. The other three LGA's tend to have a more rural focus, especially Camden and Hawkesbury (Rae, 2007).

Current plans for urban development into Western Sydney envisage the re-zoning of areas in the catchment. To date 39,500 housing lots have been accepted for release and an additional 141,500 housing lots are expected by 2021. Most of this development is slated to occur in the North West Growth Corridor in Blacktown and in the South West Growth Corridor in both Camden and Liverpool LGAs. With such developments, the population in the catchment is expected to reach one million in the next 25–30 years (NSW Department of Planning, 2007a,b). These development plans are well under way and will not only result in dramatic changes in land-use, but also have a concomitant effect on water resources in the catchment.

Sydney is an expanding city with limited land available for growth. It has to grow somewhere and the decisions once made on how the land should be used then require supplementary actions on providing a range of necessary services including water, power, transport and education. These decisions regarding overall land use and the growth of Sydney are made by the State Government, not by the local government entities (the LGAs). Rae (2007) argues that greater planning alignment between LGAs is needed in the future and must occur in the realms of stormwater management, effluent control, sediment reduction and the development of best practice guidelines for water use in Western Sydney.

3. Scenario development

In this study, there was a need to envisage possible ways in which the future of the catchment might unfold. This was achieved by applying a Scenario Planning Framework (Malano, 2010; Van der Heijden, 1996; Van Notten, 2006) in the region. The scenarios assessed in this study were those identified by the stakeholders in the South Creek catchment and were derived from the development plans for the region (NSW Department of Planning, 2007a,b). These development plans were further discussed and clarified after meetings with the relevant authorities and stakeholders (Table 1). To appreciate the full extent of the scenarios specified in Table 1, the most important issue is to first determine the impacts of future urban population growth in the catchment. Two different futures are envisaged, one where 'growth centres' are developed to accommodate an increase in the population of an additional one million people and the other if they are not developed, termed 'natural growth'. Whether this growth in population occurs or not, will have an impact on the NPVs of undertaking a range of other innovations, such as the harvesting of stormwater, the treatment of effluent and the impacts of the Smart Farms program to save water

Table 1
Scenarios conducted on the study region.

Land use	Smart Farms	Effluent reuse	Stormwater harvesting to:		
			Public open spaces	Industrial	Residential outdoor
Natural Growth Growth predicted to remain constant in future Urban Growth Centres Two Growth centres are considered for future developed in addition to the natural growth	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

in the agricultural sector. Each of these three innovations could stand on their own, but each would still exist within some future growth in demand, *albeit* one where the population grows 'naturally' or if an additional one million people are settled into the catchment. Thus, in this study there are two separate 'baseline scenarios' that need to be considered, each dependent on the rate of population growth. Each innovation needs to be evaluated with its appropriate baseline, which can be defined as the future demand for water given a selected rate of growth (either Natural Growth or Urban Centre Development) in the absence of any new innovation to save potable water. Each of these scenarios is discussed individually and in greater detail below.

3.1. Natural Growth

The model presented in Davidson et al. (in press) detailed results that represent the 'Business-as-Usual' conditions in the study area. It was derived with an estimate of the conditions and urban growth rates that may occur over the next 20 years and as such can be termed the 'Natural Growth' scenario.

In the Natural Growth scenario the numbers of dwellings in the catchment are assumed to expand from 91,650 in the year 2000 to 155,000 in 2030 (Table 2). This represents a growth rate of 2.3% per annum. This growth is assumed to occur evenly over the period in question and is adjusted for the differing time horizon (from 2008 to 2030). Finally, most of this growth is assumed to occur in the already heavily populated region of Blacktown.

3.2. Urban Growth Centres development

In this scenario it is estimated that the population will rise to just under one million people and that by then there would be nearly 269,800 dwellings in the catchment (Table 2). In this scenario Blacktown, Camden and Liverpool are assumed to grow markedly and more strongly than in the case of the scenario on Natural Growth. As with the previous scenario it is assumed that the number of dwellings grows evenly over the years in question, at approximately 6.5% per annum, and is adjusted for the different time period assessed.

The costs of connecting new dwellings to the network and for the water charged to consumers are assumed to be the same as those in the Natural Growth scenario. These costs and prices and the assumptions underlying them were derived from Anderson (2006) and IPART (2006, 2010) and are fully specified in Davidson et al. (in press). The cost of connecting each additional dwelling was estimated to be $A2640 per household and the cost of potable supplies was estimated to be $A3.32/KL (Table 3). In addition, according to the Strategy Plans for the catchment (NSW Department of Planning, 2007a,b) three new additional Sewerage Treatment Plants (STP's) will be needed (one each in Liverpool and Camden and a third in the North of the Catchment) if the Urban Growth Centres development is to occur. The costs of this new infrastructure are presented in Table 3 (Sydney Water, 2009).

3.3. Stormwater harvesting

The State government has introduced new water sharing rules that require increased water allocations for environmental flows in order to maintain river health, particularly in low flow periods and measures to save water use in new dwellings. Implicit in these measures is the need to harness stormwater flows.

In this scenario, stormwater harvesting was seen as an environmentally friendly option and the water is used to replace potable water used in either outdoor residential uses, parks or in industry. Thus, with this scenario three different outcomes are possible, depending on what use the collected stormwater is put to. Distributed hydrological model outputs were used to estimate stormwater generation on an LGA scale in the catchment. It is assumed that 70% of the surface runoff is captured for reuse and the remaining 30% is passed downstream.

Both Jacobs Marsden (2006) and Moran (2008) have reported the variable costs of processing stormwater and estimates vary from $A0.10 to $A1.50/KL. Fernandez (2010) estimated the cost of harvesting stormwater in South Creek to be $A1.00/KL. In addition, there is a cost associated with capital works required to both collect and store the stormwater. The NSW Government (2009) estimated the cost of establishing a stormwater collection facility in North West Sydney at $A24.3 million. It is assumed that one stormwater harvesting facility will be established in each LGA and the cost will be expended in the first year of the analysis (2008). Finally, as stormwater needs to be distributed by a separate second-pipe network, the costs of establishing the mains to all three different uses (at $A690/dwelling) and in the case of when it is restricted to outdoor use alone an additional $A1950/dwelling to account for a separate distribution system to households.

3.4. Effluent reuse

In Western Sydney, the State Government is committed to treating sewerage effluent in order to improve both the quality and quantity of the environmental flows in the catchment. Average yearly effluent generated under natural growth and growth centres is presented in Table 4. These rates of effluent generation were calculated by assuming that they are equivalent to 65% of the potable supplies used for indoor residential use in the catchment.

The NSW Government (2009) reported that $A71.5 million had been allocated to upgrade the Rouse Hill STP to treat effluent (Table 3). Within the Urban Growth Centre scenario, it is assumed that two upgrades will be required in the North of the catchment and one in the South (NSW Department of Planning, 2007a,b). The expenditure on these facilities is assumed to occur in the first year of the analysis (2008). In addition, if the water is used for industrial

Table 2
Population growth and the increase in the number of dwellings anticipated as a result of both Natural Growth and the Urban Growth Centres policies of the NSW Government in South Creek Catchment (no). *Source*: Rae, 2007, 'Water Management in South Creek Catchment: Current state, issues, and challenges', *CRC for Irrigation Futures Technical Report* 12/07, UWS Richmond, Sydney.

LGA	Dwellings			Population		
	2000	2030		2000	2030	
		Natural Growth	Urban Growth Centres		Natural Growth	Urban Growth Centres
Blacktown	55,400	98,100	113,300	204,980	363,000	419,500
Camden	1760	2900	57,500	6512	10,800	213,000
Liverpool	2070	3900	40,300	7659	14,500	149,500
Penrith	24,850	37,600	43,400	91,945	139,200	160,500
Hawkesbury	7570	12,500	15,300	28,009	46,300	57,000
SC catchment	91,650	155,000	269,800	339,105	573,800	999,500

Table 3
The prices and costs used in various scenarios imposed in South Creek catchment.

Item		Source	Units	Value
Connection costs				
Mains pipe installation		Anderson (2006)	$A/household	690
In house pipe Installation		Anderson (2006)	$A/household	1950
Infrastructural renewal throughout Sydney		Sydney Water (2009)	$A million/yr	130
Major works costs				
Construction costs stormwater facility		Costa (2009)	$A million	24.3
Upgrading St Marys STP for effluent treatment		Costa (2009)	$A million	71.5
Construction costs at West Camden STP		Sydney Water (2009)	$A million	49
Construction costs of STP		Costa (2009)		
	Freemans reach		$A million	47
	Hawkesbury Heights		$A million	28.4
	Agnes Banks		$A million	42
	Blue Mountains		$A million	11.4
No. of works required				
No. of new STPs in				
	North West	NSWDP (2007a)	No.	1
	South West	NSWDP (2007b)	No.	3
No. of upgrades to STP in				
	North West	NSWDP (2007a)	No.	2
	South West	NSWDP (2007b)	No.	1
Prices				
Price of potable water	Variable	IPART (2010)	$A/KL	1.61
	Fixed	IPART (2010)	$A/KL	0.23
	Sewerage	IPART (2010)	$A/KL	1.47
Price of ground water		IPART (2010)	$A/KL	0.002
Price of river water		IPART (2010)	$A/KL	0.003
Price of recycled water		Jacobs Masden (2006)	$A/KL	5.8
	Rouse Hill	IPART (2010)	$A/KL	1.29
	Stormwater reuse	Jacobs Masden (2006) and Moran (2008)	$A/KL	1
Smart Water		Kelly (2007)		
Distributed by area (ha.)	Camden (364.44)		$A million	17.95
	Liverpool (395.24)		$A million	19.47
	Penrith (267.62)		$A million	13.18
	Blacktown (341.08)		$A million	16.80
	Hawkesbury (194.9)		$A million	9.60
	Total		$A million	77.00

Table 4
Annual average effluent generated in each LGA in South Creek (ML).

LGA	Natural Growth	Urban Growth Centres
Camden	408	2502
Liverpool	550	2165
Penrith	4387	4689
Blacktown	7866	8415
Hawkesbury	1139	1253
SC catchment	14,351	19,024

Notes: Calculated by assuming that the effluent generated is equivalent to 65% of the potable water supplied for residential indoor use.

purposes, agriculture or in open spaces, then a greater investment is needed to develop a distribution network, incurring the same costs as those described above with respect to stormwater harvesting and urban development.

3.5. Smart Farms

The NSW Government is committed to saving water used in agriculture and open spaces, through its Smart Farms program. Kelly (2007) noted that $A77 million was spent on the program and this is assumed to be expended over each LGA, according to the importance of agriculture in each region. Thus, the distribution of expenditure in Camden was assumed to be $A17.95 million, in Liverpool $A19.47 million, in Penrith $A13.18 million, in Blacktown $A16.80 million and in Hawkesbury $A9.60 million. In this scenario it was assumed that irrigation demand would be reduced by 10% as a result of the infrastructure improvement, while the output remains the same.

4. The model

A hydro-economic model of the catchment, based on LGA political boundaries, has been constructed and is presented in Davidson et al. (in press). In this model the water that is allocated and distributed to multiple uses (agriculture, industry, households, recreation and the environment) across the five LGAs is determined over the period from 2008 to 2030. In this model a range of measures are used. They include more than just a summary of supply reliability for each water source at a catchment aggregate level. In addition to these basic outputs from a hydrological model, it is necessary to assess average potable water savings from each scenario and the economic worth of each scenario to each LGA.

The net economic benefits are derived by taking total values derived from the allocation of water to its various uses in different locations from the costs incurred from distributing the water in any select manner for each individual year. These net values are combined in a Social Benefit–Cost analysis and discounted at 7% per annum over the period from 2008 to 2030. The choice of an appropriate discount rate is always a contentious issue in a Social Benefit–Cost Analysis (see Scarborough, 2010 and Harrison, 2010). However, the Australian Government (2010) suggests that in Australia a discount rate of 7% is appropriate, with testing over the range from 3% to 10%. This rate is in accordance with those accepted by the NSW State Treasury. The validation of this rate was tested at the 4% and 10% levels in the companion paper. It should be noted that in the companion paper a sensitivity analysis was conducted on a number of exogenous factors that could affect the outcomes and it was found that the model is most sensitive to changes in the own-price elasticity of demand for residential use, the choice of the discount rate, the cost of infrastructural improvements and the price of potable water (see Davidson et al., in press). While water users' willingness-to-pay is always changing, to guess that it might rise in the future, when there is a fair bit of evidence to suggest that values and prices fall in the long run, is beyond the scope of this paper. Thus, it is assumed that willingness to pay remains constant over the period under investigation.

By adopting a Social-Benefit Cost approach, it is assumed that water is distributed for the benefit of society as a whole. Thus, both the private and public costs and benefits associated with distribution schemes and improvements are assessed. This approach allows for the identification of the perceived most and least beneficial activities connected to each water allocation policy, along with a comparison of these with the Natural Growth (assumed to be the Business as Usual) scenario. Details on the costs of individual items needed for each scenario are discussed above and are summarised in Table 3.

5. Scenario results

To make informed decisions about a future course of action requires measures of both the potable water savings and the economic impacts of each water management strategy across the catchment as a whole. It is only by comparing the costs of each policy scenario with the amount saved that a rational decision can be made on which path to follow. While the impacts on individual LGAs cannot be ignored (something that is discussed later in this Section), initially the broad catchment wide policy picture needs to be presented.

5.1. Hydrology-catchment wide

From a perspective of potable water substitution, the modelling results are presented for each combination of land use and water substitution scenario. The results of the hydrologic scenario assessment for the period from 2008 to 2030 are shown in Fig. 1a and b, while in Table 5 the entire results ensemble disaggregated by LGAs for all scenario combinations are presented.

It was found that there is an increasing demand for potable water over this period as a result of a steady increase in population and runoff from impervious areas. Under a Natural Growth scenario the system will demand on average 54,022 ML/yr over the forecast period. With the establishment of the Urban Growth Centres, and without any water saving strategies, the average potable water demand over the same period will be 66,226 ML/yr, an extra 23% increase on that of Natural Growth (Table 5).

There is an increase in the average annual volume of potable water substitution in all water saving scenarios, albeit of a different magnitude for each (Table 5). Effluent reuse provides the greatest potable water substitution under both Natural Growth (12,709 ML/yr) and Urban Growth Centres (16,368 ML/yr) scenarios. This can be ascribed to the greater area of impervious surfaces resulting from the greater concentrations of population under the Urban Growth Centres option. The Smart Farms scenario delivers the lowest amount of potable water savings regardless of whether society opts for Natural Growth or the Urban Growth Centres development, of only 926 ML/yr and 729 ML/yr, respectively. Developing facilities to store and distribute Stormwater yields savings of potable water in the case of Natural Growth of between 3394 and 6667 ML/

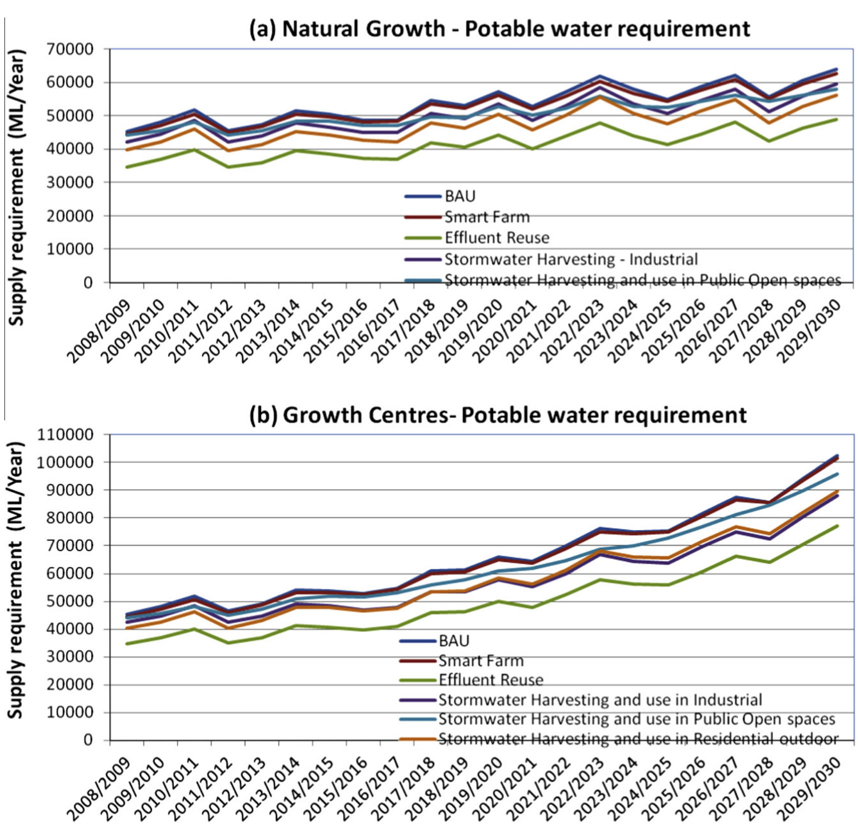

Fig. 1. Potable water supply reliability relationships at catchment aggregate level for each water substitution scenario. (a) Natural Growth, (b) Urban Growth Centres.

Table 5
Average annual water allocations by LGA 2008 to 2030 (ML/yr).

Scenario	LGA	Natural Growth						Urban Growth Centres					
		Potable	Surface water	Groundwater	Treated effluent	Stormwater	End flow	Potable	Surface water	Groundwater	Treated effluent	Stormwater	End flow
Baseline	Camden	1356	844	30	0	0	8771	4759	478	30	0	0	24,596
	Liverpool	3741	479	26	0	0	20,659	6549	497	26	0	0	46,927
	Penrith	12,972	1477	102	0	0	59,072	14,351	1478	102	0	0	91,425
	Blacktown	32,002	1530	18	0	0	72,194	36,126	1352	18	0	0	89,005
	Hawkesbury	3951	633	58	0	0	147,532	4441	568	58	0	0	198,682
	SC Catchment	54,022	4964	234	0	0		66,226	4373	234	0	0	
Smart Farm	Camden	1278	784	30	0	0	8831	4717	441	30	0	0	24,633
	Liverpool	3419	479	26	0	0	20,717	6336	493	26	0	0	46,967
	Penrith	12,772	1413	102	0	0	59,192	14,154	1414	102	0	0	91,528
	Blacktown	31,687	1455	18	0	0	72,194	35,859	1270	18	0	0	89,005
	Hawkesbury	3941	575	58	0	0	147,779	4431	517	58	0	0	198,913
	SC Catchment	53,096	4706	234	0	0		65,497	4135	234	0	0	
Effluent reuse	Camden	1087	727	30	387	0	8888	3787	202	30	1248	0	24,872
	Liverpool	3189	480	26	551	0	20,793	4622	402	26	2022	0	48,515
	Penrith	9521	555	102	4372	0	60,124	10,363	759	102	4707	0	93,821
	Blacktown	24,525	1141	18	7867	0	72,194	27,783	1279	18	8416	0	89,005
	Hawkesbury	2991	453	59	1140	0	149,118	3303	451	59	1254	0	201,172
	SC Catchment	41,313	3356	235	14,316	0		49,858	3094	235	17,646	0	
Stormwater harvesting to:													
Public open spaces	Camden	1322	682	30	0	197	8733	4638	393	30	0	207	24,468
	Liverpool	3390	384	26	0	446	20,267	6198	426	26	0	422	46,449
	Penrith	11,914	1473	102	0	1062	57,655	13,297	1463	102	0	1069	89,928
	Blacktown	30,137	1462	18	0	1935	70,259	34,197	1322	18	0	1959	87,046
	Hawkesbury	3867	623	58	0	95	144,317	4360	552	58	0	97	195,332
	SC Catchment	50,628	4623	234	0	3735		62,690	4156	234	0	3754	
Industrial	Camden	1312	807	30	0	81	8729	4721	441	30	0	75	24,558
	Liverpool	3719	456	26	0	45	20,597	5484	442	26	0	1120	45,831
	Penrith	12,190	1453	102	0	806	58,247	12,909	1445	102	0	1475	88,948
	Blacktown	29,316	1481	18	0	2736	69,458	30,917	1302	18	0	5258	83,747
	Hawkesbury	3626	601	58	0	357	143,869	3972	536	58	0	501	190,893
	SC catchment	50,164	4798	234	0	4025		58,004	4166	234	0	8430	
Residential outdoor	Camden	1294	820	30	0	87	8710	4187	407	30	0	643	24,024
	Liverpool	3633	464	26	0	122	20,495	6028	467	26	0	551	45,854
	Penrith	11,260	1481	102	0	1708	57,235	12,530	1474	102	0	1825	88,599
	Blacktown	27,781	1532	18	0	4220	67,974	31,608	1348	18	0	4522	84,483
	Hawkesbury	3387	632	58	0	565	141,203	3821	567	58	0	622	191,066
	SC Catchment	47,355	4929	234	0	6703		58,174	4263	234	0	8163	

yr depending on how the water is used. In the case of the development of the Urban Growth Centres the potable water savings vary from 3536 and 8222 ML/yr. The greatest savings are made when the stormwater is used to replace water used for residential outdoor purposes.

5.2. Economic-catchment wide

From an economic perspective, the worth of a scenario is measured by the NPV and the Benefit–Cost ratio derived from deploying the water over the whole period in question. In this study, where the worth of a scenario may not be evenly spread over all users and regions, it is also necessary to identify and measure of the changes to the equity that will occur across the regions (something that will be discussed in Section 6).

The NPVs and Benefit–Cost ratios for the water used in each LGA in the South Creek catchment, disaggregated by each scenario, are shown in Table 6. From an economic perspective, the Natural Growth scenario was found to have the highest NPV of $A301.29 million and the highest Benefit–Cost ratio of 1.06. If the Urban Growth Centre scenario is assumed, overall the system makes a loss in NPV of $A1036.79 million, while the Benefit–Cost ratio falls to 0.88.

Any attempt to introduce a policy that saves potable water supplies comes at a cost that is greater than the corresponding base case of either Natural Growth or the Urban Growth Centres. The least expensive option results from the Smart Farms policy, while the most expensive were the scenario that directed harvested stormwater to residential outdoor use. In this worst-case scenario (Stormwater used for residential outdoor purposes) the loss in NPV was estimated to be $A7052.93 million and the Benefit–Cost ratio falls to 0.51. A policy to reuse effluent waste with the development of Urban Growth Centres was estimated to result in the second greatest loss in NPV of $A3364.80 million. Under a Natural Growth scenario, effluent reuse across the catchment also resulted in a significant loss of NPV of $A1074.86 million. Regardless of whether the Urban Growth Centres were pursued or Natural Growth occurs, effluent treatment results in significant reductions in the Benefit–Cost ratios to 0.69 and 0.84, respectively.

5.3. Combining the hydrological economic results at a catchment wide level

A summary of the losses in the NPVs, the reductions in the Benefit–Cost ratios and savings in potable water supply arising from all scenarios tested in this study is presented in Table 7. These results reveal that the cost of following an Urban Growth Centre strategy over a Natural Growth policy across all LGAs means that the positive NPV of $A301.26 million falls to a loss of $A1036.79 million. The Benefit–Cost ratio in this situation falls from 0.98 to 0.82. The system requires annually on average a further 12,204 ML/yr to service the population.

Table 6
The Net Present Values ($ million) and Benefit Cost ratios for water used in each LGA under each scenario tested.

Scenario	LGA	Natural Growth		Growth centres	
		NPV	B:C ratio	NPV	B:C ratio
Baseline	Camden	−7.44	0.94	−369.55	0.65
	Liverpool	−51.89	0.76	−339.88	0.66
	Penrith	76.09	1.06	−151.47	0.92
	Blacktown	245.88	1.08	13.16	1.00
	Hawkesbury	38.64	1.09	−189.05	0.79
	SC catchment	301.29	1.06	−1036.79	0.88
Smart Farm	Camden	−19.83	0.85	−385.62	0.64
	Liverpool	−59.68	0.73	−353.08	0.65
	Penrith	68.99	1.05	−160.98	0.91
	Blacktown	236.54	1.08	−0.07	1.00
	Hawkesbury	30.85	1.07	−198.53	0.78
	SC catchment	256.87	1.05	−1098.28	0.87
Effluent reuse	Camden	−78.34	0.64	−747.03	0.48
	Liverpool	−58.29	0.76	−584.91	0.53
	Penrith	−264.00	0.84	−637.25	0.72
	Blacktown	−566.95	0.86	−921.30	0.80
	Hawkesbury	−107.29	0.82	−474.31	0.60
	SC catchment	−1074.86	0.84	−3364.80	0.69
Stormwater harvesting					
Public open spaces	Camden	−42.76	0.73	−623.52	0.52
	Liverpool	−83.29	0.67	−556.48	0.54
	Penrith	−131.53	0.91	−483.31	0.78
	Blacktown	−235.82	0.93	−610.66	0.86
	Hawkesbury	−45.83	0.91	−391.13	0.64
	SC catchment	−539.23	0.91	−2665.10	0.74
Industrial	Camden	−41.34	0.74	−624.67	0.52
	Liverpool	−88.92	0.65	−558.04	0.54
	Penrith	−151.54	0.90	−499.59	0.77
	Blacktown	−259.67	0.93	−621.61	0.86
	Hawkesbury	−46.13	0.91	−390.50	0.64
	SC catchment	−587.59	0.90	−2694.41	0.73
Residential outdoor	Camden	−90.18	0.57	−1270.43	0.35
	Liverpool	−147.33	0.53	−1116.35	0.37
	Penrith	−727.35	0.65	−1408.44	0.54
	Blacktown	−1613.30	0.67	−2368.26	0.61
	Hawkesbury	−230.63	0.66	−889.46	0.44
	SC catchment	−2808.79	0.66	−7052.93	0.51

Table 7
Losses in the Net Present Values, Benefit Cost Ratios, annual average potable supplies from the various policies tested over the whole of the South Creek Catchment, 2008–30.

Scenario	Measure (units)	Smart Farms	Effluent reuse	Stormwater harvesting to:		
				Public open spaces	Industry	Resident outdoor
Natural Growth	Loss in NPV (from $A-301.29 million)	44.42	1376.15	840.52	888.88	3110.08
	Fall in B:C ratio (from 1.06)	0.01	0.22	0.15	0.16	0.40
	Savings in annual potable supply (from 54,022 ML/yr)	926	12,709	3394	3858	6667
Urban Growth Centres	Loss in NPV (from $A-1036.79 million)	61.48	2328.10	1628.31	1657.62	6016.14
	Fall in B:C ratio (from 0.87)	0.01	0.19	0.14	0.15	0.36
	Savings in annual potable supply (from 66,226 ML/yr)	729	16,368	3536	8222	8052

Notes: All changes in this Table are compared to the baseline Natural Growth and the Urban Growth Centres scenarios. As such a comparison between the two broad approaches to growth cannot be compared. NPVs and Benefit Cost ratios exclude the benefits from end flows through the catchment.

Pursuing the effluent reuse scenario results in a far worse financial position for the catchment, regardless of the rate of population growth that is assessed. In the case of a Natural Growth pattern a further $A1376.15 million of NPV is estimated to be lost and the Benefit–Cost ratio falls by 0.22. In the case of an Urban Growth Centre situation the loss in NPV is higher (at a further $A2328.1 million), yet the fall in the Benefit–Cost ratio is only 0.19. However, the potable water saved in effluent reuse, under a Natural Growth scenario, is approximately 12,709 ML/yr, and with Urban Growth Centres 16,368 ML/yr. This is approximately double the reductions in potable water supply from the best of the stormwater harvesting strategies, (for residential outdoor use) and yet financially comes at approximately two to three times less than the losses associated with this scenario. The Smart Farm policy will only save on average a minimal 729 ML/yr with an Urban Growth Centre scenario or 926 ML/yr if Natural Growth is pursued and comes at a cost that increases the losses in NPV from the system by approximately $A61.48 million and $A44.42 million, respectively.

5.4. Combining the hydrological and economic results within catchment on a political scale

Stakeholders may well be inclined to ask: What is the cost in terms of lost NPV of each strategy to save potable water (on a per unit basis) across each LGA? Answering this question allows stakeholders to make a rational choice regarding the best water saving strategy to chose, if any, and to evaluate the impacts of each approach from the perspective of each political jurisdiction within the catchment. This question can be addressed by dividing the extent of the losses in NPV associated with each scenario (a measure of its cost) by the savings in potable water associated with each, over the whole inclusive 23 year period under analysis (Table 8). The cost estimates in this table are the reductions in NPV that result from implementing each measure, while the savings are those attributable to potable water supplies alone. It should be noted that the information presented in Table 8 cannot be interpreted as a measure of the 'cost effectiveness' of any scenario under investigation as the cost in question is a reflection of losses in NPVs, not the total costs of any individual scenario. As this analysis is about the best water saving strategy to choose, it should be noted that it is impossible to compare each of them across the Natural Growth and Urban Growth Centres scenarios. Consequently, the figures presented in Table 8 are an estimate of the costs of each unit of water saved through each measure from the baseline of either Natural Growth or the Urban Growth Centre developments, on an LGA basis.

Taking the case of natural Growth first, on a catchment wide basis, the measures designed to save water in agriculture (Smart Farms) and to treat effluent cost $A2.09/KL and $A4.17/KL. Given that water currently retails at $A1.61/KL (Table 3) both options would seem unrealistically expensive. The costs of saving water through harvesting stormwater, catchment wide, is estimated to be in the order of $A10.02/KL and $A20.28/KL, depending on how the water is used. This high rate, especially in public open space use, occurs because the savings in potable supplies are relatively small in comparison to the costs of provision.

More interestingly, the cost per kilolitre of each policy varies greatly between LGAs. For instance, with effluent recycling the cost of saving each kilolitre of water in Camden, assuming a Natural Growth pattern is $A11.46/KL, whereas in the adjoining LGA of Liverpool it is a more feasible $A0.50/KL, and in the other three LGA's the cost is a more realistic $A4.28 to $A6.61/KL. Certain activities, such as the Smart Farms policy in Liverpool LGA look more than worthwhile (at $A1.05/KL) and in Blacktown (at $A1.29/KL) if a Natural Growth strategy is pursued. On the other hand, it is hard to justify any expenditure on harvesting stormwater when the water is deployed to industrial or residential outdoor use. Yet, whether the strategy pursued is one of Natural Growth, such expenditure in Liverpool on public open space use looks almost

Table 8
The losses in the Net Present Values per litre of various potable water saving measures in South Creek catchment, under policies of both Natural Growth and Urban Growth Centres 2008 to 2030 ($A/KL).

Scenario	LGA	Natural Growth	Growth Centres
Smart Farm	Camden	6.91	399.19
	Liverpool	1.05	72.07
	Penrith	1.54	35.53
	Blacktown	1.29	0.01
	Hawkesbury	33.88	863.19
	SC catchment	2.09	65.50
Effluent reuse	Camden	11.46	33.42
	Liverpool	0.50	13.20
	Penrith	4.28	6.95
	Blacktown	4.73	4.80
	Hawkesbury	6.61	18.12
	SC catchment	4.71	8.94
Stormwater harvesting			
Public open spaces	Camden	45.17	224.04
	Liverpool	3.89	68.93
	Penrith	8.53	19.94
	Blacktown	11.23	13.76
	Hawkesbury	43.72	209.95
	SC catchment	10.77	32.77
Industrial	Camden	33.50	714.72
	Liverpool	73.18	22.78
	Penrith	12.66	15.06
	Blacktown	8.18	5.19
	Hawkesbury	11.34	36.20
	SC catchment	10.02	14.25
Residential outdoor	Camden	58.03	96.57
	Liverpool	38.42	93.16
	Penrith	20.40	33.63
	Blacktown	19.15	22.79
	Hawkesbury	20.76	62.37
	SC catchment	20.28	38.08

feasible at $A3.89. This occurs because the estimated rate of potable water savings off impervious surfaces in this area is relatively high.

In observing the cost per kilolitre measures across LGA's, it is apparent that Liverpool LGA would benefit most from either the Smart Farms and effluent reuse policies, but suffer greatly from policies that promote stormwater harvesting where it is used for industry or residential outdoor use. Alternatively, if water is to be saved, then those from Blacktown and Penrith would have no problem supporting the policy that also promotes Smart Farms, yet might be more sanguine regarding a policy that promotes any other form of water saving. Any other scenario in any other LGA (than those mentioned directly above) cost more per kilolitre than the cost of the potable water supplies they replace.

The same could be said for all water saving strategies in all LGAs if the Urban Growth Centres scenario, with the exception of the Smart Farms in Blacktown. This result occurs because the costs of each strategy are great and the water saved is small. This can be seen with respect to the case of the small rural LGAs of Hawkesbury and Camden. The costs per kilolitre are phenomenally high for most water saving innovations purely because the amounts saved are extremely small. The bigger more urban LGAs suffer the same excessive costs of each water saving strategy (regardless of whether the Urban Growth Centres are adopted or not), yet have the advantages of reaping and using larger potable water savings.

6. Policy implications

There are many ways the financial losses that have been estimated to exist from attempts to save potable could be viewed. From a strictly financial perspective the argument could be made that doing anything in the catchment, rather than just letting it grow naturally, is not worth the effort and the investment in the Smart Farm program, effluent reuse technology or stormwater harvesting should be avoided. However, all such decisions are not made along strictly narrow financial guidelines or for that matter on the basis of the water supply system in the catchment alone. There are significant benefits that accrue to society from the settlement of an additional one million people in the catchment; well beyond those that accrue to the water system itself. Thus, connecting one million extra people to the water network could well be viewed as the cost society is obligated to incur to maintain the social welfare of its citizens. Seen under these less strict terms, the financial losses identified in this analysis could be viewed in terms of the 'social obligation cost' to new residents of that society. In this type of situation the government should attempt to minimise the costs of achieving a known policy goal (in this case of saving potable water supplies).

However, in making this argument on social inclusion and the costs a government might be obligated to pay, it cannot be implied that government policies to save water should be evenly spread across the catchment. So long as water is saved somewhere in the system, then the benefits of that act will flow onto all citizens, regardless of which LGA they reside in. In the case of the South Creek catchment if the government wants to save water and to minimise its cost (thus attempting to maximise its cost effectiveness), then it should promote different strategies in different LGAs.

6.1. Smart Farms

Implementing a policy like Smart Farms, that is intended to increase the efficiency of agricultural water use results in the least amount of potable water savings (926 ML/yr) in relation to the Natural Growth scenario, and only 729 ML/yr under an Urban Growth Centre development policy. Economically, this strategy results in a $A44.42 million loss on top of that resulting from just the Natural Growth rate (Table 7). Despite this, the reduction in the Benefit–Cost ratio was only slightly lower (by 1%). However, in Camden, a relatively rural LGA, the impact of the Smart Farms policy results in a 9% reduction in the cost–benefit ratio beyond what was already lost in the region (0.94–0.85, Table 6). The size of the loss in Camden rises by $A12.39 million over the whole period, yet only 78 ML/yr of potable water is saved along with 60 ML/yr in surface water supplies. The highest potable water savings are derived in Liverpool (322 ML/yr) and yet the loss in NPV is only $A7.79 million. This would yield a cost per kilolitre outcome of $A1.05/KL saved, considerably better than the cost effectiveness of the same policy implemented in Camden of $A6.91/KL. A similar but less satisfactory result was also obtained in Blacktown and Penrith. Thus, from a catchment wide perspective, it could be argued that in a situation of Natural Growth implementing the Smart Farms program, while making a loss, is relatively benign, especially when compared to the other scenarios that have been suggested. However, in individual LGA's, like Camden, the cost is great and the water savings are negligible.

6.2. Effluent reuse

This strategy produces the largest saving in potable water demand over the entire catchment, ranging from 10.723 ML in 2008 under the Natural Growth scenario and up to 22,187 ML in 2030 for the Urban Growth Centre scenario. Of these savings, more than half occur in Blacktown and more than a quarter in Penrith, the two most heavily populated LGAs in the catchment. The adoption of effluent reuse causes the overall economic losses across the catchment to rise by $A1074 million over the period from 2008 to 2030, while the Benefit–Cost ratio falls by 0.22, if effluent reuse plans are considered in an environment where the population grows naturally (Tables 6 and 7). In the individual and relatively small LGA's of Camden and Hawkesbury, the falls in the Benefit–Cost ratio are 30% and 28%, respectively, although the losses in the NPVs are relatively modest at $A70.90 million and $A145.93 million, respectively. The savings in potable water supply in Camden and Hawkesbury LGA's amount to only 251 ML/yr and 886 ML/yr, respectively (Table 5). In the relatively populous LGA's of Penrith and Blacktown the reductions in the Benefit–Cost ratios are more modest at 0.22 each; but in terms of the NPVs the losses (of $A340.09 million and $A812.83 million, respectively) over those already incurred from the system with natural growth, are quite significant. Effluent reuse, viewed from a cost per kilolitre perspective, would appear to be most effective in Liverpool (at between $A0.50/KL and $A13.20/KL depending on the growth scenario chosen) and least so in Camden (Table 8).

It should be remembered that any decision on the use of recycled water has more to do with the attitudes of the public than with any financial considerations involved. The point that in general the public in Australia does not accept the use of recycled water for residential use means that they value it less highly than other sources of potable water. If this is the case, then the estimates of the losses that accrue to the use of recycled water are going to be greater than those presented above, further weakening the argument for recycling water.

6.3. Stormwater harvesting

On a catchment wide basis, this strategy produces varying degrees of potable water savings depending on the final allocated use for either industrial, public spaces or residential outdoor use. Assuming a Natural Growth scenario, the largest saving occurs when stormwater is directed to residential outdoor use (on average 6667 ML/yr) compared with industrial use (on average

3858 ML/yr) and public open spaces (on average 3394 ML/yr). These savings are 8052 ML/yr, 8222 ML/yr and 3536 ML/yr respectively, for the Urban Growth Centre strategy (Table 5). In terms of potable water saved at catchment level, the gains are large across the catchment, yet these savings are only half those achieved through effluent reuse (which were estimated at 12,709 ML/yr if Natural Growth is assumed, or 16,368 ML/yr if Urban Growth Centres are assumed). In individual LGAs most of these savings are concentrated in Blacktown (4221 ML/yr) and Penrith (1712 ML/yr). In the other LGA's the saving are approximately one third or less of those experienced in Penrith.

Under this scenario the losses in NPV are estimated to be between $A840.52 million and $A6016.14 million more than not harvesting the water (Table 7). It is estimated that in harvesting stormwater and using it on open public spaces or industry, the Benefit–Cost ratios fall a further 15–20%. These losses are of an even greater magnitude if an Urban Growth Centres scenario is assumed, yet the reductions in the Benefit–Cost ratios are of a smaller order of magnitude. As with the case of effluent reuse, using stormwater on public open spaces and in industry incurs the greatest losses in NPVs in the populated LGA's of Blacktown and Penrith, while the falls in the Benefit–Cost ratios are greatest in the more rural LGA's of Camden and Hawkesbury (Table 6).

A whole order of magnitude worse financially for the system is directing harvested stormwater to residential outdoor use. The cost of reticulating the stormwater to households' results in an additional loss beyond that incurred under a natural growth scenario of $A3110.08 million over the period from 2008 to 2030. The Benefit–Cost ratio for the catchment falls to 0.40 (Table 6). Within the catchment the losses in all LGA's are quite significant, but greatest in all LGAs except Liverpool, where the Benefit–Cost ratio falls by approximately 40% and the losses in NPV are great.

From a cost per kilolitre perspective utilising potable savings from harvesting stormwater is a most ineffective policy, in all LGAs when either growth scenario is assumed and the water is directed towards residential outdoor use (Table 8). The great diversity in estimates of the cost effectiveness of stormwater harvesting across the various LGAs in the catchment is also cause for concern. It implies that the ability to harvest stormwater varies greatly and that the selection of a site to place the scheme would need to be carefully considered.

6.4. Urban Growth Centres

Finally, it would be remiss not to mention the differences that result from a comparison between the two growth strategies (Natural Growth and Urban Growth Centres) in the absence of any water saving policies being deployed. Adding the extra households means that the potable water requirements grow by 12,204 ML/yr (Table 7). The greatest increase in requirements occurs in Blacktown (4124 ML/yr), Camden (3403 ML/yr) and Liverpool (2808 ML/yr).

Doing so, over the period from 2008 to 2030, results in a loss over the whole catchment of $A1036.79 million and the benefit cost-ratio falling to 0.88, even if no water saving strategies are deployed (Table 6). This is a significant fall over the just breakeven Natural Growth scenario of $A301.29 million. In the heavily populated regions of the catchment (Penrith and Blacktown) the additional NPV losses of $A227.56 million and $A232.72 million, respectively; are less than the losses in Camden of $A362.11 million and in Liverpool of $A287.99 million (Table 6). This difference in impact occurs because the latter two LGA's are where the South West Growth Centre is located, which requires the establishment of more infrastructure than in the North West Growth Centre to account for the increase in population. It should be noted that it was assumed that the population growth rate would be constant over the period in question and that infrastructural innovations would be timed to occur with the increases in population. If the rate of population growth occurs initially at a slower rate and then accelerates towards the end of the period, then the losses would be reduced somewhat from what was estimated above, and vice versa.

Undertaking effluent reuse or stormwater harvesting in light of establishing the growth centres further increases the magnitude of the financial losses significantly beyond the baseline scenario of Natural Growth with no policy interventions (Table 6). In these circumstances, while increasing effluent reuse is more financially detrimental than harvesting stormwater for use in public open spaces or for industry use, using harvested stormwater for residential outdoor use with an extra one million people in the catchment results in a loss of approximately $A7530 million.

7. Conclusions

The overall implication of this research is that, while it has always been known that decisions regarding water resource management do not have an even impact across a catchment, the different impacts between regions within a catchment can be quite large and in places quite detrimental. In this paper these impacts were assessed in the South Creek catchment of Western Sydney, where (under two different growth strategies) the impacts of different potable water saving policies on different LGAs were assessed. There is a difficulty in assessing these policies (to save water used in agriculture, to undertake stormwater harvesting and direct it to different uses and to treat effluent) because some save a lot of water, but come at a high cost, while others are relatively inexpensive but do not save much water. By segregating these policy differences and growth strategies out and identifying those according to the political jurisdiction in which they occur a meaningful discussion on the precise effects of adopting one measure over another were determined. In each case the amount of potable water saved and the cost of that savings (measured in terms of the losses in NPV) were determined for each LGA. Then, still adopting the same politically determined boundaries the cost per kilolitre of saving potable water (measured in terms of $A/KL) was determined.

It was found that any measure to save potable water, whether a Natural Growth or Urban Growth Centres scenario was employed, would incur a cost that was greater than the existing cost of supplying potable water (estimated to be $A1.61/KL). The only exception to this finding was in the case of the Smart Farms program in Liverpool, Blacktown and Penrith LGAs, where the cost per kilolitre of the measure was estimated to be between $A1.05 and 1.54/KL. In addition, the cost of effluent reuse in Liverpool was also found to cost only $A0.50/KL.

It can generally be concluded that while some measures to save water are relatively more cost effective than others (for instance Smart Farms over stormwater harvesting) they do not save a great quantity of the resource. It would appear that effluent reuse does save a considerable quantity of water and its cost per kilolitre (while still prohibitive in most LGAs) was most possibly the best approach to take if potable water is to be saved.

However, more importantly it was found that the differences in cost effectiveness across the catchment of any single measure designed to save potable water was great. This means that different approaches to saving potable water are going to cost residents within each LGA in the catchment different amounts. As a consequence residents of one LGA are going to argue for one particular method over another in opposition to residents from another LGA who will prefer a different water saving measure. Complicating this picture is the finding that generally speaking some LGAs fare relatively better off than others regardless of the water saving strategy that could be adopted. The more urban LGAs (Blacktown in particular) generally do better than the rural LGAs (Camden in particular).

In a wider context the modelling approach outlined in Davidson et al. (in press) and the way that model is used in this paper could be applied to the multitude of cases that exist throughout the world, where catchments cross political boundaries. The models and the techniques discussed in this paper and the companion and paper could be used to propose solutions whereby actions in one jurisdiction that have an adverse impact on another are discussed and the level of compensation that is required to resolve the matter is agreed upon (Davidson et al., 2008).

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