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REVIEWS

Economic Evaluation of Stormwater Harvesting—A Case Study

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Abstract | Harvesting Stormwater is gaining importance as it is viewed as a potential alternative source for meeting non-potable water demand from consumers. However, there have not been many economic studies carried out on the cost of supplying stormwater to consumers. The study reported in this paper makes an effort to estimate the cost of supplying stormwater to consumers using a case study from Gosford Local Government Area (GLGA). A significant finding of this study is that the larger urbanised catchments are the most suitable locations for stormwater harvesting projects. The results obtained indicated that the cost of supplying treated stormwater for non-potable purposes varied between $3/kL and $5/kL, which is significantly higher than the cost of town water supply. In depth analyses revealed that the major component of the capital cost is attributed to the cost of distribution system. Therefore, in areas that are already serviced by dual reticulation, it is possible that the cost of supplying stormwater would be equal to or lower than that of the existing town water supply. In addition, further refinement of cost functions can lead to more realistic $/kL values for the water harvested from stormwater.

1 Introduction

In New South Wales (NSW), there has been an increased interest in Integrated Water Cycle Management (IWCM), in part due to the severe water shortages experienced in the years following 2000. IWCM is a planning tool that integrates the sustainable management of water supply, sewerage, and drainage over a long term planning horizon (30 to 50 years). In New South Wales, the Department of Water and Energy has encouraged Local Water Utilities to undertake IWCM studies.[1] As part of this initiative, most of the water utilities in NSW commissioned IWCM studies, including Gosford City Council (GCC)[2] which is a Local Council and Water Authority located in the NSW Central Coast region. Gosford City is located about 75 km north of Sydney.

Due to inconsistent rainfall patterns, the water supply of the NSW Central Coast has, at times, experienced severe shortages. Stress on the local water supply system is expected to increase over the next 30 to 40 years due to the combined pressures of climate change and the growing population of the region. To meet these challenges, Gosford City Council (GCC) is actively investigating alternative sources for its water supply, including augmenting the supply of water via stormwater harvesting, sewer mining, and desalination, thus making it less reliant on dam water supplies. Several investigations were undertaken to assess the technical and economic feasibility of sewer mining and desalination.[3]

The objective of this study was to undertake a preliminary investigation into the feasibility of stormwater harvesting in selected catchments of the Gosford Local Government Area (GLGA). This paper presents some parts of the study conducted by a former student of the University of Technology, Sydney.[4]

2 Water Demand for Gosford Local Government Area

It is expected that demand on the potable water supply will increase linearly due to the

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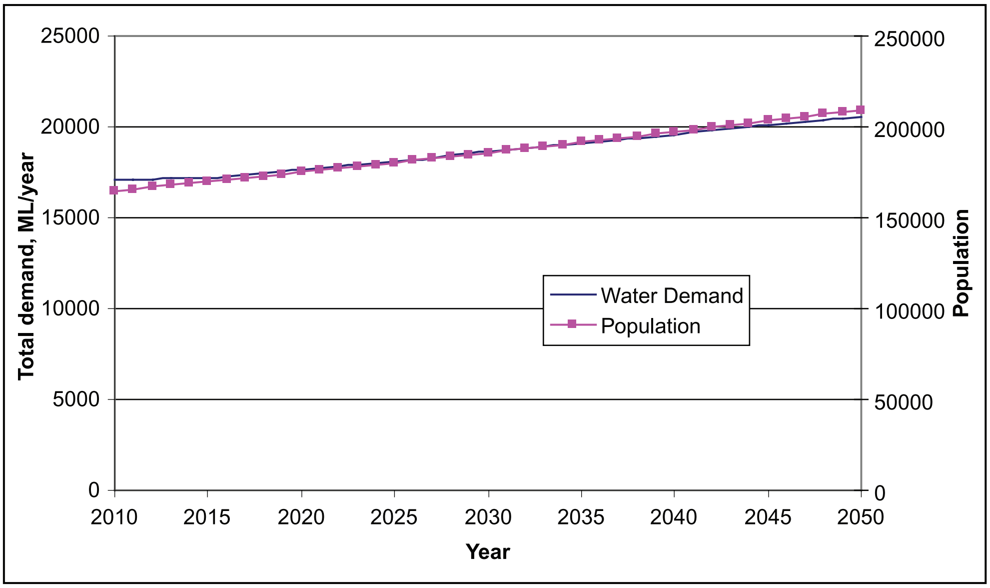

Figure 1: Forecasted water demand and population (adopted from WaterPlan 2050).

corresponding increase in local population, as displayed in Figure 1. The population of the GLGA is projected to reach 210,000 by 2050.[3] Assuming that no restrictions of water usage are implemented, the forecast potable supply demand is expected to reach 20,569 ML/a by 2050. This demand was estimated using the forecast per capita demand between the period 2010 and 2050;[3] the forecast per capita demand is expected to vary from 284 L/capita/d in 2010 to 268 L/capita/d in 2050.[5]

Table 1 shows the distribution of water consumption within a typical residence. As shown in the table, only a total of 36% of the supply needs to be of potable quality and the rest can be of non-potable quality. As such, it is possible to source the non-potable portion (64%) of the supply via the stormwater and wastewater reuse schemes.

Table 1: Residential water use patterns.[4]

		Typical Australian cities	
Type of use	Category	L/cap/d	%
Kitchen	Potable	28	10
Bathroom	Potable	74	26
Toilets	Non-potable	65	23
Laundry	Non-potable	46	16
Gardening/ outdoor/indoor cleaning	Non-potable	71	25
Total		284	100

Table 2: Source of water supply.[2]

Source of supply	Catchment area (Sq. km)
Mooney Mooney Creek Dam	39
Mangrove Creek Dam	101
Lower Mangrove Creek Weir	140

3 Water Supply

The potable water supply infrastructure currently developed within the Gosford LGA includes two dams and a weir as listed in Table 2.

To determine the worst year for meeting the demand, past rainfall data were collected and checked for a year with lowest rainfall. For this purpose, the yearly rainfall data for Narara Observatory Station (BoM Station No. 061087) were collected.[6] This station has recorded rainfall data since 1917, hence the annual rainfall data between 1917 and 2009 were inspected for the lowest annual rainfall. It was discovered that the lowest rainfall year on record, with 630.2 mm of total annual rainfall, was in 1944.[6] Using the established relationships between rainfall and water yield, stream flows corresponding to the lowest

Table 3: Comparison of demand and supply.[5]

Description	Demand (ML/yr)	Supply (ML/yr)
Unrestricted Demand	20,569	
Lower Mangrove Creek Weir Supply		3,565
Mangrove Creek Dam Supply		2,877
Mooney Mooney Creek Dam Supply		2,318
Total	20,569	8,760
Shortfall, ML/yr	11,809	
Shortfall, %	57	

rainfall (in 1944) were calculated for each of the surface water sources and are given in Table 3.

4 Shortfall in Supply

The shortfall in supply in 2050, assuming that 2050 receives the lowest (1944) rainfall, is given in Table 3. As shown in the table, during low rainfall periods, there appears to be a significant shortage in the quantity of water available to meet potable demand. Hence, there is a need for developing alternative sources of water supply. Four possible alternative sources of water for GLGA are:

- Seawater (desalination);
- Groundwater;
- Recycled water; and
- Stormwater harvesting.

Use of seawater as a possible source of water supply is limited due to the high capital and operating costs involved in setting-up of desalination plants. Use of groundwater as source can be unsustainable due to the risk of salt water intrusion. Due to the associated risk factors, the groundwater is generally considered to be a reserve water source that will be utilised only under severe drought conditions. Recycled water and stormwater are therefore considered the most acceptable sources of alternative water supplies.

Gosford City Council has established two recycled water plants with a total capacity of 400 ML/yr. At this capacity, recycled water alone will not be able to meet the potential shortfall in supply. Stormwater harvesting is an option that can assist in meeting this potential shortfall.

The objective of this study is to estimate the quantity of stormwater that is available for supply as an alternative source of water, and to estimate the cost of developing this supply option.

5 Stormwater Quantity Estimation

As shown in Figure 2, the GLGA is divided into 138 sub-catchments based on topography. Each sub-catchment drains into a predetermined drainage point. The potential for stormwater harvesting in each sub-catchment can therefore be assessed independently based on economic, environmental, and social considerations.

Sub-catchments were grouped into three categories based on the density of development and the existing level of stormwater infrastructure. These categories were:

- Urban (sub-catchments with large percentage of development and considerable amount of stormwater infrastructure);
- Rural (sub-catchments with minimal to no development and no existing stormwater infrastructure); and
- Semi-urban (sub-catchments which fall in between the above two categories).

Table 4 summarises the number of sub-catchments under each one of the above three categories.

In this study, stormwater runoff volumes were estimated exclusively from the urban sub-catchments. The majority of urban sub-catchments are located in the South Eastern part of GLGA mainly comprising Gosford, Terrigal and Woy Woy areas. Commercially available modelling software, MUSIC v4,[7] was used to estimate the stormwater from each of the urban sub-catchments.

Rainfall and Evapo-transpiration data was obtained from the Australian Bureau of Meteorology.[6] The methodology is detailed further in Walter (4). The area of each sub-catchment was measured using Gosford City Council's GIS mapping system. The permeability of each sub-catchment was determined through analysis of aerial photography. Soil properties were categorised based on data used for a similar soil landscape at another Australian region.[4] Each sub-catchment was considered to be either upland, sandy, or lowland. Salient characteristics of each type are summarised in Table 5. Most of the sub-catchments fall under the sandy and lowland categories. The model input values are summarised in Table 6.

6 Rainfall Data Collection

Initial analysis indicated that there were 53 rainfall monitoring stations in and around GLGA. The following 3 specific criteria were used to select most appropriate rainfall stations, which can be

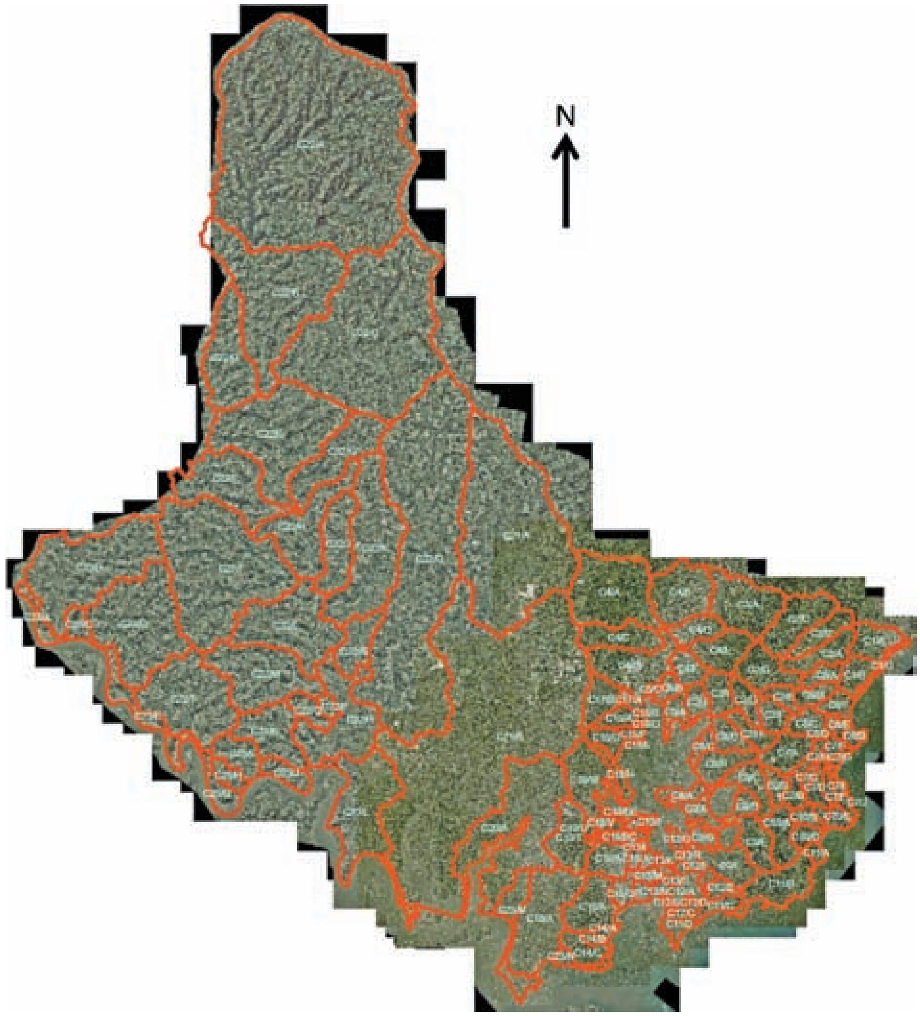

Figure 2: Gosford local government area and its sub-catchments.

Table 4: Number of sub-catchments under each category.

Type	Number of sub-catchments	Location within LGA
Urban	52	South-East
Rural	55	North-West
Semi-urban	31	Central

Table 5: Major categories of soil topography.

Soil category	Description
Upland	Soils of uplands acid crystalline tuffs on 1–4% slope or similar type.
Sandy	Soil types of beaches and ridges.
Lowland	Soil types not covered by the above two categories.

Table 6: Input values for MUSIC model.

	Soil topology		
Parameter*	Upland	Lowland	Sandy
Rainfall threshold, mm	1	1	1
Soil capacity, mm	200	250	250
Initial storage, %	30	30	5
Field capacity	80	100	100
Infiltration capacity coefficient, *a*	200	200	200
Infiltration capacity coefficient, *b*	1	1	1
Initial depth, mm	10	10	0
Daily recharge rate, %	0.5	4	25
Daily base flow rate, %	0.16	2	0
Deep seepage, %	2	0.4	0

*More details related to these parameters can be found in MUSIC Model Online Manual (8).

Table 7: Monitoring stations selected for rainfall data.

Station name	BOM station no	Completeness of data (%)	Years of operation	Year closed
Eloora Street, The Entrance	61074	92	67	Open
Golf Club, Wyong	61083	94	125	Open
Narara Research Station, Gosford	61087	94	94	Open
Dog Trap Road, Ourimbah	61093	99	57	Open
Lighthouse, Norah Head	61273	98	36	2005
Bowling Club, Avoca Beach	61294	99	40	Open
Everglades Country Club, Woy Woy	61294	99	46	Open
Bowling Club, Newport	66045	97	79	Open

used to estimate the runoff from each of the urban sub-catchments:

- contained greater than 30 years of data;
- station had not been closed on or before year 2000; and
- data set had completeness of more than 90% (that is less than 10% of the missing data).

Using the above criteria, the number of appropriate stations was reduced to 8 and these stations are listed in Table 7. The missing rainfall data for the given monitoring station was estimated using the Inverse Square Distance (ISD) method. Further information regarding the application of this method is detailed in Walter (4).

7 Results and Discussions

The stormwater quantities for each of the 52 urban sub-catchments were estimated using the MUSIC software. The volume of stormwater estimated to be produced from each sub-catchment is detailed in Walter (Walter, 2010). However, to facilitate discussions, the following parameters are presented in Table 8.

- Total Stormwater Runoff—which is the summation of all the stormwater quantities expected to be produced from all the sub-catchments.
- Average Stormwater Runoff—which is the average quantity of stormwater per sub-catchment and is calculated by dividing the total quantity of stormwater by the number of sub-catchments (=37383/52).
- Minimum—is the lowest modelled annual stormwater quantity produced by a sub-catchment.
- Maximum—is the highest modelled annual stormwater quantity produced by a sub-catchment.

Table 8: Summary of stormwater quantity produced by the sub-catchments.

Parameter	Quantity (ML/yr)
Total for all catchments	37,383
Average per catchment	719
Minimum	42
Maximum	5,616

As shown in Table 8, there is substantial quantity of stormwater generated from the urban sub-catchments, exceeding the shortfall estimated in Section 4. In order to meet the projected shortfall, it may be sufficient to harvest stormwater from 2 to 3 sub-catchments. In order to determine which sub-catchments are best suited for stormwater harvesting, a preliminary economic analysis model was established.

Economic analysis

Figure 3 shows a proposed stormwater harvesting system. The following cost functions were developed using Rawlinsons Australian Construction Handbook (9) and the data obtained through extensive research and experience:[4]

Storage cost:

$$C_s = (Y + L)V + 6.9Z\sqrt{V} + 1.2XV$$

Treatment cost:

$$C_T = AG + C_{UV}$$

Distribution system cost:

$$C_D = C_{pu} + 45(C_{xp} + C_p)P$$

Total capital cost (assuming 20% contingency):

$$C_{CC} = 1.2(C_s + C_T + C_D)$$

where,

C_{cc} = Total capital cost, \$
C_S = Cost of storage, \$
X = unit cost of excavation for underground storage, \$/m^3
Y = unit cost of the module, \$/m^3
Z = unit cost of the membrane, \$/m^2
L = unit cost of installation, \$/m^3
V = storage volume, m^3
C_T = cost of treatment, \$
A = catchment area, ha
G = average unit cost of GPT, \$/ha
C_{UV} = cost of the UV unit, \$
C_D = cost of distribution system, \$
C_{xp} = unit cost of excavation for laying pipeline, \$/m
C_p = unit cost of laying pipe, \$/m
C_{pu} = pump station cost (lumpsum), \$
P = population in the catchment, capita

The annual maintenance cost is assumed to be 2% of the total capital costs for the storage tank and treatment.

Table 9 presents the unit prices for the various components of stormwater harvesting system used in the current economic analysis.

Using the unit prices given in Table 9, the cost of harvesting stormwater for each sub-catchment was estimated. A sample of cost calculations is given in Table 10. As shown in the table, net present value (NPV) of both capital and operation and maintenance (O&M) costs have been calculated. For calculating the net present value of O&M costs, the following capitalisation equation was used:

$$P_w = \frac{A_n[(1+i)^n - 1]}{i(1+i)^n}$$

where

P_w = present worth of all the uniform future payments of A_n, \$;
A_n = uniform future annual payments, \$/yr;
i = discount rate, fraction; and
n = project period, yr.

The discount rate and the project period for computing the present worth were assumed to be 7% (0.07) and 50 years, respectively. The unit cost of water supply (\$/kL) is calculated by dividing the NPV with the total non-potable water supplied over 50 years. Figure 4 shows the variation of unit cost of stormwater with respect to the area of catchment. As displayed in Figure 4, the unit cost of supplying stormwater reduces with the increase

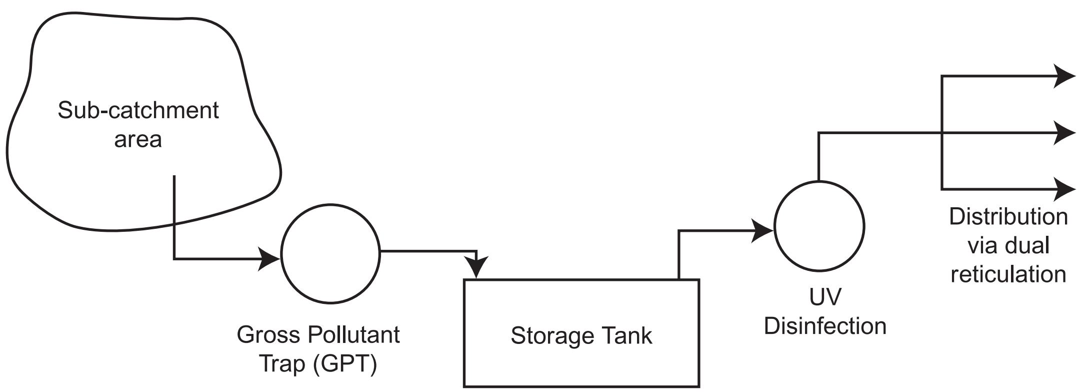

Figure 3: Proposed stormwater harvesting system.

Table 9: Unit prices (in 2010 Australian dollars).

Storage system cost		Distribution system cost		Treatment system cost	
Item	Cost (\$)	Item	Cost (\$)	Item	Cost (\$)
Excavation, m^{-3}	20.00	Excavation, m^{-1}	14.50	GPT, ha^{-1}	5,257.55
Module, m^{-3}	300.00	Pipework, m^{-1}	90.00	UV	5,000.00
Membrane, m^{-2}	25.00	Pump station	28,000.00		
Installation, m^{-3}	150.00				

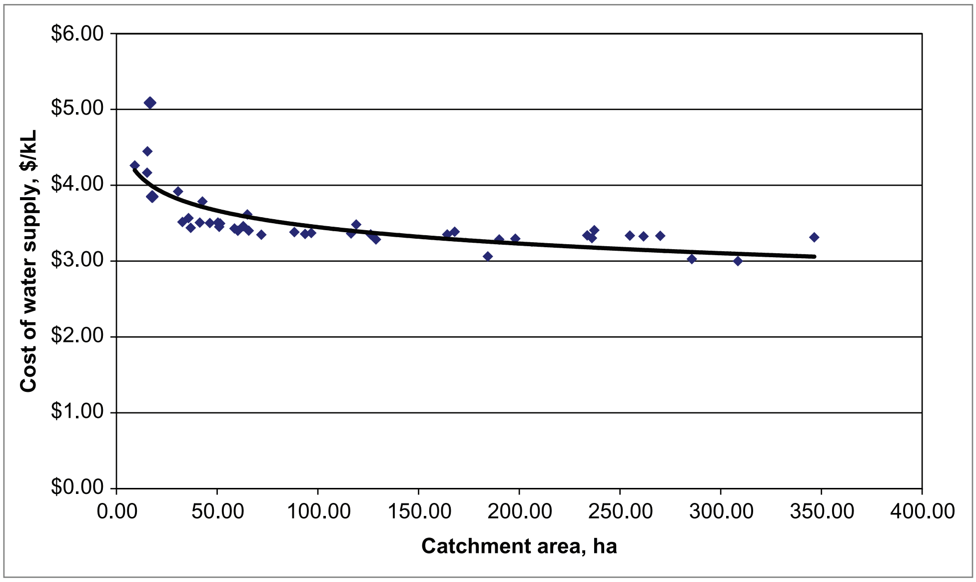

Figure 4: Unit cost of supplying stormwater for the case of Woy Woy catchment.

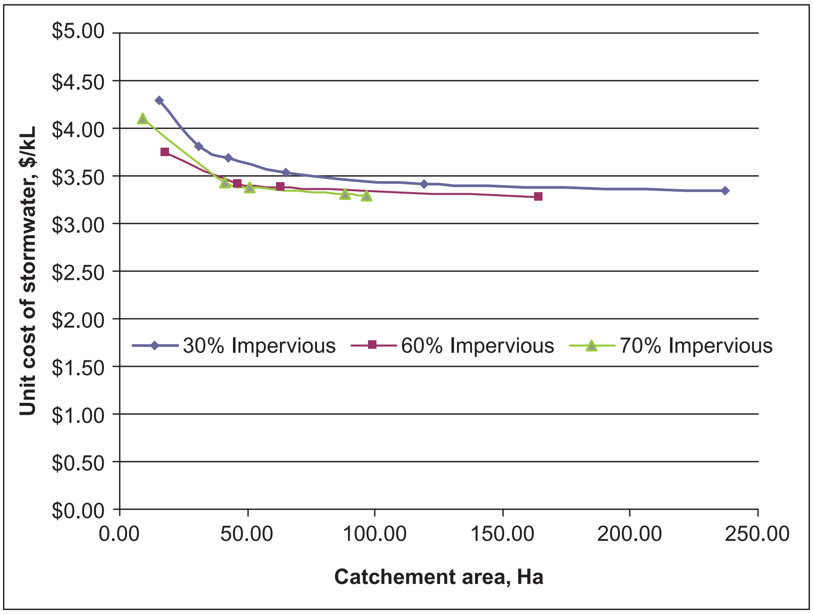

Figure 5: Variation of unit cost of supplying stormwater with respect to imperviousness for the case of Woy Woy catchments.

in the area of catchment. This is due to the unit capital cost of storage reduces with the increase in the area of catchment.

To investigate the effect of imperviousness on the unit cost of stormwater, several plots of unit cost vs catchment area were drawn for the Woy Woy catchments as displayed in Figure 5, which shows that higher the imperviousness of the catchment, lesser the unit cost of harvesting the stormwater.

These findings indicate that the larger urbanised catchments are the most suitable sites for stormwater harvesting projects. It should be noted that this cost analysis does not take into account the cost of land which is required to establish the stormwater harvesting project. As far as the land area required for establishing stormwater harvesting is concerned, the major component that requires large land area is the storage tank. Often, it is possible to construct a storage tank underneath

Table 10: Sample cost calculations (all costs are in 2010 Australian dollars).

Area (ha)	Population, capita	Average non-potable water demand, (kL/d)	Total storage size including 72 hr buffer storage (m^3)	Storage tank tost	Treatment cost	Distribution system cost	Total capital cost	Annual maintenance cost	Net present value (NPV)	Cost of water supplied over 50 years period ($/kL)
17.79	111	15	305	$147,749	$98,534	$549,447	$954,876	$4,926	$1,062,835	$3.85
65.03	405	55	966	$463,138	$346,922	$1,934,204	$3,293,116	$16,201	$3,648,210	$3.62
42.73	266	36	759	$364,475	$229,632	$1,280,318	$2,249,310	$11,882	$2,509,741	$3.79
51.05	318	43	580	$279,138	$273,408	$1,524,366	$2,492,294	$11,051	$2,734,506	$3.45
46.40	289	39	568	$273,476	$248,956	$1,388,049	$2,292,578	$10,449	$2,521,589	$3.50
63.00	393	54	741	$355,733	$336,225	$1,874,571	$3,079,835	$13,839	$3,383,159	$3.46
237.33	1479	202	2705	$1,291,125	$1,252,779	$6,984,332	$11,433,884	$50,878	$12,549,019	$3.41
119.10	742	101	1504	$719,387	$631,159	$3,518,817	$5,843,235	$27,011	$6,435,254	$3.48
88.38	551	75	925	$443,830	$469,657	$2,618,450	$4,238,325	$18,270	$4,638,758	$3.38
96.76	603	82	997	$477,861	$513,746	$2,864,246	$4,627,025	$19,832	$5,061,702	$3.37

a car park or road. Thereby, it is possible to incorporate the stormwater harvesting system within the existing infrastructure in the central business district area.

The unit cost of supplying stormwater varies between $3/kL and $5/kL, which is approximately 2 times the rate currently being paid by the customers for town water. On a purely economic basis, stormwater harvesting is therefore a relatively expensive option. However, factors including, improved water security, environmental benefits, energy conservation, and social benefits will enhance the viability of stormwater harvesting projects. In addition, the cost functions used in this study are the 'best estimates' based on the available data, further refinement of these cost functions will yield more realistic $/kL values for stormwater harvesting.

Though, this paper presents a case study particular to Gosford City, some of the findings may as well be applicable to any stormwater harvesting projects. Key findings that may be applicable to other locations are preference for large urbanised catchment area and the selection city centre for locating a stormwater harvesting project.

8 Conclusions

This paper presents the water balance over the next 50 years and identifies a possible shortfall in the water available for supply for Gosford Local Government Area (GLGA). A typical residence requires only about 36% of its supply of potable quality. Remaining 64% can be of non-potable quality, which can be potentially sourced either from stormwater or wastewater reuse schemes. In this paper, an economic analysis is carried out for supplying stormwater for non-potable purposes and thereby meeting the forecasted shortfall in 2050 under drought conditions.

The commercially available MUSIC model was used to estimate the volumes of stormwater runoff from the selected catchments. The analyses indicated that the cost as well as the storage required for stormwater would largely depend on the catchment area. The larger the catchment area, the lower is the unit cost of storage and hence the unit cost of supply. Catchment areas with greater levels of development also have a reduced unit cost of supply relative to less developed catchments. This is because of lesser unit cost for the distribution system for the relatively developed catchment areas. Therefore the results indicate that large urbanised catchment areas are the most appropriate candidates for stormwater harvesting projects.

The results obtained using the model indicated that the cost of supplying treated stormwater for non-potable purposes varied between $3/kL and $5/kL, which is significantly higher than the cost of the town water supply, which is approximately $1.90/kL. In depth analyses revealed that the major component of capital cost is attributed to the cost of distribution system. Therefore, in areas that are already serviced by dual reticulation, it is possible that the cost of supplying stormwater would be equal to or lower than that of the existing town water supply. In addition, further refinement of cost functions can lead to more realistic $/kL values for stormwater harvesting.

Finally, any assessment of the feasibility of stormwater harvesting should consider water security, environmental benefits, energy conservation, and social benefits, in addition to economic factors in the overall analysis.

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Disclaimer

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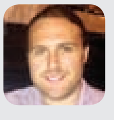

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