Stormwater harvesting infrastructure systems design for urban park irrigation: Brimbank Park, Melbourne case study

Jake Kyle Day and Ashok K Sharma

ABSTRACT

Stormwater harvesting for residential and non-residential reuse is an important and crucial aspect to reduce freshwater demand to address climate change, population growth and urbanisation challenges. It is important that freshwater be conserved as much as possible through capturing rainwater and stormwater and using these resources for fit for purpose end uses such as irrigation of public open parks and residential non-potable end uses. The paper describes a methodology for the planning and design of a stormwater harvesting system for park irrigation. The application of suitable models for storage tank capacity and pipe sizing considering peak flows are described. The application of the approach is demonstrated with a local case study for the benefit of wider water professionals engaged in water-sensitive urban design.

Key words | irrigation, reuse, storage, stormwater harvesting, treatment

Jake Kyle Day
College of Engineering and Science,
Victoria University,
Melbourne,
Australia

Ashok K Sharma (corresponding author)
Institute of Sustainable Industries and Liveable Cities, Victoria University,
Melbourne,
Australia
E-mail: *ashok.sharma@vu.edu.au*

HIGHLIGHTS

- Stormwater harvesting system design for park irrigation.
- Water Sensitive Urban Design approaches for stormwater quality management.
- Economic design of stormwater collection pipes.
- Selection of storage capacity based on volumetric reliability considerations.

INTRODUCTION

Integrated Urban Water Management (IUWM) concepts consider stormwater and wastewater as resources and not a waste. These resources can provide support in reducing the load on freshwater resources based on fit for purpose applications. Stormwater harvesting is of significant importance when thinking about our future, with freshwater water availability a constant concern for many due to climate change, urbanisation and population growth challenges. Rain and its associated stormwater runoff being a natural water source, means it offers the potential to mitigate shortage of freshwater vital for human and ecosystem needs. Stormwater harvesting has significant potential as an alternative water supply as it is relatively in abundance, often available close to urban demands, can improve water security and increase resilience to climate change in urban areas and, if not harvested, can cause environmental harm (Hoban *et al.* 2015; Fisher-Jeffes *et al.* 2017). Water-sensitive urban design (WSUD) approaches incorporate stormwater harvesting, which can deliver multiple benefits including water supply, flood control, landscape amenity, healthy living environment and ecosystem health improvement of urban waterways (Sharma *et al.* 2019). WSUD concepts emerged across the globe with different nomenclature and drivers (Fletcher *et al.* 2015; Radcliffe 2019). With proper planning, design, execution and management of stormwater harvesting schemes, freshwater use can be dramatically

doi: 10.2166/aqua.2020.047

reduced. Harvesting stormwater also provides the opportunity to irrigate more public open spaces regularly, therefore creating beautiful green spaces for people to indulge in and enjoy. Thus, public open green spaces support a community's mental and physical well-being through providing a desirable space for social interaction. It is also important for WSUD approaches to be considered when planning stormwater harvesting systems so that environmental impacts of urbanisation are reduced in regards to demand for water and the potential pollution threat to waterways. Various drivers are reported in the literature, including the need for better management of stormwater flows, improvement in water quality, reducing mains water consumption, reduction in financial costs and protection of local ecosystems or improving landscape amenities (Sharma *et al.* 2016; Fisher-Jeffes *et al.* 2017).

Stormwater that is harvested has many non-potable end uses, including irrigation for public open spaces and playing fields, garden watering, toilet flushing, laundry supply, hot water supply, firefighting, groundwater recharge and environmental applications (Hatt *et al.* 2004; Philp *et al.* 2008; Hamlyn-Harris *et al.* 2019). These potential uses of harvested stormwater can lead to an opportunity to save vast amounts of water from freshwater supplies.

Hamlyn-Harris *et al.* (2019) further indicated that the technical feasibility and stormwater harvesting potential of a scheme is generally affected by a range of factors including: catchment area, its characteristics and nature; amount of rainfall and temporal distribution; capacity to divert runoff to a storage during storm events; nature of storage; environmental flow requirements for water ways; harvested water demand in the area; and need for water quality requirements. Thus, it is clear that a detailed investigation is required for planning and developing stormwater harvesting schemes.

The main aim of stormwater harvesting is to capture the maximum amount of stormwater during rainfall and runoff events so that it is available for use when needed. Therefore, storage is a crucial factor in any stormwater harvesting system. There are various options for stormwater storage which can be grouped as follows: natural surface storages, disused quarries, man-made lagoons, tanks, cellular systems and aquifers (Philp *et al.* 2008; Hamlyn-Harris *et al.* 2019).

Stormwater requires appropriate treatment before use. Philp *et al.* (2008) indicated that the level of treatment required is largely determined by both the catchment properties and the intended end use. Lindsey *et al.* (1992) suggested that stormwater best management practices must be properly adhered to regarding maintenance in order to achieve design objectives. One of the most widely desired end uses of harvested stormwater is for irrigation purposes (Philp *et al.* 2008). The application of harvested stormwater for irrigation purposes at parklands, open spaces and sports fields means that the urban spaces can maintain a healthy and green environment, which has many benefits. Such benefits include better mental and physical health of the community derived from the enhanced urban green spaces, increased value of homes, amenity values, freshwater savings and preservation of flora and fauna and more (Fam *et al.* 2008).

It can be concluded that stormwater harvesting for irrigation of urban green spaces is beneficial, not only environmentally but also socially and economically (Inamdar *et al.* 2013; Liu *et al.* 2019). Therefore, it is reasonable to state that with proper planning, design and implementation, stormwater harvesting for reuse schemes can be implemented at suitable locations and result in multiple benefits. Wu *et al.* (2020) developed a comprehensive framework to better evaluate and enhance performance that shows the benefit of sustainable stormwater management. Similarly, stormwater management infrastructure systems have been studied for lessons to be learned (Sharma *et al.* 2016; Liu *et al.* 2019). Various studies have reported site selection for stormwater harvesting based on various criteria including social, economic and environmental factors (Mahmoud *et al.* 2015; Inamdar *et al.* 2018; Ariza *et al.* 2019; Dandy *et al.* 2019; Pathak *et al.* 2019; Shojaeizadeh *et al.* 2019). However, any framework for the comprehensive design of a stormwater harvesting scheme for the purpose of irrigating urban parks is lacking.

This paper presents a methodology for the design of a stormwater harvesting scheme for the irrigation of an area at a local park and its application for sizing various components of the stormwater harvesting system for a park in Melbourne, Australia. It is hoped that the presented methodology and its application to a case study will help water professionals engaged in this area to design similar stormwater harvesting projects.

GENERALISED DESIGN METHODOLOGY FOR STORMWATER HARVESTING SCHEME FOR PUBLIC OPEN SPACES

Considering the varying nature of public open spaces and building upon existing knowledge (Hellstorm *et al.* 2000; Lundie *et al.* 2006; Sharma *et al.* 2009; Sapkota *et al.* 2016), a generalised methodology coupled with analysis tools and approaches for the design of a stormwater harvesting scheme was conceptualised (Figure 1). The methodology is described in the following steps:

1. **Understand stormwater harvesting specific local conditions:** This step involves collection of required information for the design of a stormwater harvesting scheme for the specific public open space area (park). This will include (but not limited to) local climate, geometry, geology, total park area, built-up area, paved area potential for stormwater harvesting, preferred area for irrigation, information on local guidelines for stormwater treatment. Engagement with local area management and environmental regulatory agencies for park development-related policies and guidelines is essential.
2. **Establish design objectives:** These objectives can be established for freshwater savings, maximum stormwater harvesting from paved surfaces within the park area, sizing of stormwater storage based on volumetric reliability considerations, utilising maximum area for irrigation based on local management preferences and selection of preferred method for irrigation. These can be quantitative and qualitative in nature. The design of the stormwater harvesting system and selection of system technologies will be heavily dependent on these objectives.
3. **Selection of site locations for harvesting scheme:** Based on the topography of the area, size of the park, paved area available to act as the stormwater catchment and preferred area for irrigation, locations need to be identified for: (1) paved area as stormwater catchment and collection point; (2) location for stormwater storage tank and treatment unit (if required) based on local land use constraints and management preferences; (3) alignment of stormwater pipe from stormwater catchment outlet to the storage tank; (4) location of irrigation area based on topography and management preferences; and (5) alignment of stormwater supply main from storage tank to irrigation area.
4. **Options for various harvesting components – their locations and nature:** There can be a number of options that may be considered regarding the location and nature of the system components. These options can be associated with harvesting area, storage tank location, pipe alignments, storage tank material and type based on capacity, stormwater treatment systems and their commercial availability, and irrigation methods for watering the designated park area.
5. **Hydrological, water balance and hydraulic assessment for component design/sizing:** This step would require conducting hydrological, water balance and hydraulic analysis/assessment for the sizing of various components of the stormwater harvesting system. The stormwater runoff estimation from the designated harvesting area can be conducted on either daily or at finer time steps, such as hourly or 6-minute time steps based on the design requirements, data needs and availability of local climate data. Water balance modelling will provide information on the stormwater storage capacity requirements based on stormwater inflow from the catchment and irrigation water demand. Hydraulic assessment is required for sizing of various pipes considering the gravitation energy available and the pumping requirements.
6. **Life cycle costing:** Life cycle costing (LCC) is primarily conducted to compare the feasibility of various options based on economic considerations. This includes the capital cost at the time of construction, replacement cost of equipment after their useful life over the analysis period and annual cost of operation and maintenance of the harvesting scheme.
7. **Final selection of system components – their types and sizes:** Based on the assessment and analysis, managers and stakeholders can make well-informed decisions regarding the final system components to be utilised in the stormwater harvesting scheme.

CASE STUDY AREA

Coinciding with 'Greening the West's' vision to facilitate sustainable, liveable and healthy communities through urban

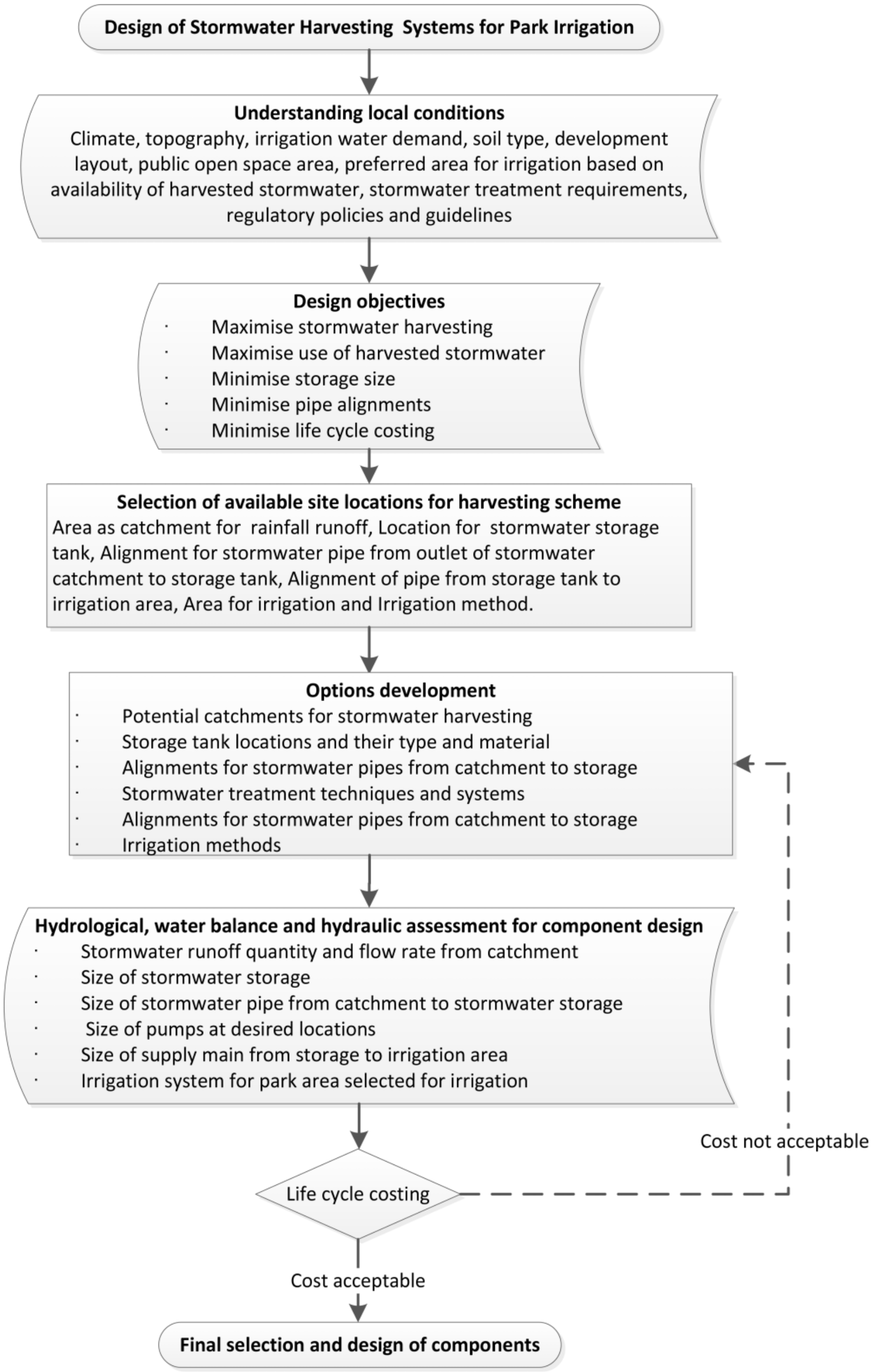

Figure 1 | Design methodology flowchart for stormwater harvesting scheme.

greening, this project aims to further develop one of the largest recreational parks in Melbourne's west – Brimbank Park. The park is currently water deprived for most months of the year and lacks green spaces where families can enjoy hot summer days. The park offers a remarkable setting for people, especially families, to enjoy picnics and BBQs, cycling and walks along the beautiful Maribyrnong River, fishing and bird watching. It is also home to Horseshoe Bend Children's Farm and the Kulin Wetlands which families can also enjoy (Park Victoria 2019). Brimbank Park is 328.7 hectares in size and has many attractions for visitors. The park is located approximately 15 kilometres north-west of Melbourne's CBD in Keilor East (Figure 2). The park is managed by the Victorian State Agency 'Parks Victoria' (Parks Victoria 2019).

The stormwater harvesting and its use for park irrigation is planned for implementation in a preferred area. Under this plan, works include detailed design and costing of a stormwater collection, storage and irrigation system for the park in key areas of interest that are most likely to provide the biggest impact in the area socially and environmentally.

APPLICATION OF THE METHODOLOGY FOR THE DESIGN OF A STORMWATER HARVESTING SYSTEM AT BRIMBANK PARK

The application of the developed planning/design methodology is described for Brimbank Park Stormwater Harvesting Project in the following section.

Understand stormwater harvesting specific local conditions

Information regarding local climate, topography of the area, nature of soil, proposed irrigation area, potential paved areas for the stormwater catchment, location of stormwater storage, treatment units, layouts for stormwater collection and distribution pipes were collected in close consultation with stakeholders. Local water utility 'City West Water,' local council 'Brimbank City Council' and park management authority 'Parks Victoria' were the key stakeholders led by 'City West Water' for this project. The information collected in discussion with stakeholders is shown in Figure 3. The local climate data are provided in the section 'Hydrological, water balance and hydraulic assessment for component design/sizing' and soil data obtained were used for hydrological and water balance modelling as described in the same section.

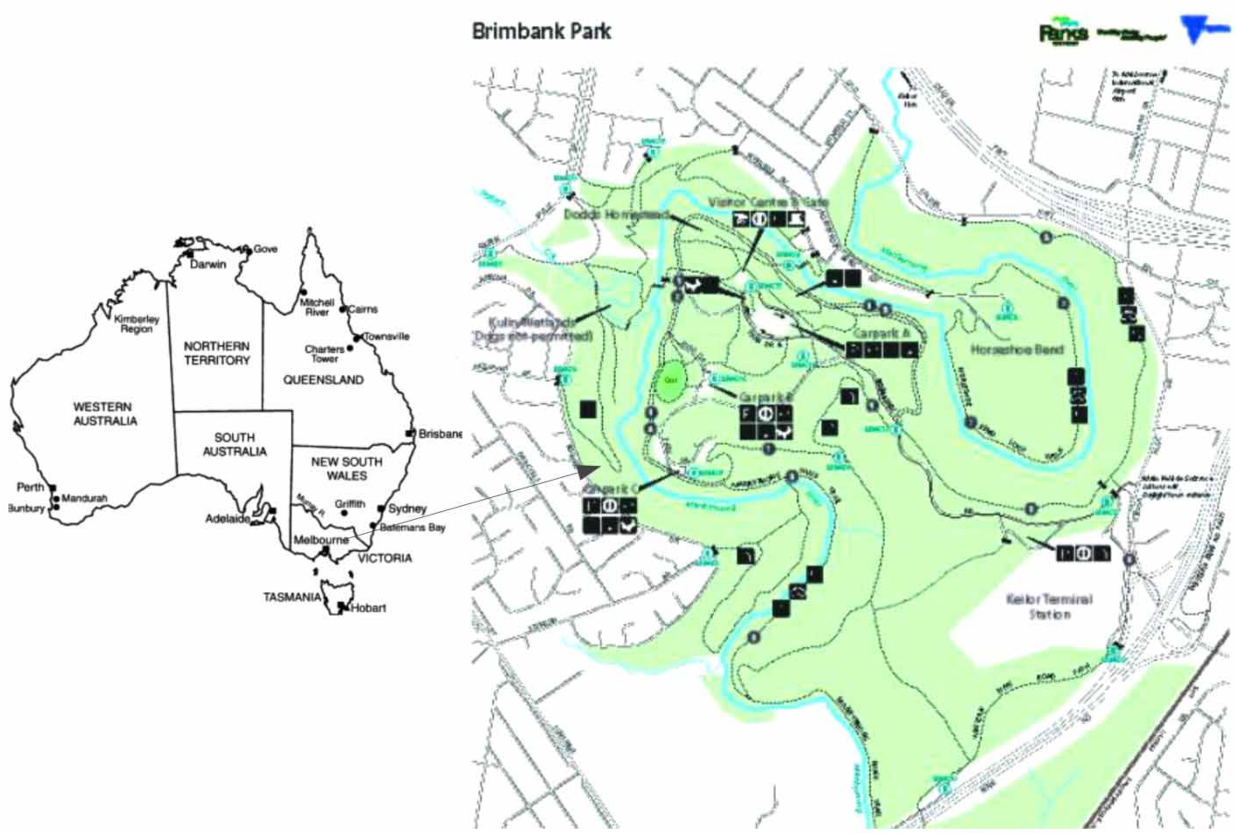

Figure 2 | Brimbank Park case study area location.

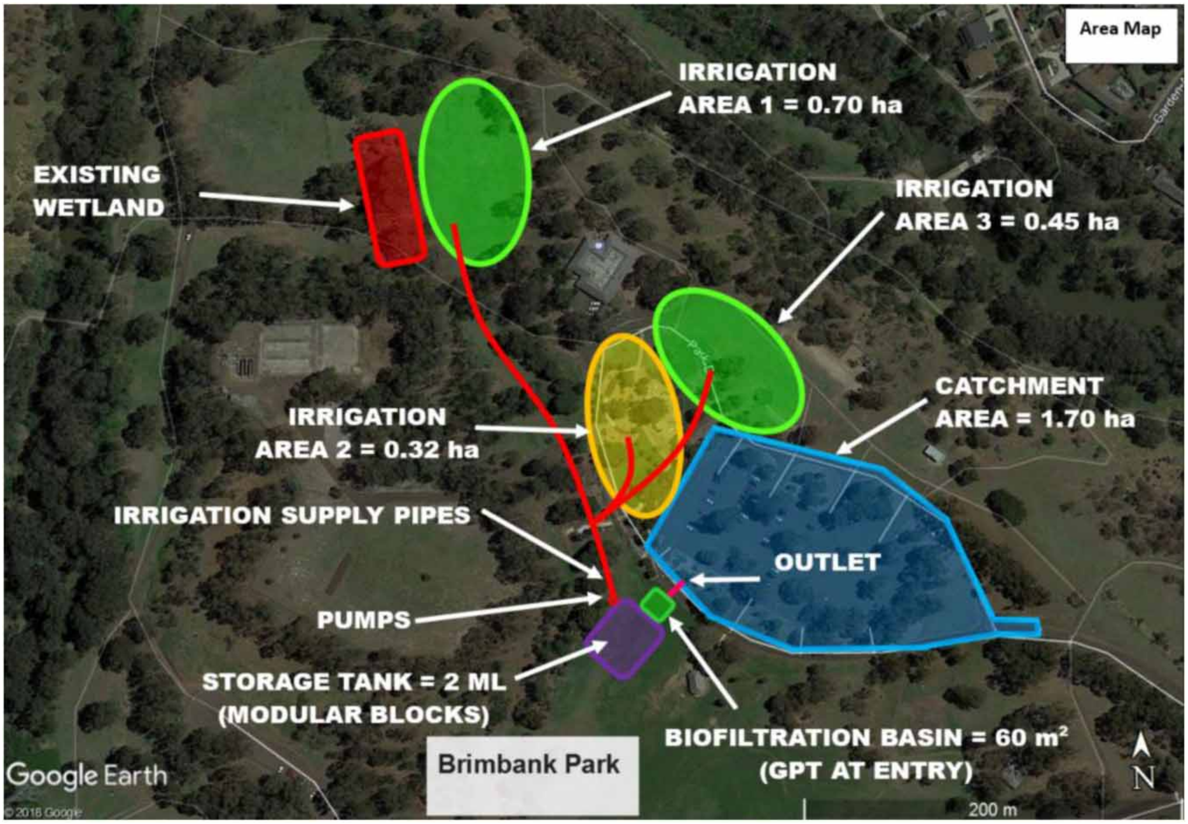

Figure 3 | Layout of the stormwater harvesting catchment, storage tank and other components.

Establish design objectives

The purpose of this project was to propose and design a stormwater harvesting system for reuse at Brimbank Park to irrigate more spaces with stormwater, making them greener and more attractive, which will ultimately lead to benefiting the park environment and improving the health and well-being of the community. Thus, the main objective was to utilise maximum local stormwater generated for the irrigation of public open spaces within the park, leading to more green spaces and saving limited and scarce freshwater sources. It will significantly reduce the use of freshwater supply. As such, no quantitative target for water saving was considered.

Selection of site locations for harvesting scheme

Detailed investigations of potential options for the stormwater harvesting areas, locations of preferred irrigation areas and stormwater storage tank, and alignments for stormwater collection and distribution pipes were conducted and discussed with stakeholders. The final selected sites and layouts can be seen marked in Figure 3.

Options for various components – their locations and nature

Based on the site investigation and consultation with stakeholders, for the planned stormwater harvesting system, there were limited options for stormwater catchment area and its associated location for a stormwater storage tank, alignments for pipes and irrigation areas.

The main asphalt carpark, having a capacity of 260 cars, was considered as the main stormwater catchment area with a stormwater storage near the car park to avoid any pumping requirement. The areas for irrigation identified are as shown in Figure 3. Consultation with stakeholders helped identify and select the park's main activity areas to be irrigated based on their year-round programmes for the local community.

The ultimate task was to design a stormwater collection, storage and irrigation system at Brimbank Park that can be implemented in future through stakeholder funding. This task was broken down into the following key activities:

- Capturing and storing maximum stormwater runoff from the main carpark so it can be used for irrigation purposes.
- Using the captured stormwater to irrigate the grassed open area just behind the café to the north-west, and to replace the use of freshwater that is currently used to irrigate the playscape.
- Plan an underground tank near the main carpark to minimise the reduction of public open space.
- Design the required irrigation layouts and pumping requirements in order to achieve an efficient and effective irrigation system.
- Design a treatment system that will effectively treat the stormwater to the required levels.
- Conduct life cycle costing of the harvesting system.

Hydrological, water balance and hydraulic assessment for component design/sizing

Hydrological modelling for the estimation of stormwater peak flow rate and annual runoff

Long-term hydrological assessment of the stormwater catchment area is required to estimate annual runoff from the catchment for harvesting potential and peak stormwater flow at the catchment outlet in order to size the stormwater pipe from catchment outlet to stormwater storage tank by selecting an appropriate design flow.

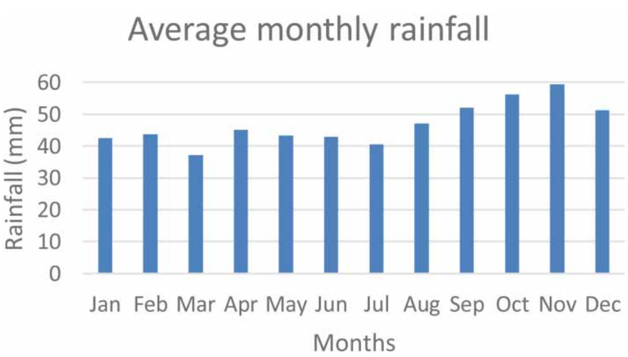

Figure 4 | Average monthly rainfall (2010–2018).

US EPA Storm Water Management Model (SWMM) was applied for hydrological modelling of the catchment area (Rossman & Huber 2016). SWMM is a dynamic rainfall-runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity and quality primarily from urban areas (Rossman & Huber 2016). SWMM allows an accurate representation of the study area to be modelled and thus produce peak and average runoff results likely to be expected from the selected catchment (car park and adjacent area).

Six-minute rainfall data from 2008 to 2018 were obtained from Bureau of Meteorology Australia for the nearest weather station for hydrological modelling; however, only the climate data from 2010 to 2018 were used as 2008 and 2009 were included in millennium drought years (late 1996 to mid-2010). The monthly average rainfall data are shown plotted in Figure 4. It can be seen from Figure 4 that rainfall occurs every month with some variability, thus highlighting high suitability of the rainfall pattern for a stormwater harvesting scheme.

The stormwater catchment area considered is 1.7 ha in size with a 120 m wide flow path. The area has a slope of 1% and overall is 70% impervious. Hydrological modelling was conducted for the period 2010–2018. Hydrological modelling outcomes for year 2018 having maximum peak flow are shown in Table 1. The maximum peak flow reported was 0.68 m^3/s and the total annual runoff was 7,090 m^3. Total stormwater runoff estimated over the analysis period of nine years was 69,840 m^3. Based on the total runoff and average rainfall over the analysis period a runoff coefficient of 0.81 was estimated. The harvesting system can deliver, on average, 7,760 m^3/year of stormwater for park irrigation, which can be a direct saving of freshwater if the total quantity can be utilised.

Table 1 | Hydrological model output for the year 2018

Total precipitation (mm)	Total evaporation (mm)	Total infiltration (mm)	Impervious runoff (mm)	Pervious runoff (mm)	Total runoff (mm)	Total annual runoff m^3	Peak runoff m^3/s	Runoff coeff.
548.40	84.00	55.00	324.50	93.90	418.30	7,090	0.68	0.76

The hydrological modelling was conducted using 6-minute time steps to develop information on peak flows at the catchment outlet, thus 6-minute climate data were used for modelling. Six-minute time step hydrological modelling generated 9,146 flow data sets over the nine-year analysis period with flows at the catchment outlet varying from 0.68 m^3/s to 0.01 m^3/s. These flow rates from the 9,146 events were arranged in descending order with the first 90 events' flow rates shown plotted in Figure 5. This aided in selecting the design flow to use for sizing the stormwater collection/outlet pipe.

Design of stormwater collection pipe from catchment outlet to stormwater storage tank

The sizing of a stormwater collection pipe from catchment outlet to stormwater storage tank requires information on design discharge, length of pipe, available slope and roughness factor for the hydraulic flow equation used for pipe size estimation. The pipe size can be estimated using Darcy–Weisbach equation:

$$h_f = \frac{8fLQ^2}{\pi^2 g D^5} \quad (1)$$

where h_f = head loss on account of surface resistance (also called friction loss); L = the pipe length; Q = discharge (flow) in pipe; D = pipe diameter; f = coefficient of surface resistance (traditionally known as friction factor); and π and g are constants.

The selection of a suitable flow rate is the most critical parameter. It can be seen from the hydrological analysis

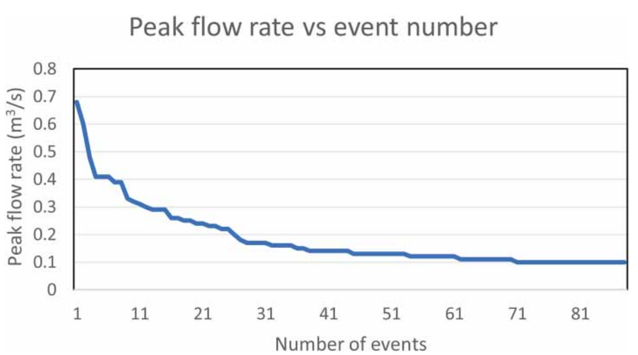

Figure 5 | Plot of flow rates for the first 90 events over the nine-year modelling period.

(Figure 5) that over the nine-year period, the peak stormwater flow at catchment outlet was 0.68 m^3/s. Over the nine-year modelling period, only 17 runoff events have a flow rate over 0.25 m^3/s and 24 events over 0.20 m^3/s. This information is critical for the sizing of the stormwater collection pipe discharging from stormwater catchment outlet to storage tank. The designer has the option to either select the peak flow occurring over the assessment period or to select a lesser flow rate considering the loss of stormwater due to reduced capacity of collection pipe for transferring stormwater.

The pipes are shown calculated for various pipe flows varying from peak flow 0.68 m^3/s to 0.10 m^3/s in Table 2, considering slope of 0.75% and $f = 0.02$. Table 2 also includes calculated continuous pipe sizes, nearest available commercial pipe sizes for adoption, flow rate if commercial size is adopted, % loss of stormwater from capturing over the analysis period if reduced size is adopted, cost of commercial pipe and % change in cost due to reduced pipe size.

The availability of commercial pipe sizes and their supply and construction cost can also play a significant role in the selection of an appropriate flow rate for the design of pipe size. In this assessment, information on the commercial available pipe sizes in the range of interest were obtained from MC Pipes (https://www.mcpipes.com.au/concrete-pipes/). The discrete sizes available in the interest range are 300 mm, 375 mm, 450 mm, 525 mm, 600, 675 and 750 mm. Information developed as listed in Table 2 can help decision-makers to make better and well-informed decisions about the pipe size for conveyance of stormwater from catchment outlet to storage tank. Based on Table 2, a pipe size of 450 mm can be selected rather than 675 mm, which will be able to capture 99.19% of stormwater with 32% less cost. Such an analysis can be more valuable if the length of collection pipe is significant resulting in high capital cost (or even life cycle cost).

Hydrological water balance modelling for stormwater

Urban Volume and Quality (UVQ) water balance model developed by Commonwealth Scientific and Industrial Research Organisation, Australia (CSIRO), was used for investigating the capacity of stormwater storage tank (Mitchell & Diaper 2005, 2010).

Table 2 | Estimation of pipe sizes for various flow rates and associated stormwater loss

Peak discharge (m^3/s)	Pipe diameter calculated (mm)	Commercial pipe size available (mm)	Capacity of commercial pipe size adopted (m^3/s)	Loss of stormwater due to reduced capacity of pipe (m^3)	% loss of water over analysis period of 9 years	Cost of pipe and installation (AUD$)	% change in cost
0.68	633	675	0.79	0	0	6,660	0
0.41	517	525	0.42	180	0.26	5,010	−25
0.3	457	450	0.29	558	0.81	4,550	−32
0.25	425	450	0.29	558	0.81	4,550	−32
0.2	388	450	0.29	558	0.81	4,550	−32
0.15	346	375	0.18	1,375	2.00	4,100	−38
0.1	294	300	0.1	2,664	3.87	3,700	−44

The water demand requirement for turf grasses at Brimbank Park was estimated using the method described in the Code of Practice for Irrigated Open Space (SA Water 2015).

The average irrigation water demand of the selected park area of 1.47 ha was estimated using monthly rainfall for the area, evapotranspiration, crop coefficient (0.7) and crop stress factor (0.45 and 0.50). The average irrigation water demand was estimated to be between 3,600 m^3/annum and 4,500 m^3/annum over the analysis period for crop stress factors of 0.45 and 0.50, respectively. This irrigation water demand was used to calibrate the UVQ model parameters for estimating stormwater storage capacity.

The input data provided for the modelling included total catchment area, irrigation area, % of area irrigated, capacity of soil store, paved area losses, effective paved area, base flow index and garden trigger to irrigation point.

Using the daily rainfall data and varying the capacity of storage tank incrementally by 250 m^3, the annual average stormwater usage for irrigation was estimated. An underground stormwater tank was considered to allow flow of the stormwater from catchment outlet to storage tank to flow via gravity, thus avoiding any additional pumping, sump and other mechanical equipment requirement. The modelling was conducted considering a covered and uncovered stormwater storage. Figure 6 shows the modelling outcome of three scenarios considering (1) storage tank is exposed and zero initial storage level, (2) storage tank is covered and zero initial storage level and (3) storage tank is

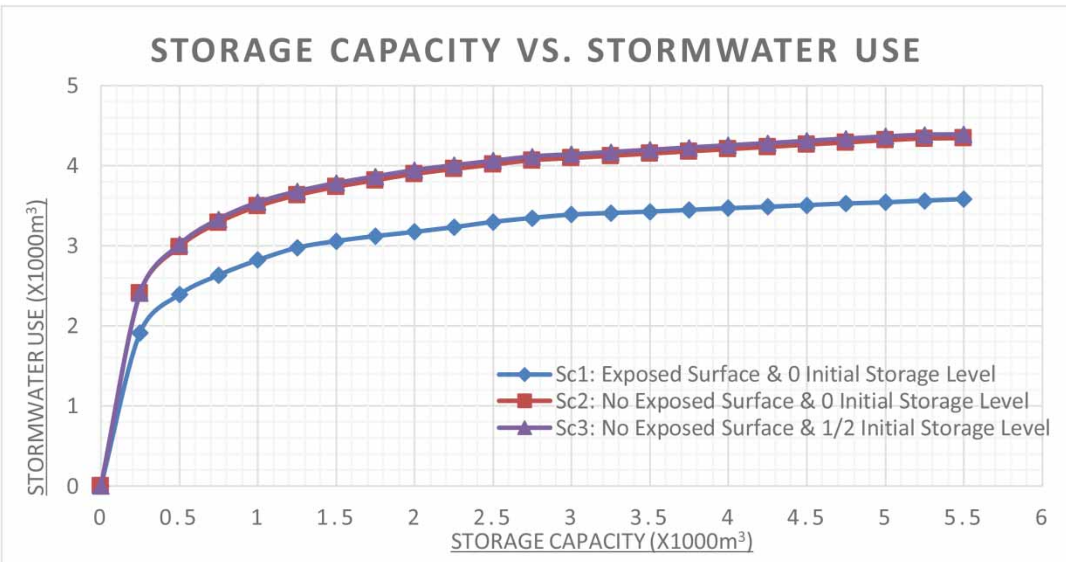

Figure 6 | Stormwater usage for irrigation and storage capacity.

covered and half initial storage level. The stormwater usage (availability) is significantly high if the storage tank is covered due to almost zero evaporation losses from the tank. Considering the tank half full at the start of the modelling indicated slightly more stormwater usage. If the simulation is conducted over a long period of time, the average annual stormwater usage will be very close to the simulation with zero initial storage level in the tank.

Figure 7 highlights the relationship between volumetric reliability and the tank size for the three scenarios. The volumetric reliability is the ratio of annual stormwater usage for irrigation (availability of stormwater for irrigation) and annual irrigation water demand. It can be seen from Figure 7 that the volumetric reliability increases as tank size increases. It is also noted that the volumetric reliability is greater if the storage tank is covered. The estimation of volumetric reliability is sensitive to length of rainfall records, inter-annual variability of seasonal demand and storage surface type – covered or exposed (Mitchell *et al.* 2008).

It can also be seen from Figures 6 and 7 that beyond the storage capacity of 2,000 m^3, there is small gain in additional water availability or increase in volumetric reliability for a large increase in storage capacity. A tank size of 2,000 m^3 can be adopted with nearly 75% volumetric reliability for the upper irrigation demand of the area (4,500 m^3/annum) if the tank is covered. The designer can conduct economic analysis similar to that described in Table 2 for pipe size selection to help make a more informed decision on tank size. Mohanrao (2014) indicated that in order to minimise storage system costs, the stormwater harvesting storages are often designed for a lower level of annual volumetric reliability (i.e., 70%) in comparison to that of traditional water supply storages such as dams (i.e., 95%). There can be various options for the construction of a storage tank starting from onsite construction of a concrete tank, prefabricated in parts and onsite installation or using commercial geocellular stormwater storage modular systems. The storage tank costing is based on considering a modular system.

Stormwater treatment system

Treatment of the harvested stormwater will be required to ensure water quality standards are met for managing health and environmental risks. Australian national guidelines recommend stormwater treatment criteria for 20- and 100-year life spans of treatment systems (NHMRC 2009). For the design period of 20 years, the guideline recommends that suspended solids should be <50 mg/L, coarse particles <2 mm diameter, iron <10 mg/L, phosphorus <0.8 mg/L and hardness <350 mg/L. The information on stormwater quality specifically from the catchment in the case study (i.e., car park) is not available; however, significant literature is available on the untreated stormwater quality from Australian urban catchments (Goonetilleke & Lampard 2019; Hamlyn-Harris

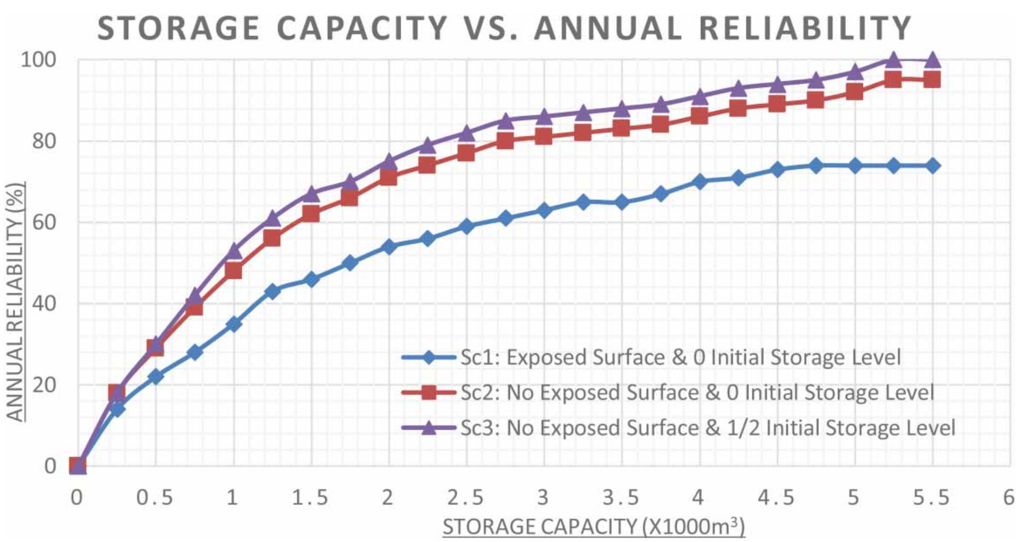

Figure 7 | Annual volumetric reliability of storage capacity.

et al. 2019), which were considered for design of the treatment system. The components selected to form part of the Brimbank Park stormwater treatment system were, a gross pollutant trap and sedimentation chamber, a bioretention/filtration basin and a UV treatment for final disinfection.

A commercially available gross pollutant trap (GPT) was selected for the scheme based on catchment-specific parameters: catchment area 1.7 ha, 20 year average recurrence interval (ARI) flow = 0.4 m^3/s, three-month ARI = 0.07 m^3/s and pipe size 450 mm diameter. The length, width and depth (from inlet invert level) of the GPT selected were 2.7 m × 1.35 m × 0.75 m, respectively (Urban 2019). Water professionals should look into other similar products that are available in their geographical location.

Melbourne Water (2005) provides engineering procedures for the design of water sensitive urban design approaches. A bioretention/filtration basin of 10 m × 6 m (60 m^2 area) with 300 mm extended detention was considered suitable for the required level of stormwater treatment using the design procedure. There are various options within the industry regarding UV disinfection, which can be selected based on compact design, cost and performance.

Design of sprinkler system

A layout of the sprinkler system was developed for the irrigation of the park area as shown in Figure 8. These designs require iterative approaches starting from smaller distances between sprinklers and laterals to larger, based on the commercially available sprinklers and their radius of influence. To initiate the process, a commercially available sprinkler discharging 93 L/min flow at 46 m head (h_S) with an influence diameter of 20 m was selected.

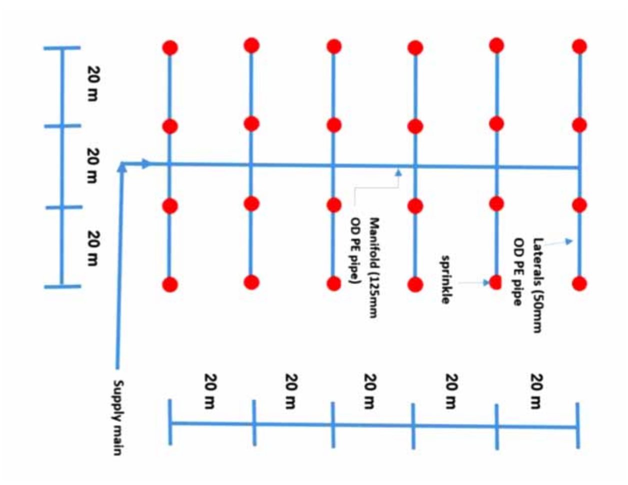

Figure 8 | Sprinkler system layout.

- Sizing of sprinkler lateral pipes:
  - Estimating the total flow in a lateral (3.1 L/s), a pipe size of 50 mm OD PE pipe (class 6) with head loss of 8 m/100 m was estimated using a flow resistance chart. Equation (1) can also be used for pipe sizing. Christiansen (1942) reduction coefficient for head loss in the lateral with sprinklers, F (for two 'effective outlets' in the plastic pipe), where the first outlet is half spacing from supply main = 0.64 (Waller & Yitayew 2016). An allowable head loss of 10–20% can be considered across the irrigation area based on local guidelines, thus considering 20% head loss, the maximum allowable pressure head variation across the whole irrigation area = 0.2 × 46 m = 9.2 m
  - Head loss along lateral (h_L) = 1.1 × 0.52 × 30 × 8/100 = 1.40 m (considering 10% form or minor losses)
  - Lateral upstream pressure (h_U) required = h_S + 0.75 h_L = 46 + 0.75 × 1.40 = 47.10 m.
- Sizing of sprinkler manifold pipes:
  - Flow in the upstream end of the manifold = 12 (number of laterals) × 3.1 (flow in one lateral) = 37.2 L/s
  - Christiansen's reduction coefficient (the first outlet is at half spacing), F = 0.39
  - Try 125 mm OD PE pipe manifold, head loss in pipe 15 m/100 m if no sprinklers
  - Head loss along the manifold with sprinklers (h_L) = 1.1 × 0.39 × 110 × 15/100 = 7.10 m
  - Pressure head at the upstream end of the manifold $h_U = h_S + 0.75\,h_F = 47.10 + 0.75 \times 7.10 = 52.5$ m
  - Maximum head loss in the sprinkler across the area = 7.1 + 1.4 = 8.5 m (<9.2 m permissible limit).

The sizing of the laterals and manifolds requires an iterative approach to finalise the sizes to maintain allowable head loss across the area. Using a similar design approach, sprinkler systems for all the three irrigation areas were finalised.

Design of pressure main from storage tank to sprinkler systems

Using hydraulic principles (Swamee & Sharma 2008), the capacity of a pump and pressure main size to transfer stormwater to the sprinkler system was determined as part of the park's irrigation system. The LCC was conducted using three pipe size options and their associated pumping requirements (100, 150 and 200 mm). The capital cost of a pump, pressure main and associated maintenance and operation cost over the analysis period of 20 years was estimated for the three pipe sizes. LCC for 100, 150 and 200 mm pipe systems was estimated to be $120,200, $113,800 and $118,700, respectively. The analysis resulted in the selection of a 150 mm pipe and associated pump of 35 kW.

LCC

The LCC was conducted using the net present value (NPV) method described by Newnan *et al.* (2004) and Swamee & Sharma (2008). In this method, all the future costs, incurred in operation and maintenance of the system including replacement of any component after its useful life over the analysis period, are converted to present cost/value. The sum of the capital cost of the infrastructure systems and present value of the operation/maintenance and replacement of components over the analysis period gives NPV. Equation (2) was used for NPV estimation:

$$P = A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] \quad (2)$$

where P is present cost, A is annual operation and maintenance cost, i is discount rate and n is analysis period.

Similarly, future cost F for the replacement of system components (e.g., pumps) after their useful life was converted to present cost P using Equation (3):

$$P = F(1+i)^{-n} \quad (3)$$

where n is useful life of the system or replacement period. In this study, an analysis period of 20 years and a discount rate of 5% was adopted.

Table 3 | Life cycle cost of stormwater harvesting system

Item	Capital cost	LCC
Collection system works at catchment site	$170,400	$191,632
Storage tank	$1,700,000	$1,704,250
Collection pipe	$4,550	$4,833
Treatment system	$100,000	$112,460
Irrigation sprinkler system	$45,045	$59,077
Pumping main	$64,800	$65,278
Pump and pumping cost	$22,000	$48,039
Total	**$1,936,395**	**$2,185,569**

There were only limited options for stormwater harvesting systems at Brimbank Park and the preferred option was selected in consultation with stakeholders. The LCC of the proposed stormwater harvesting system was estimated as shown in Table 3.

Final selection of system components – their types and sizes

The stormwater harvesting system was designed to irrigate 1.47 ha of park public open space area using a 1.7 ha carpark as the primary stormwater catchment. The system design included a stormwater storage tank of 2,000 m^3, stormwater collection pipe of 450 mm, bioretention/filtration system of 600 m^2 area, 150 mm pressure main with a pump of 35 kW and a sprinkler system with a manifold of 125 mm and laterals of 50 mm.

CONCLUSIONS

A methodology for the planning and design of a stormwater harvesting system is presented and its application has been demonstrated through the design of such a system at Brimbank Park in Melbourne's west. The applications of hydrological and water balance models including hydraulic design and LCC approaches were conducted for design purposes. Detailed discussions with stakeholders and the agency responsible for operating the system should be conducted for detailed option development.

It can be concluded that the sizing of a stormwater storage and collection pipe should not just be based on achieving 100% reliability or capturing peak flow occurring once over the analysis period. A thorough analysis is required to be able to make informed decisions and to minimise subjectivity in decision-making.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

ACKNOWLEDGEMENTS

Authors acknowledge City West Water, Melbourne and Parks Victoria for their help and support in conducting this study.

REFERENCES

Ariza, S., Martínez, J., Muñoz, S., Quijano, J., Rodríguez, J., Camacho, L. & Díaz-Granados, M. 2019 A multicriteria planning framework to locate and select sustainable urban drainage systems (SUDS) in consolidated urban areas. *Sustainability* **11**, 2312.

Christiansen, J. E. 1942 Irrigation by Sprinkling. California agriculture experiment station bulletin 670. University of California, Davis. In: 2016. *Irrigation and Drainage Engineering* (P. Waller & M. Yitayew, eds). Springer.

Dandy, G. C., Marchi, A., Maier, H. R., Kandulu, J., MacDonald, D. H. & Ganji, A. 2019 An integrated framework for selecting and evaluating the performance of stormwater harvesting options to supplement existing water supply systems. *Environmental Modelling & Software* **122**, 104554.

Fam, D., Mosley, E., Lopes, A., Mathieson, L., Morison, J. & Connellan, G. 2008 *Irrigation of Urban Green Spaces: A Review of the Environmental, Social and Economic Benefits*. Cooperative Research Centre for Irrigation Futures, technical report no. 04/08, April 2008. Available from: https://www.irrigationaustralia.com.au/documents/item/219 (assessed 9 June 2020).

Fisher-Jeffes, L., Carden, K., Armitage, N. P. & Winter, K. 2017 Stormwater harvesting: improving water security in South Africa's urban areas. *South African Journal of Science* **113**, 1–4.

Fletcher, T. D., Shuster, W., Hunt, W. F., Ashley, R., Butler, D., Arthur, S., Trowsdale, S., Barraud, S., Semadeni-Davies, A., Bertrand-Krajewski, J.-L., Mikkelsen, P. S., Rivard, G., Uhl, M., Dagenais, D. & Viklander, M. 2015 SUDS, LID, BMPs, WSUD and more – the evolution and application of terminology surrounding urban drainage. *Urban Water Journal* **12**, 525–542.

Goonetilleke, A. & Lampard, J.-L. 2019 Stormwater quality, pollutant sources, processes, and treatment options. In: *Approaches to Water Sensitive Urban Design: Potential, Design, Ecological Health, Economics, Policies and Community Perceptions* (A. K. Sharma, T. Gardner & D. Begbie, eds). Elsevier, UK.

Hamlyn-Harris, D., McAlister, T. & Dillon, P. 2019 Water harvesting potential of WSUD approaches. In: *Approaches to Water Sensitive Urban Design: Potential, Design, Ecological Health, Economics, Policies and Community Perceptions* (A. K. Sharma, T. Gardner & D. Begbie, eds). Elsevier, UK.

Hatt, B., Deletic, A. & Fletcher, T. 2004 *Integrated stormwater treatment and re-use systems – inventory of Australian practice*. Cooperative Research Centre for Catchment Hydrology, technical report 04/1, June 2004 https://ewater.org.au/archive/crcch/archive/pubs/pdfs/technical200401.pdf

Hellstrom, D., Jeppsson, U. & Karrman, E. 2000 A framework for systems analysis of sustainable urban water management. *Environmental Impact Assessment Review* **20** (3), 311–321.

Hoban, A., Mills, S. K., Tanner, C. & Hamlyn-Harris, D. 2015 Climate change impacts on stormwater harvesting yields. *Water: Journal of the Australian Water Association* **42**, 5.

Inamdar, P. M., Cook, S., Sharma, A. K., Corby, N., O'Connor, J. & Perera, B. J. C. 2013 A GIS based screening tool for locating and ranking of suitable stormwater harvesting sites in urban areas. *Journal of Environmental Management* **128**, 363–370.

Inamdar, P. M., Sharma, A. K., Cook, S. & Perera, B. J. C. 2018 Evaluation of stormwater harvesting sites using multi criteria decision methodology. *Journal of Hydrology* **562**, 181–192.

Lindsey, G., Roberts, L. & Page, W. 1992 Inspection and maintenance of infiltration facilities. *Journal of Soil & Water Conservation* **47** (6), 481–486.

Liu, L., Fryd, O. & Zhang, S. 2019 Blue-green infrastructure for sustainable urban stormwater management – lessons from six municipality-led pilot projects in Beijing and Copenhagen. *Water* **11**, 2024.

Lundie, S., Peters, S., Ashbolt, N., Lai, E. & Livingston, D. 2006 A sustainability framework for the Australian water industry. *Water, Journal of Australian Water Association* **33**, 83–88.

Mahmoud, S. H., Alazba, A. A., Adamowski, J. & El-Gindy, A. M. 2015 GIS methods for sustainable stormwater harvesting and storage using remote sensing for land cover data – location assessment. *Environmental Monitoring and Assessment* **187**, 598.

Melbourne Water 2005 *WSUD Engineering Procedures: Stormwater*. CSIRO Publishing, Melbourne, Australia. Available from: https://ebooks.publish.csiro.au/content/wsud-engineering-procedures-stormwater

Mitchell, V. G. & Diaper, C. 2005 UVQ: A tool for assessing the water and contaminant balance impacts of urban development scenarios. *Water Science and Technology* **52** (12), 91–98.

Mitchell, G. & Diaper, C. 2010 *UVQ User Manual*. CSIRO, Melbourne, Australia.

Mitchell, V. G., McCarthy, D. T., Deletic, A. & Fletcher, T. D. 2008 Urban stormwater harvesting – sensitivity of a storage behaviour model. *Environmental Modelling & Software* **23**, 782–793.

Mohanrao, I. P. 2014 *Selection and Evaluation of Potential Stormwater Harvesting Sites in Urban Areas*. PhD Thesis, College of Engineering and Science, Victoria University, Melbourne, Australia. Available from: http://vuir.vu.edu.au/25797/1/Inamdar%20Prasad%20Mohanrao.pdf (assessed 9 June 2010).

Newnan, D. G., Eschenbach, T. G. & Lavelle, J. P. 2004 *Engineering Economic Analysis*, 9th edn. Oxford University Press, New York, USA.

NHMRC 2009 *Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2) Stormwater Harvesting and Reuse*. Natural Resource Management Ministerial Council, Environmental Protection and Heritage Council, National Health and Medical Research Council. Available from: https://www.waterquality.gov.au/guidelines/recycled-water

Parks Victoria 2019 *Brimbank Park*. Available from: https://parkweb.vic.gov.au/ (accessed 9 June 2020).

Pathak, S., Garg, R. D., Jato-Espino, D., Lakshmi, V., Ojha, C. S. P. & F. ASCE 2019 Evaluating hotspots for stormwater harvesting through participatory sensing. *Journal of Environmental Management* **242**, 351–361.

Philp, M., McMahon, J., Heyenga, S., Marinoni, O., Jenkins, G., Maheepala, S. & Greenway, M. 2008 *Review of Stormwater Harvesting Practices*. CSIRO, Melbourne, Australia. Available from: https://publications.csiro.au/rpr/download?pid=procite:6057d2b6-42b7-4d03-9fd7-ddd451b9d269&dsid=DS1

Radcliffe, J. C. 2019 History of water sensitive urban design/low impact development adoption in Australia and internationally. In: *Approaches to Water Sensitive Urban Design: Potential, Design, Ecological Health, Economics, Policies and Community Perceptions* (A. K. Sharma, T. Gardner & D. Begbie, eds). Elsevier, UK.

Rossman, L. & Huber, W. C. 2016 *Storm Water Management Model Reference Manual, Vol.1 – Hydrology (Revised)*. Office of the Research and Development, Water Supply and Water Resources Division, United States Environmental Protection Agency. Available from: http://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100NYRA.txt

Sapkota, M., Arora, M., Malano, H., Moglia, M., Sharma, A., George, B. & Pamminger, F. 2016 An integrated framework for assessment of hybrid water supply systems. *Water* **8** (1), 4. doi:10.3390/w8010004.

SA Water 2015 *Code of Practice for Irrigated Public Open Space*. Available from: https://www.sawater.com.au/__data/assets/pdf_file/0020/40493/Code_of_Practice_Irrigated_Public_Open_Space_201015_standard-UPDATED.pdf (assessed 3 June 2020).

Sharma, A., Grant, A., Grant, T., Pamminger, F. & Opray, L. 2009 Environmental and economic assessment of urban water services for a greenfield development. *Environmental Engineering Science* **26** (5), 921–934.

Sharma, A. K., Pezzaniti, D., Myers, B., Cook, S., Tjandraatmadja, G., Chacko, P. C. S., Kemp, D., Leonard, R., Koth, B. & Walton, A. 2016 Water sensitive urban design: an investigation of current systems, implementation drivers, community perceptions and potential to supplement urban water services. *Water MDPI* **8**, 272.

Sharma, A. K., Gardner, T. & Begbie, D. 2019 *Approaches to Water Sensitive Urban Design: Potential, Design, Ecological Health, Economics, Policies and Community Perceptions*. Elsevier, UK.

Shojaeizadeh, A., Geza, M., McCray, J. & HogueE, T. 2019 Site-scale integrated decision support tool (i-DSTss) for stormwater management. *Water* **11**, 2022.

Swamee, P. K. & Sharma, A. K. 2008 *Design of Water Supply Pipe Networks*. John Wiley and Sons Inc, Hoboken, NJ, USA.

URBAN 2019 *Ecosol™ Gross Pollutant Trap Technical Specifications, Ecological Filtration Systems*. Urban Asset Solutions, Pooraka, SA, Australia. Available from: https://urbanassetsolutions.com.au/wp-content/uploads/UAS-GPT-Technical-Specifications-2019.pdf (assessed 4 June 2020).

Waller, P. & Yitayew, M. 2016 *Irrigation and Drainage Engineering*. Springer, Cham, Switzerland.

Wu, T., Song, H., Wang, J. & Friedler, E. 2020 Framework, procedure, and tools for comprehensive evaluation of sustainable stormwater management: a review. *Water* **12**, 1231.

First received 15 June 2020; accepted in revised form 20 October 2020. Available online 3 November 2020