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Abstract

There is a need to re-configure current urban water systems to achieve the objective of sustainable water sensitive cities. Stormwater represents a valuable alternative urban water source to reduce pressure on fresh water resources, and to mitigate the environmental impact of urban stormwater runoff. The selection of suitable urban stormwater harvesting sites is generally based on the judgement of water planners, who are faced with the challenge of considering multiple technical and socio-economic factors that influence the site suitability. To address this challenge, the present study developed a robust GIS based screening methodology for identifying potentially suitable stormwater harvesting sites in urban areas as a first pass for subsequent more detailed investigation. The study initially evaluated suitability based on the match between harvestable runoff and demand through a concept of accumulated catchments. Drainage outlets of these accumulated catchments were considered as potential stormwater harvesting sites. These sites were screened and ranked under three screening parameters, namely demand, ratio of runoff to demand, and weighted demand distance. The methodology described in this paper was successfully applied to a case study in Melbourne, Australia, in collaboration with the local water utility. The methodology was effective in supporting the selection of priority sites for stormwater harvesting schemes, as it provided the basis to identify, short-list, and rank sites for further detailed investigation. The rapid identification of suitable sites for stormwater harvesting can assist planners in prioritising schemes in areas that will have the most impact on reducing potable water demand.

Keywords: Stormwater harvesting, Urban area, GIS, Suitable sites, Decision making

1. INTRODUCTION

Cities are faced with the need to diversify their water supply sources to cope with growing population driven demand, and uncertainty in the security of supply from water catchments due to recent droughts and the potential impacts of climate change (Goonrey et al., 2007; Lloyd et al., 2001). Also, current configurations of urban water systems are being questioned due to the accumulated pressures of demand for finite fresh water sources for all uses, regardless of quality requirements, and the environmental impact of the discharge of urban runoff to receiving waters. This has caused a re-evaluation of urban water management that reflects the need to move towards more sustainable configurations by integrating the planning and management of water supply, wastewater services and stormwater (Brown, 2005). Under this integrated urban water management concept the use of stormwater is considered a valuable resource, where it can be used on a fit for purpose basis to reduce demand for potable water and overcome current capacity constraints (Fletcher et al., 2008).

Mitchell et al. (2002) found that the community preferred stormwater over recycled wastewater. Stormwater harvesting and reuse involves the collection, storage, treatment and distribution of stormwater (Goonrey et al., 2009; Hatt et al., 2006). Internationally, the terms 'stormwater harvesting', 'rainwater harvesting' and 'water harvesting' have been used interchangeably, as they can convey a similar concept (Che-Ani et al., 2009; Hamdan, 2009; Sekar and Randhir, 2007). In the Australian context, rainwater harvesting is used to describe the collection of rainwater from roofs. All other runoff in urban areas, such as from roads, contributes to stormwater flows.

In cities, water planners are faced with the challenge of selecting appropriate stormwater harvesting sites that consider technical, social, economic and environmental aspects of suitability. Examples of stormwater harvesting sites in Australian cities can be found in public parks, and in newer Greenfield urban developments. The selection of these locations is often made on an opportunistic basis using the best judgment of water infrastructure planners. There is the need for a city wide screening tool that can identify sites potentially suited to stormwater water harvesting, including existing developments and new growth areas. Geographic Information System (GIS) have been recognised as a useful tool for supporting the identification of potential stormwater harvesting sites, as it has the capability for spatial analysis of multiple datasets representing bio-physical and anthropogenic factors (Malczewski, 2004; Mbilinyi et al., 2005). GIS enable the rapid screening of potentially suitable stormwater harvesting sites across a region, which is an inherently spatial problem.

There is extensive literature available on the use of GIS for the suitability assessment of stormwater harvesting sites in rural areas. In India, potential sites for water harvesting were identified applying the International Mission for Sustainability Developments guidelines within a GIS environment (Kumar et al., 2008; Singh et al., 2009). In South Africa, there are several studies where GIS based decision support systems were developed to locate suitable sites for water harvesting (De Winnaar et al., 2007; Kahinda et al., 2008; Kahinda et al., 2009; Mbilinyi et al., 2005). There are similar examples in other countries where GIS was used to consider stormwater harvesting potential in rural areas (Bakir and Xingnan, 2008; El-Awar et al., 2000; Hamdan et al., 2007; Kirzhner and Kadmon, 2011; Viavattene et al., 2008; Ziadat et al., 2012).

In cities, in addition to technical consideration such as the availability of storage spaces and proximity to existing drainage networks, the local social, institutional, environmental and economic factors often put further constraints on locating suitable stormwater harvesting sites. There have been few studies where GIS based stormwater harvesting systems have been proposed for urban areas. Chiu et al. (2009) proposed a GIS-based rainwater (roof water) harvesting design system in Taiwan where hydraulic simulation and economic feasibility were incorporated in a GIS to support urban water-energy conservation planning. Lee et al. (2007) proposed a GIS based methodology for demonstrating the benefits of water harvesting in Chiba city of Japan.

In summary, a review of the literature show there is a paucity of studies on the use of GIS based stormwater harvesting suitability assessment across a region. Furthermore, it was identified that there is no accepted methodology that integrates social, environmental and economic factors for assessing stormwater harvesting suitability across a city. To address these knowledge gaps, the present study was aimed at developing a GIS screening methodology for identifying stormwater harvesting sites in existing urban areas, which is presented in this paper. The methodology was then applied to a portion of the City of Melbourne (CoM) municipal area, in Australia for identifying and ranking suitable stormwater harvesting sites. It is hoped that the developed methodology will befit water professional engaged in integrated urban water management planning and stormwater harvesting across the globe.

2. Methodology

The methodology for GIS based screening tool of potential stormwater harvesting sites is described in the following four main steps, which can be applied to greenfield areas as well as existing urban areas.

2.1 Step 1- Evaluation of Suitability Criteria

Three tasks are involved in this step: a) Criteria identification for stormwater harvesting suitability, (b) Data acquisition and processing to create spatial maps for identified criteria, and c) Estimation of suitability indices.

In task (a), annual runoff and non-potable demand are considered as the suitability criteria, as they are the principal drivers for any stormwater harvesting scheme. It should be noted that social, economic and environmental considerations also play an important role in selecting overall suitable stormwater harvesting sites. However, suitability at the screening stage of planning process needs to consider first if there is a reasonable match between supply and demand before proceeding to more detailed assessment.

The runoff criterion considered runoff generated from impervious and pervious areas within the study region. The water demand is calculated from potential residential and non-residential water uses, such as irrigation of parks. .

The stormwater harvesting catchments can also be considered as the ‘accumulating catchments’ with their runoff and demand. The accumulated catchment concept is explained using Figure 1. For example in Figure 1, catchments *a* and *b* are upstream catchments which drain at *outlet-1* and *outlet-2* respectively. The catchment *c* which drains at *outlet-3* is an accumulated catchment, consisting of catchments *a* and *b* with an additional drainage area of *c*.

< Figure 1 can be here >

From stormwater harvesting perspective, it is essential to understand the behaviour of the catchment with respect to stormwater flows and respective water demands. The accumulated catchment concept is therefore important, as the decision maker has the preference of implementing stormwater harvesting schemes in various single or accumulated catchments depending on the catchment specific quantity of runoff and the nature of demand. Therefore, this study assesses runoff and demand through accumulated catchments. The drainage outlets of accumulated catchments can be considered as potential stormwater harvesting sites where stormwater can be captured and infrastructure can be built.

In Task (b) spatial maps are generated for runoff, demand and accumulated catchments, which requires the collection of data such as rainfall, water demands, impervious-pervious area, digital elevation model (DEM), and digital cadastre. For the GIS based screening tool, an annual time scale for estimating runoff was chosen for both stormwater runoff and demand, as the tool only dealt with preliminary evaluation and ranking of potential stormwater harvesting sites. Thus, the current methodology is designed for a quick and simple investigation of stormwater harvesting suitability across a city. However, detailed analysis using a daily or sub-daily time step for estimating runoff and demand, can be undertaken for few highly suitable sites identified through the screening methodology as outlined in this paper. The simple rational method as suggested by Schueler (1987) can be used to generate the runoff map for screening purposes. Thus, yearly rainfall and an impervious-pervious area map should be used to compute yearly runoff. The runoff coefficient map can be generated from the impervious-pervious area map.

For generating demand maps, a combination of the data of annual demands (spatial point format) and landuse such as park, industrial or household area (polygon) can be used for desired usage of stormwater reuse. In task (c), spatial maps of runoff and demands are overlayed on the accumulated catchments. The accumulated catchments can be derived from individual catchment layer obtained from delineation of DEM. Each drainage outlet of these accumulated catchments represents a potential site for stormwater harvesting having attributes of runoff and demand.

2.2 Step 2 - Estimation of Environmental Flows

Environmental flows are the flow regimes necessary to maintain or improve the natural ecological health of urban waterways. Stormwater harvesting has the potential to mitigate a number of harmful impacts of urban development on the flow regime, including the reduction of peak flows, and the reduction in the number of stormwater flow events, and therefore could enhance urban stream health while meeting potable water conservation requirements (Mitchell et al., 2007). These environmental benefits from stormwater harvesting can be achieved by reducing runoff volumes to predevelopment levels (NRMMC et al., 2009).

Therefore, in this step, pre-development flows are assumed to be the flows which should be released to the rivers and streams before implementing the stormwater harvesting scheme. The pre-development runoff can be estimated assuming the catchment as 100% pervious, simulating land cover conditions prior to urban development. This pervious runoff is deducted from the total runoff estimated for each accumulated catchment in Step-1. The resultant runoff is termed as ‘harvestable runoff’, which is used in later steps.

2.3 Step 3 - Evaluation of Screening Parameters

In this step, three screening parameters are identified for screening and ranking of potential stormwater harvesting sites: demand, ratio of runoff to demand and weighted demand distance. All the catchments with harvestable runoff and demands in previous steps are used in the estimation of these screening parameters. The estimation of the values of the screening parameters is conducted through a ‘radius of influence’ concept (Figure 2).

2.3.1 Radius of Influence concept

The harvestable runoff corresponds to an accumulated runoff at the catchment outlet (which is also considered as a potential harvesting site). From the accumulated catchment perspective, runoff at the catchment outlet can be utilized for meeting upstream catchment demands. However, there is the need to consider the distance from the harvesting point (outlet) to the point of demand. Furthermore, there is a possibility that demand locations within adjoining catchments, can be at close to the outlet of the accumulated catchment under consideration. Therefore, the matching of supply from the harvesting site with areas of demand is handled through the "radius of influence concept" in this methodology.

The physical distance between the stormwater harvesting site and the demand areas is critical for considering the economic feasibility of a stormwater scheme as it determines infrastructure requirements for distribution and associated costs. For example, in Figure 2, runoff in the *catchment-b* is draining at *outlet-2* which is intersecting a demand location. Thus, the *outlet-2* is an ideal potential stormwater harvesting site as the catchment outlet and demand is co-located. However, as the distance to demand locations within *catchment-b* increases from *outlet-2* the costs to service this demand increases. Thus, with the radius of influence concept, the supply of proximal water demands areas to a stormwater harvesting site are preferred.

<Figure 2 can be here>

In Figure 2, the radius of influence is shown at four different levels as *0 m*, *300 m, 500 m*, and *1000 m* from the *outlet-1* for demonstration purposes. These radii of influence levels can be altered depending upon the site specific characteristics such as slope that may influence the distance it would be considered feasible to supply a demand point due to pumping requirements.

2.3.2 Estimation of Screening Parameters

The screening parameters considered important in screening the suitability of harvesting sites were: a) demand, b) ratio of runoff to demand, and c) weighted demand distance. *Demand* is the total demand from the selected end usages within the radius of influence of a stormwater harvesting site. This parameter can identify sites of high demand that should be given higher priority when planning stormwater harvesting schemes to maximise the substitution of potable water demand. Moreover, a stormwater harvesting scheme satisfying relatively small demand may not be cost effective due to the significant capital investment required, particularly in existing urban environments, where retrofitting infrastructure is expensive. The screening parameter *ratio of runoff to demand* assesses the match between harvestable runoff and the associated demand. The *weighted demand distance* refers to the average weighted distance of demand areas from the given site. This gives preferences to sites close to high demand areas to minimise transport and water infrastructure costs.

2.4 Step 4 - Ranking and Validation

The potential stormwater harvesting options are then ranked. Thresholds can then be defined for screening parameters to eliminate the sites where stormwater is not feasible and shortlist potentially feasible sites on the basis the match between harvestable runoff and demand, and weighted demand distances. Sites are ranked according to the highest demand, highest ratio of runoff to demand and lowest weighted demand distance. The user can determine the relative importance of the three parameters in developing the ranking of potential stormwater harvesting sites. The most highly ranked sites can be considered for validation with the stakeholders who have a strong local knowledge of stormwater harvesting potential.

Validation is an essential component of the methodology development, as the stakeholders will provide valuable contextual insight into the feasibility of harvesting stormwater at the ranked sites based on their local knowledge of existing drainage infrastructure, soil and terrain characteristics, local water bodies, and open spaces. This local knowledge can assist in refining the ranking of potentially suitable stormwater harvesting sites. They are also likely to be aware of planning and regulatory issues associated with stormwater harvesting at particular sites. Thus, the validation process assists in confirming and refining the ranking of potentially suitable stormwater harvesting sites identified from the GIS based screening tool. Top ranked sites can then be considered for detailed assessment.

3. STUDY AREA

The study area, shown in Figure-3, selected is part of the City of Melbourne (CoM), where City West Water is responsible for providing water and wastewater services.

< Figure 3 can be here>

The study area of 26 km^2 includes the central business district of Melbourne so is predominantly made up of commercial land uses. Other land uses include public parks, residential and industrial. The total non-residential water demand for the study area in the year 2010 was estimated as 11 GL. Commercial customers are responsible for 82% of the total non-residential demand. The next highest non-residential demand results from the irrigation of parks and open spaces accounting for 6% (of total non residential demand). Irrigation demand is largely supplied by mains potable water, and is impacted by water restrictions. Therefore, irrigation of parks is suited to stormwater harvesting schemes as the required water quality can be met without treatment.

The application of the stormwater harvesting methodology on the case study is described in the following section.

4. APPLICATION OF THE METHODOLOGY

4.1 Evaluation of Suitability Criteria

As highlighted in section 2.1 of methodology, GIS maps were developed for the suitability criteria of runoff and demand. The accumulated catchment map was also generated for the study area with its drainage network information. Drainage outlets of these catchments were considered as potential stormwater harvesting sites. The detailed procedure used in evaluating the suitability criteria is documented below

4.1.1 Data Acquisition and Processing

The raw datasets collected from a range of agencies included: impervious area map, landuse map, study area boundaries, council boundaries, customer demand map, and Digital Elevation Model

(DEM). Table 1 shows some details of these datasets. All raw datasets were processed into the runoff layer, the demand layer and the catchment layer using Arc GIS version 9.3, Spatial Analyst tools and Arc Hydro tools.

< Table 1 can be here>

4.1.2 Runoff Layer

The drought period of 1997-2009 in Melbourne was considered in developing the runoff layer as this provided a conservative estimate of harvestable runoff. While any length of rainfall data can be used it is recommended to use at least ten years to capture annual rainfall variability. The runoff layer was generated in raster grid format of cell size 30m X 30m. The selected fine resolution was based on the trade-off between spatial scale of rainfall and impervious-pervious area (parcels) map. At a lower (larger cell size) resolution, the information of pervious-impervious areas may be lost, although rainfall data is not as spatially variable.

An interpolated rainfall map was prepared from point source rainfall data, with the average annual rainfall for the period of 1997-2009 used. This data was interpolated to represent rainfall at a 30m X 30m resolution using the Inverse Distance Weighting (IDW) method in Arc GIS 9.3.. The impervious-pervious area map classified land uses into either impervious (e.g., roads) or pervious (e.g. parks). This map was used to generate the runoff coefficient map where values 0.9 and 0.1 were used as runoff coefficients for impervious and pervious areas respectively (Argue and Allen, 2005) The runoff coefficient map and the impervious-pervious map were combined with the rainfall map using the 'Raster Calculator' in ArcGIS to compute the spatial distribution of annual runoff.

4.1.3 Demand Layer

In this study the stormwater reuse was limited to parks irrigation demands. The most recent park water demand was used, which was the year 2010 where the demand was 0.65 GL. CWW provided a park water demands with their spatial locations in shape file format (point). These demand points were intersected with the park landuse map to allocate demand to the appropriate park. The demand points in each park were summed to represent the total demand the park area (ML/m^2).

4.1.4 GIS Layers for Accumulated Catchments

Using Arc Hydro tools, a DEM of 10 metre resolution was processed to delineate the catchments in the study area, resulting into 95 individual catchments. The accumulated catchment layer was then generated using the 'Accumulate Shape' function of Arc Hydro, resulting in 88 accumulated catchments. This accumulated catchment layer was further used in the study to generate the drainage network and drainage outlets. Figure 4 shows the generated accumulated catchments together with their drainage network and outlets and parks.

<Figure 4 can be here>

The raster runoff layer was overlayed and aggregated with the accumulated catchment layer to compute the total catchment runoff as the mean annual flow, within the each of the 88 catchments. The total volume of mean annual runoff generated by all the study area catchments was 6.7 GL. This figure was found to correlate reasonably with a study carried out by the CoM in 2008 which indicated that mean runoff was around 13 GL in a base year 2000 from an area of 36 km^2 (CoM, 2011). The 6.7 GL figure represents the mean annual runoff from the portion of the CoM (i.e. study area) within the CWW boundary of 26 km^2 in the drought period of 1997-2009. Furthermore, the mean rainfall in year 2000 (629 mm) was above the mean rainfall over the period 1997-2009 (514 mm) across the study area.

4.2 Estimation of Environmental Flows

This study estimated pre-development flows to derive the flow needed to maintain environmental health of waterways. The pre-developed flow was computed for all accumulated catchments using the rational formula. To estimate the pre-developed flows all surfaces in the catchment were considered pervious, as pervious catchments reflected pre-development landuse. The runoff coefficient for the pervious areas was assumed as 0.1 as explained in section 4.1.2. The total pre-developed flow was estimated as 4.3 GL and by subtracting this from the total runoff the harvestable runoff was estimated as 2.4 GL. Harvestable runoff from each of accumulated catchments was used in the analysis of screening of stormwater harvesting sites in later assessment steps.

4.3 Evaluation of Screening Parameters

Screening parameters of demand, ratio of runoff to demand and weighted distance were calculated for all 88 stormwater harvesting sites generated from the accumulated catchments. They were computed for different radii of influence (i.e. *a = 0 m, b = 300 m, c = 500 m* and *d =1000 m* from each of these sites as described in Figure 2) for this study. However, the designer can select suitable radii of influences based on their local conditions. Table 2 shows the screening parameters for a sample site (ID-22).

<Table 2 can be here >

As the site listed in Table 2 did not intersect with any of the parks, radius of influence 0 m (a) was not applicable in this case. From Table 2, it is clear that with an increase in radius of influence, demand also increased as more demands were aggregated (with increased distance). The ratio of runoff to demand also decreased with the increase in the demand for the same amount of runoff. The nearest park for this site was at 48 m distance.

Theoretically, four options were possible for four levels of radii of influence at each site. However, in reality, there will not be a demand within each radius of influence. Thus, the analysis generated total 97 potential stormwater harvesting options based on various radii of influence considered from 88 accumulated catchments.

4.4 Refinement and Ranking of Stormwater Harvesting Options

The ranking of the options was carried out in two steps. Step (a) involved introducing a set of thresholds to the screening parameters to refine the stormwater harvesting. CWW stormwater professionals were consulted in developing the following thresholds for technical feasibility: demands greater than or equal to 5 ML, weighted demand distance less than or equal to 300 m, and ratio of runoff to demand greater than 1.

In step (b), short listed options were ranked based on screening parameters to identify the sites with highest demand, or highest ratio of runoff to demand or lowest weighted demand distance. This two-step ranking approach provided a combined set of stormwater harvesting sites with high demand, high ratio of runoff to demand and less weighted distance.

All thresholds of screening parameters identified in step (a) were applied to all 97 options. The analysis resulted in 33 potential short-listed options which are shown in Table 3. These options are ordered according to their site identification (ID) number.

<Table 3 can be here>

Among these 33 options, the demands of the sites ranged from 5 ML to 126 ML, the ratios of runoff to demand from 1.3 to 65.1, and the weighted distances from 0 to 300 m. Table 3 further shows the number of parks whose demands were considered in this study, within the corresponding radii of influence. Also, in Table 3, all drainage locations (i.e. stormwater harvesting sites) have been represented by the nearest park available from the sites.

4.4.1 Ranking Based on High Demand

The top 10 stormwater harvesting options ranked according to high demand are listed in Table 4. It should be noted that *a, b, c* and *d* in Table 4 represent the radius of influence levels at distances 0 m, 300 m, 500 m and 1000 m respectively. The Royal Park (option *14b*) was ranked high as it had the largest water demand from the golf course, zoo and several playgrounds. Drainage outlets of options *17d*, *29d*, *41d*, *29c*, *41c*, *20a* and *29a* were closely located near JJ Holland Reserve making the JJ Holland Reserve another preferable site for stormwater harvesting (Figure 4). Stormwater harvesting options *29c* and *41c* had the same amount of demand under 300 m radius of influence level. A higher ranking was given to the site with higher amount of ratio of runoff to demand (option *29c* with ratio 4.6 here).

<Table 4 can be here>

4.4.2 Ranking Based on High Ratio of Runoff to Demand

Ranking of the top 10 options on the basis of ratio of runoff to demand are shown in Table 5. The Batman Park was highly ranked stormwater harvesting site (option *69b*), as it had the highest ratio of runoff to demand. The large runoff volume generated at this site was due to the highly impervious catchment. The Clayton Reserve was ranked second with multiple closely spaced drainage outlets with options *44b, 44c, 43b, 43c, 28)*. The Victoria Parade Plantation (option *52a*) was also a preferable stormwater harvesting site, as it required minimum infrastructure costs at 0 m weighted demand distance.

<Table 5 can be here>

4.4.3 Ranking Based on Less Weighted Demand Distance

Table 6 shows the top 10 options ranked on basis of the weighted demand distance. From Table 6, it is evident that 9 out of the top 10 options had 0 m weighted demand distance, as the corresponding drainage outlets were intersected with respective parks. Among these options, J J Holland Park (*29a*) and Birrarung Marr Park *(76a*) are preferable choices as they also represent parks with high demands in Table 5. Furthermore, the Victoria Parade Plantation *(52a)* from Table 6 was also highly ranked based on the ratio of runoff to demand. Such commonly ranked sites under different screening parameters provided confidence to the stormwater harvesting decision making.

<Table 6 can be here>

4.5 Validation

The validation procedure finalised the best stormwater harvesting sites from the 33 options obtained from the GIS screening. The CWW officers were consulted to confirm the overall suitability of highly ranked stormwater harvesting sites based on their experience/local knowledge and previous investigations conducted by them for stormwater harvesting sites.

During validation, the suitability of the Royal Park (highest demand site) for stormwater harvesting was confirmed as there was already a stormwater harvesting scheme in operation. However, CWW officers identified other parks such as JJ Holland Reserve, Princess Park, Batman Park, Birrarung Marr Park, Ieveres Reserve, and Clayton Reserve were as potentially suitable sites, regardless of their ranking in respective categories (Figure 4). For these parks, CWW had already given consideration for developing the potential stormwater harvesting schemes.

Although Victoria Parade Plantation was a highly ranked site in terms of high ratio of runoff to demand and less weighted demand distance, it was not considered suitable by the CWW because of its relatively low demand. Furthermore, the decision maker's selection of threshold values would significantly influence the final short-listing of suitable stormwater harvesting sites. The tool will enable the decision makers to investigate outcomes of various threshold values quickly. Validation of ranking results provided a greater degree of confidence to the CWW to investigate the high ranked sites for more detailed investigation. This study also provided flexibility of prioritizing the potential stormwater harvesting sites based on either high demand, high ratio of runoff to demand or less weighted demand distance.

5. SUMMARY AND CONCLUSIONS

Stormwater harvesting has been emerging as a popular sustainable alternative water resource to meet non potable demands compared to other alternative water resources. The selection of suitable stormwater harvesting sites is essential and equally challenging for the urban water infrastructure planners. Currently, the selection of these sites is achieved by the best judgment of water infrastructure planners, which can be very subjective. Therefore, the present research was focussed on developing a robust methodology for evaluating and ranking suitable stormwater harvesting sites using GIS. The study used runoff and open space demand as suitability criteria and also utilized the concept of 'accumulated catchments' to evaluate the suitability of stormwater harvesting sites.

The GIS based screening tool methodology described in this paper was effective in terms of identifying, short-listing, and ranking of potential suitable stormwater harvesting sites in a portion of the City of Melbourne municipality. The proposed methodology evaluated stormwater harvesting sites from demand, supply and infrastructure perspectives. The suitable sites obtained from the study were in good agreement with the City West Water officers' judgement based on their knowledge of the potential stormwater harvesting schemes in the study area.

The proposed methodology has successfully demonstrated the capacity of screening potential stormwater harvesting sites and the benefits of such tool for water professionals. Currently, detailed conceptual designs are being developed for the highly ranked screened sites for life cycle costing for further assessment. In next phase of this research, these stormwater harvesting sites will be evaluated with respect to social, environmental and economic perspectives using a multi criteria decision framework. Such evaluation will ensure more informed decision making on site selection for stormwater harvesting.

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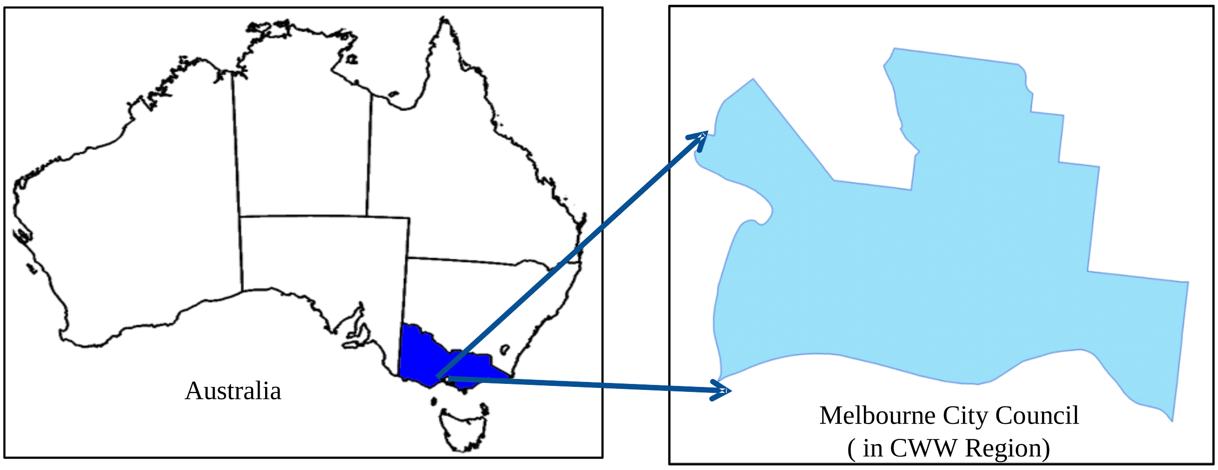

Figure 1: Study Area

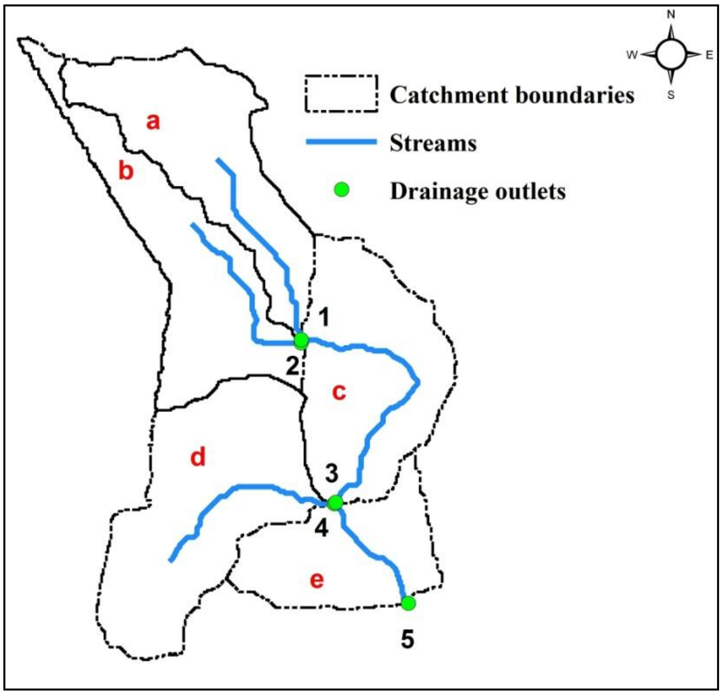

Figure 2: Accumulated Catchments

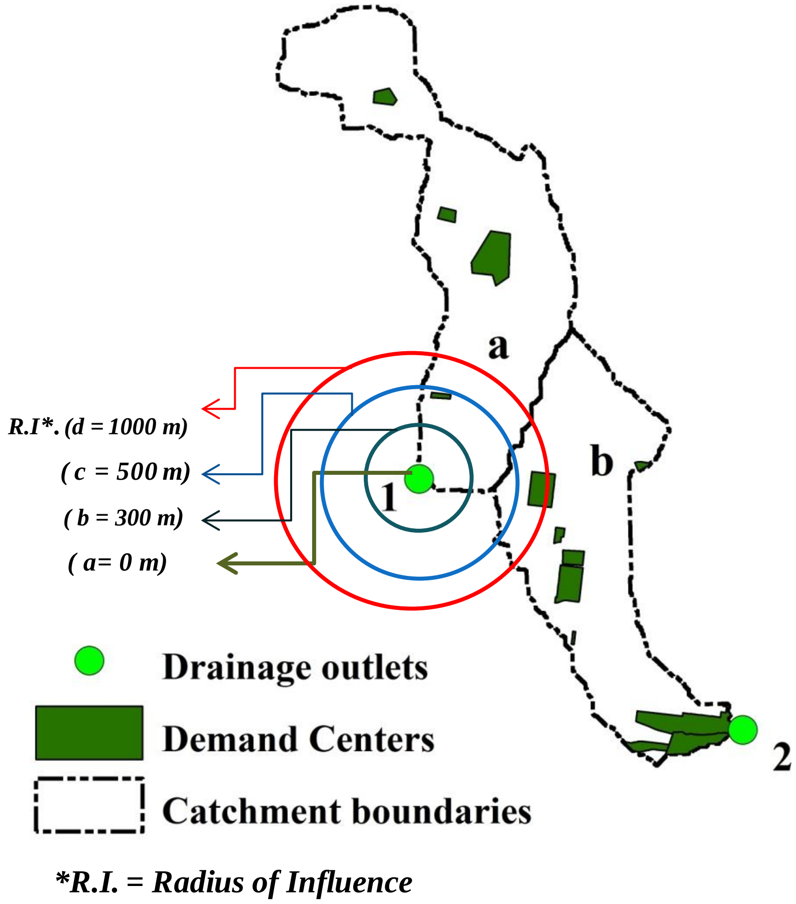

Figure 3: Radius of Influence concept

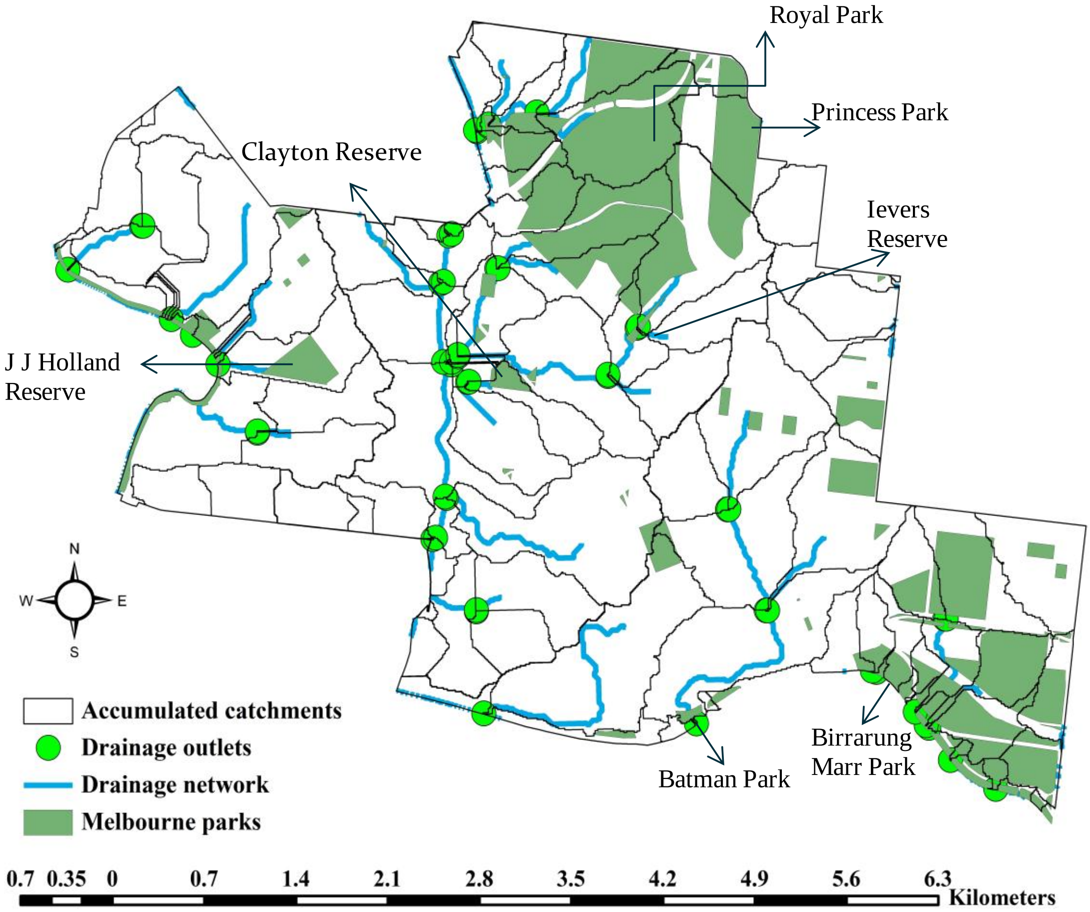

Figure 4: Accumulated catchments with drainage networks and parks

List of Tables

Table 1: Data description

Data	Source	Format	Scale
Rainfall data	SILO	Text	1:300,000
Impervious area map	Melbourne Water	Vector (Polygons)	1:50,000
Customer demands	CWW	Vector (Point)	1:50,000
Study area	CWW	Vector (Polygon)	1:300,000 (CWW) 1:50,000 (CoM)
Planning zone map (Landuse)	CWW	Vector (Polygon)	1:50,000
DEM (10 m)	Land Victoria	Raster (ESRI grid)	1:60,000

Table 2: Estimation of screening parameters

Site ID	Radius of influence (m)	Harvestable runoff (ML)	Demand (ML)	Ratio of runoff to demand	Weighted distance (m)
22	300 (b)	3.28	0.25	13.1	48
	500 (c)		1.91	1.7	390
	1000 (d)		7.02	0.5	596

Table 3: List of sites for stormwater harvesting

(Demand > =5 ML, Ratio of runoff to demand > 1, and Weighted demand distance < =300)

Site ID	Possible Options	Harvestable Runoff (ML)	Demand (ML)	Ratio of runoff to demand	Weighted distance (m)	No of parks	Park location
9	9b	38.6	28.67	1.3	0	1	Princes Park, Royal Parade
12	12b	228.41	15.88	14.4	210	1	Royal Park South
14	14b	229.39	125.60	1.8	182	2	Royal Park South
17	17a	69.4	23.14	3.0	0	1	J J Holland Park
	17d		53.79	1.3	112	7	
20	20a	64.53	23.14	2.8	0	1	J J Holland Park
26	26b	50.3	19.35	2.6	87	3	Ievers Reserve, Flemington Road
28	28b	97.34	6.18	15.8	243	3	Clayton Reserve
29	29a	133.05	23.14	5.8	0	1	J J Holland Park
	29c		28.92	4.6	80	4	
	29d		31.65	4.2	136	8	
39	39b	31.91	19.35	1.6	87	3	Ievers Reserve, Flemington Road
41	41a	67.7	23.14	2.9	0	1	J J Holland Park
	41c		28.92	2.3	67	4	
	41d		30.65	2.2	103	7	
43	43b	181.52	5.82	31.2	277	2	Clayton Reserve
	43c		6.18	29.4	283	3	
44	44b	402.39	6.18	65.2	250	3	Clayton Reserve
	44c		6.43	62.6	255	4	
46	46b	104.68	5.82	18.0	182	2	North Melbourne Cricket Ground
	46c		6.84	15.3	217	6	
	46d		7.47	14.0	256	7	
47	47b	72.04	5.82	12.4	182	2	Clayton Reserve
	47c		6.84	10.5	218	5	
	47d		7.47	9.6	256	7	
52	52a	116.5	5.33	21.9	0	1	Victoria Parade Plantation
	52b		13.70	8.5	134	3	
69	69b	948.22	11.62	81.6	175	2	Batman Park, Spencer Street
76	76a	62.65	5.30	11.8	0	1	Birrarung Marr Park, Batman Avenue
	76b		49.07	1.3	300	1	
77	77a	17.18	5.30	3.2	0	1	Birrarung Marr Park, Batman Avenue
78	78a	19.36	5.30	3.7	0	1	Birrarung Marr Park, Batman Avenue
	78b		13.07	1.5	70	2	

Table 4: Ranking based on demand

Site ID	Harvestable runoff (ML)	Demand (ML)	Ratio of runoff to demand	Weighted distance (m)	No of parks	Park location
14b	229.39	125.60	1.8	138	2	Royal Park
17d	69.40	53.79	1.3	112	7	J J Holland Park
76b	62.65	49.07	1.3	300	1	Birrarung Marr Park, Batman Avenue
29d	133.05	31.65	4.2	136	8	J J Holland Park
41d	67.70	30.65	2.2	103	7	J J Holland Park
29c	133.05	28.92	4.6	80	4	J J Holland Park
41c	67.70	28.92	2.3	67	4	J J Holland Park
9b	38.60	28.67	1.3	0	1	Princes Park, Royal Parade
20a	64.53	23.14	2.8	0	1	J J Holland Park
29a	133.05	23.14	5.8	0	1	J J Holland Park

Table 5: Ranking based on ratio of runoff to demand

Site ID	Harvestable runoff (ML)	Demand (ML)	Ratio of runoff to demand	Weighted distance (m)	No of parks	Park location
69b	948.22	11.62	81.6	175	2	Batman Park, Spencer Street
44b	402.39	6.18	65.2	250	3	Clayton Reserve
44c	402.39	6.43	62.6	255	4	Clayton Reserve
43b	181.52	5.82	31.2	277	2	Clayton Reserve
43c	181.52	6.18	29.4	283	3	Clayton Reserve
52a	116.50	5.33	21.9	0	1	Victoria Parade Plantation
46b	104.68	5.82	18.0	182	2	North Melbourne Cricket Ground
28b	97.34	6.18	15.8	243	3	Clayton Reserve
46c	104.68	6.84	15.3	217	6	North Melbourne Cricket Ground
46d	104.68	7.47	14.0	256	7	North Melbourne Cricket Ground

Table 6: Ranking based on weighted demand distance

Site ID	Harvestable runoff (ML)	Demand (ML)	Ratio of runoff to demand	Weighted distance (m)	No of parks	Park location
52a	116.5	5.33	21.9	**0**	1	Victoria Parade Plantation
76a	62.65	5.30	11.8	**0**	1	Birrarung Marr Park, Batman Avenue
29a	133.05	23.14	5.8	**0**	1	J J Holland Park
78a	19.36	5.30	3.7	**0**	1	Birrarung Marr Park, Batman Avenue
77a	17.18	5.30	3.2	**0**	1	Birrarung Marr Park, Batman Avenue
17a	69.40	23.14	3.0	**0**	1	J J Holland Park
41a	67.70	23.14	2.9	**0**	1	J J Holland Park

20a	64.53	23.14	2.8	**0**	1	J J Holland Park
9b	38.60	28.67	1.3	**0**	1	Princes Park, Royal Parade
41c	67.7	28.92	2.3	**67**	4	J J Holland Park