STORMWATER REUSE AND THE EFFECTS OF CLIMATE CHANGE – SHOULD WE BE CONCERNED?

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Abstract

Stormwater reuse is becoming an increasingly popular alternative to potable water use for locations such as parks and gardens, industrial sites and sports fields. As communities strive to become more sustainable, and the pressures from sustained drought and subsequent water restrictions are being felt, designers and planners are seeking innovative solutions to minimize the impacts of water shortages. The impacts of climate change, in particular on rainfall patterns and evaporation, have been widely researched. A collaborative investigation between Melbourne Water and CSIRO predicts reduced annual rainfall as high as 4% by 2030 for Melbourne. If this is an indication of rainfall averages for the future, how will this affect our current investments in stormwater reuse schemes? How can we design for these schemes now to minimise the effects of climate change?

This paper investigates the potential impacts of climate change on stormwater reuse schemes, focusing on:

- factoring rainfall and evapotranspiration data to account for the predicted changes from climate change
- applying the climate change scenario to model the impacts on two case studies across Melbourne, Australia
- providing guidance on the design of future stormwater harvesting schemes to account for the impacts of potential future climate change.

Based on the findings of this analysis, recommendations will be made about design considerations for future stormwater harvesting schemes and available modelling tools and methods for assessing these systems.

Introduction

Stormwater harvesting and reuse is an important component of water sensitive urban design (WSUD), and an alternative to potable water use, that is becoming more widespread across Greater Melbourne and Australia. A number of water users, including local councils, are looking to implement stormwater harvesting and reuse schemes as pressures grow to find alternatives to potable water use. The schemes are often modelled and sized using past climate records, however, should we be accounting for potential changes due to climate change?

Organisations such as the Bureau of Meteorology, the Department of Sustainability and Environment (DSE) in Victoria, and CSIRO have investigated the potential changes to weather patterns as a result of climate change. It is important that these results be considered as our cities continue to grow – how will these changes affect our infrastructure? How do we protect ourselves from increases in rainfall intensity? How do we survive in cities receiving less rainfall from year to year?

Current climate change projections indicate that average annual rainfall in Melbourne may decrease by 4% by 2030, and as much as 11% by 2070 (DSE, 2008). As well as a decrease in average annual rainfall, it is also projected that while the number of rainy days will decrease, the rainfall intensity will increase (DSE, 2008; CSIRO and Melbourne Water, 2005; CSIRO and Bureau of Meteorology, 2010). Climate change projections also indicate that temperature and evaporation will increase (DSE, 2008; CSIRO and Melbourne Water, 2005; CSIRO and Bureau of Meteorology, 2007), which may also influence current stormwater harvesting modelling.

Scope

This paper investigates the potential impacts of climate change on two stormwater harvesting and reuse case studies in Melbourne, Victoria. The two schemes are projects completed by Parsons Brinckerhoff (PB) in areas with different mean annual rainfalls, one located east of Melbourne's CBD and the second west of the CBD.

The schemes will be analysed using climate change predictions presented in the publication *Climate change in Port Phillip and Westernport* (DSE, 2008), as well as supplementary information from the CSIRO and the Bureau of Meteorology. This report will be used as a reference to modify rainfall and evapotranspiration data input into water balance models for each scheme to simulate the effects of various climate change scenarios.

Case studies

The schemes chosen for analysis were selected to vary in size, demand and location within Melbourne. Both schemes have predominantly residential catchments but were found to also differ in demand profile as a result of different end uses.

Scheme 1 – Located east of Melbourne's CBD

Scheme 1 is a stormwater capture and reuse scheme constructed to service a recreational reserve and golf course — both owned and operated by a local council east of Melbourne's CBD. The scheme comprises an 18-hole golf course, numerous sporting fields and other recreational areas. The council recently recognized the need for an additional source of water to irrigate the reserve and golf course and as a result a water management strategy was completed for the area. The strategy included a review of the existing water supply and a concept design of a stormwater harvesting and reuse system.

The existing water supply for the site is a combination of:

- potable water (26 ML/yr for the golf course and 13.9 ML/yr for sport fields)
- rainwater (minimal supply for sport fields)
- existing stormwater harvesting system (estimated 13 ML/yr for golf course).

An additional source of water is required to replace potable water and meet the annual irrigation demand where it is not already met (the current demand is 70 ML/yr yet only 39 ML/yr can be supplied). An options analysis identified stormwater harvesting and reuse as the preferred alternative water supply. The proposed stormwater harvesting system includes an off-take from a local stormwater drain, with a largely residential upstream catchment. A water balance model was completed to optimize the schemes components. In this modelling exercise it was determined that existing open water storage was sufficient to incorporate into the scheme to meet the current irrigation demands. Further details of the system are shown in Table 1.

Table 1: Details of proposed stormwater harvesting and reuse system for Scheme 1

Scheme Attribute	Details
Annual irrigation Demand	Sporting fields and rec. areas – 13.9 ML 18-hole golf course – 70 ML
Annual Demand	Sporting fields and rec. areas – 13.9 ML 18-hole golf course – 57 ML
Current Mean Annual Rainfall	678 mm/yr
Catchment Area	98 ha
Catchment Type	Residential (Fraction Impervious = 0.45)
Diversion Components	Extraction from existing stormwater drainage pit, with a low flow bypass to maintain flow depth of 75 mm in stormwater drain. Diversion of water from main drain to a 750 kL buffer tank, with a pump of 30 L/s to the main storage.
Storage Capacity	25 ML
Storage Type	Existing Dam
Annual Security of Supply	91.5%
Summer Security of Supply	90.0%
Scheme Lifespan	25 yrs

Scheme 2 – Located west of Melbourne's CBD

Scheme 2 is located to the west of Melbourne CBD. The precinct consists of three major sporting ovals and other recreational areas. The local council's Sustainable Water Plan (2006) identified a need for alternative water supplies to irrigate this area. As part of the investigation a functional design for a stormwater harvesting and reuse system was completed.

The proposed stormwater harvesting and reuse system consists of an off-take from a local stormwater drain to a 2 ML underground storage, from which the irrigation water is supplied. The upstream catchment for the drain is approximately 44 ha and is largely residential. The best storage size was determined from the water balance model and security of supply analysis. For more detail on the system refer to Table 2.

Table 2: Details of proposed stormwater harvesting and reuse system for Scheme 2

Scheme Attribute	Details
Annual irrigation Demand	30 ML
Annual Demand	30 ML
Current Mean Annual Rainfall	482 mm/yr
Catchment Area	44 ha
Catchment Type	Predominantly Residential (Fraction Impervious = 0.45)
Diversion Components	Extraction from existing stormwater drain, direct to storage tank
Storage Capacity	2 ML
Storage Type	Underground storage tank
Annual Security of Supply	77.8%
Summer Security of Supply	64.8%
Scheme Lifespan	25 yrs

Climate scenarios

The publication titled *Climate change in Port Phillip and Westernport* (DSE, 2008), was used as a reference guide to obtain the climate change parameters. Four different climate scenarios were modelled for each of the case studies:

1. Current climate scenario
2. 2030 Medium emissions climate scenario
3. 2070 Low emissions climate scenario
4. 2070 High emissions climate scenario.

The current climate scenario was based on past rainfall and evapotranspiration data obtained from the Australian Bureau of Meteorology. The data was then factored for each climate scenario, using the projected changes outlined by the DSE and as summarized in Table 3.

Whilst the year 2070 falls outside the initial life expectancy of both schemes, it is envisaged that these higher values may be used to check the sensitivity of the schemes should the 2030 estimates turn out to be low.

Table 3: Changes to rainfall and evaporation due to climate change (climate change information shown in this table is based on projections outlined by DSE, 2008)

Parameter	2030 (medium emissions)	2070 (low emissions)	2070 (high emissions)
Mean annual rainfall (mm)	- 4%	- 6%	- 11%
Number of rainy days (annual)	- 6%	- 10%	- 19%
Rainfall intensity (for top 1% of rainfall events)			
Summer	+2.5%	+8.4%	+16.3%
Autumn	+1.1%	+3.6%	+7.0%
Winter	+2.6%	+8.8%	+17.0%
Spring	+1.1%	+3.8%	+7.4%
Evapotranspiration			
Summer	+2%	+4%	+8%
Autumn	+4%	+7%	+13%
Winter	+8%	+14%	+27%
Spring	+2%	+3%	+7%

Model methodology

Prior to the development of water balance models for each scheme, rainfall and evapotranspiration was established and modified to reflect the climate change scenario predictions for each scheme.

The following section of the paper outlines the methodology used to modify and apply this climatic data.

<u>Rainfall</u>

The current climate scenario for the Scheme 1 and Scheme 2 stormwater harvesting models used hourly rainfall data (generated from pluvio data).

The existing rainfall data was then factored for each site to obtain the projected rainfall data series for each of the climate change scenarios (using the DSE climate change predictions), as follows:

- Mean annual rainfall (MAR) was calculated for the existing data set (current climate scenario)
- future MARs were calculated for each climate change scenario by factoring the current MAR using the projected changes outlined in Table 3
- current rainfall data was adjusted for each climate scenario by increasing the rainfall intensities for the larger rainfall events (99th percentile) by the percentages outlined in Table 3
- the lower percentile hourly intensities (starting from the 1st percentile) were removed from each data series until the MAR matched the projected decreased values as outlined in Table 3
- a comparison was made between the number of rainy days for each climate data series to the projected number of rainy days in Table 3
- a sensitivity analysis was completed to check the responsiveness of the rainfall data to varying the intensity of events other than the 99th percentile.

The sensitivity analysis used the following two methods to factor the rainfall data to account for climate change:

- the 99th percentile hourly intensities were factored by the amount specified in Table 3 (accounting for seasonality)
- the 99th percentile hourly intensities were factored by the amount specified in Table 3 (accounting for seasonality), and the 90th percentile hourly intensities was factored by one. The values in between were factored linearly.

For both sets of data the lower percentile hourly intensities (starting from the 1st percentile) were progressively removed until the MAR matched the projected figures in Table 3.

The results of the sensitivity analysis showed that there was no significant difference in the results for the two scenarios. For this reason the recommended approach (DSE, 2008) of only factoring the 99th percentile hourly intensities was adopted.

Evapotranspiration

Daily evapotranspiration (ET) data obtained from the Australian Bureau of Meteorology was used for both sites for the current climate scenario.

The ET data was factored to account for the potential seasonal changes to ET as a result of climate change for each of the three climate scenarios (refer to Table 3). The daily data was factored directly by the proportions shown in Table 3.

Water Balance Model

Water balance models were produced for each scheme using known catchment-specific parameters (such as size and fraction imperviousness) to simulate the stormwater runoff from the catchment. Different climate change scenarios were then trialled for each scheme by varying the rainfall and evapotranspiration input data.

The models for each scheme were produced using the Model for Urban Stormwater Improvement Conceptualisation (MUSIC), and were run to determine the quantity of stormwater available for reuse and, therefore, the security of supply. The models were run at an hourly time step. The irrigation demand was based on the monthly demand profiles as a percentage of the annual demand (refer to Table 4).

Table 4: Monthly irrigation demand profiles (as a percentage of annual demand)

Month	Scheme 1	Scheme 2
January	15.8%	11.6%
February	17.3%	9.7%
March	15.2%	7.3%
April	5.3%	4.0%
May	5.0%	6.4%
June	2.3%	3.5%
July	2.1%	4.5%
August	2.1%	6.0%
September	4.2%	7.4%
October	4.8%	19.1%
November	13.4%	10.0%
December	14.8%	10.8%

The security of supply is a measure of the scheme effectiveness to supply stormwater to meet irrigation demands. Security of supply is calculated as a percentage of days the supply meets or exceeds the irrigation demand. For these two case studies the stormwater harvesting systems are considered the only source of water for the system when calculating the security of supply.

Three periods were considered when calculating the security of supply for each scheme, annual security of supply, summer security of supply (December, January and February), and the security of supply over the top three consecutive demand months (January, February and March for Scheme 1, and January, October and December for Scheme 2).

Results

The measure used to determine the impacts of climate change on each scheme was security of supply. The results show the projected future climate change scenarios do reduce the reliability and effectiveness of each of the two reuse schemes that were investigated. The security of supply varied with the changes to rainfall, and to a lesser degree with the changes to evapotranspiration. The effect on the system varied depending on the climate scenario, the chosen security of supply scenario, and for each of the schemes, as shown in

Figure 1.

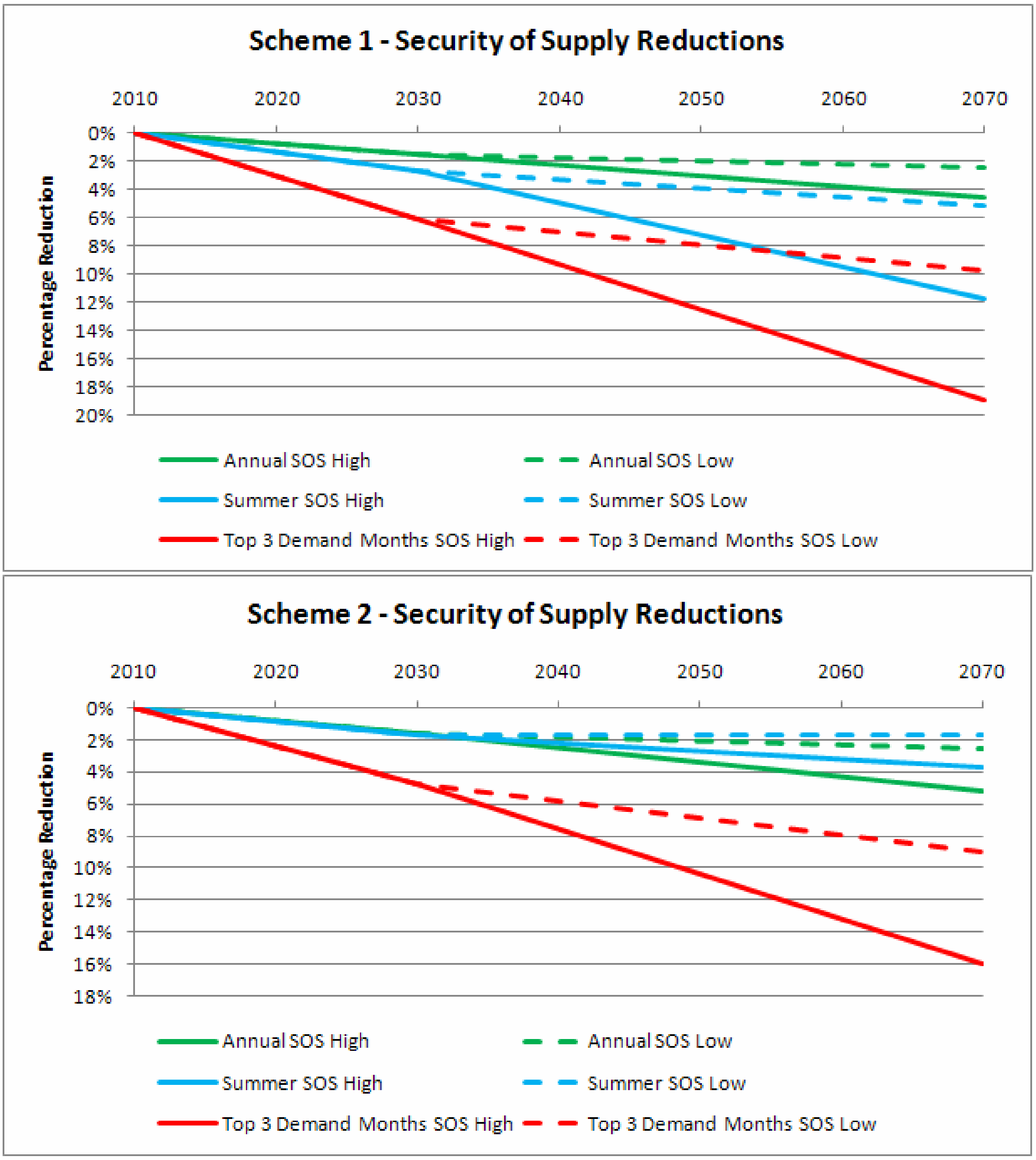


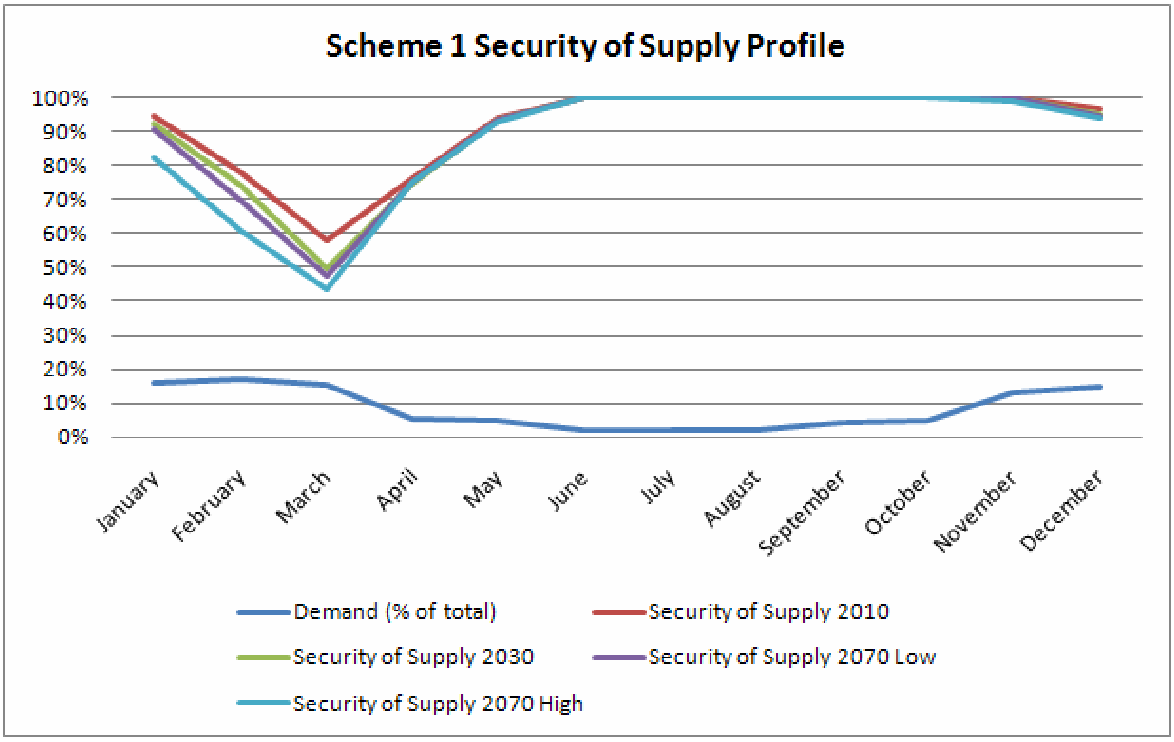
Figure 1: Irrigation security of supply, for the annual, summer and top three demand months for Scheme1 and 2

Table 5 shows the percentage reduction in security of supply for the annual, summer and top three demand months, for each of the climate scenarios and case studies.

Table 5: Effects on security of supply based on various climate scenarios for Scheme 1 and Scheme 2

Security of Supply	Climate scenario	Scheme 1	Scheme 2
Annual	2010 (current)	-	-
	2030	- 1.5%	- 1.5%
	2070 (low emissions)	- 2.4%	- 2.6%
	2070 (high emissions)	- 4.5%	- 5.2%
Summer	2010 (current)	-	-
	2030	- 2.7%	- 1.7%
	2070 (low emissions)	- 5.1%	- 1.7%
	2070 (high emissions)	- 11.7%	- 3.7%
Top three demand months	2010 (current)	-	-
	2030	- 6.0%	- 4.8%
	2070 (low emissions)	- 9.7%	- 9.0%
	2070 (high emissions)	- 18.9%	- 16.0%

Figure 2 shows the monthly security of supply variation across the four climate change scenarios.



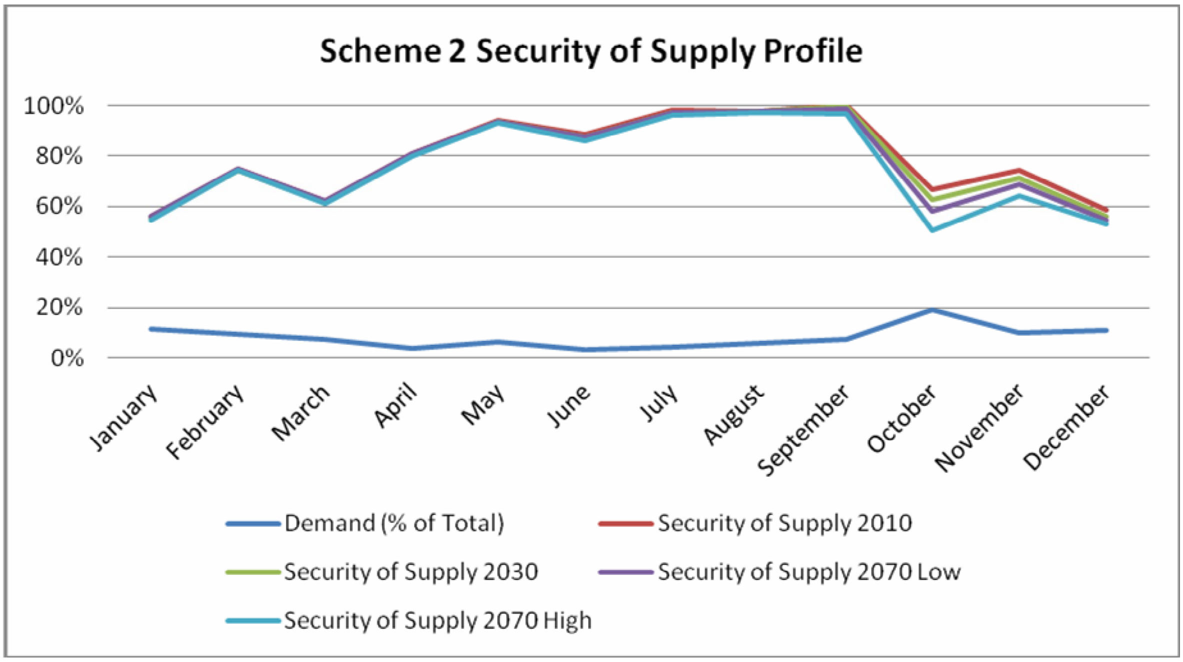


Figure 2: Monthly irrigation demand profile (as a percentage of total annual demand) and monthly security of supply for Scheme 1 and 2

Table 6 shows the impact that climate change based on evaporation from the open storage proposed for Scheme 1.

Table 6: Changes to volume supplied to storage and evaporative losses from storage for each climate scenario for Scheme 1

Climate scenario	**Annual volume supplied (ML)**	**Change in annual volume supplied**	**Annual evapotranspiration losses from storage (ML)**	**Change in Evaporation volume**
Current climate (2010)	50.6	0	3.91	0
2030	49.2	- 2.7%	3.95	+1.0%
2070 (low emissions)	48.5	- 4.1%	3.99	+2.2%
2070 (high emissions)	46.6	- 7.8%	4.08	+4.4%

Discussion

The results conclude that the potential effects of climate change in the short term (to 2030) are minimal compared to the long term high emissions projections (to 2070).

Using the security of supply for the top three demand months as a reference to determine the impacts climate change, short term climate change prediction are expected to decrease the security of supply of Scheme 1 and 2 by 6.0% and 4.8% respectively. The impacts of worst case long term climate change are expected to decrease security of supply by a further 300% for both Scheme 1 and 2 with security of supply dropping by 18.9% and 16.0% respectively.

The annual volume of stormwater run-off entering the storages for both case studies decreased in the modelled climate change scenarios. Scheme 1 had additional evaporative losses from the open water storage however these were negligible compared to reduction in supply to the scheme as a direct result of changes in rainfall.

The impacts of climate change for the two schemes are varied as a result of numerous factors which are outlined below:

- Demand Profile

The changes to summer security of supply varied for the two sites, with the smaller impact for Scheme 2 due to the larger irrigation demand in October (as opposed to over the summer months).

- Storage Size

The increase in storage size to maintain the same level of security of supply varied for both of the case studies. Typically an increase in the storage size of approximately 180% may be required to maintain current stormwater harvest volumes and security of supply levels for the top three demand months.

- Low flow diversion

Schemes relying on the capture of low flows to meet security of supply requirements will have greater impacts as a result of climate change.

- Buffer tank size

The projections for climate change impacts indicate fewer but more intense rainfall events. Increasing the size of buffer tank size to capture the larger peaks in stormwater run-off will be required.

- Storage Type

It should be noted that the further impacts of climate change are negligible if an uncovered storage is used for a stormwater harvesting scheme (as opposed to a covered storage).

It should be noted that design considerations accounting for climate change impacts should be assessed with a cost-benefit approach considering the life span of the system.

Modelling results showed that for both case studies the top three consecutive demand months were critical in assessing the impacts of climate change. The modelling methodology in assessing climate change should therefore use this criteria when assessing schemes.

Conclusions

The two stormwater harvesting schemes presented in this paper both had varied decreases in security of supply for the various climate change scenarios. Based on the findings from these schemes, the following recommendations have been made. These recommendations highlight how to model a scheme that accounts for the impacts of climate change, how to analyse the modelling results, and how to further adapt a system to suit supply objectives:

1. Methodology

This paper demonstrates a simple method for modelling potential impacts to stormwater harvesting systems as a result of climate change. This method, which can be adapted to other regions using the relevant climate data and climate change projections, is summarized below:

- Develop a water balance model using existing recorded climate data sets for the region and determine total water harvest and security of supply for:
    - top three demand months
    - summer
    - annual.
- Determine the scheme's life span and choose relevant climate change projections to simulate and quantify potential impacts on the total water harvest and security of supply of the proposed scheme.
- Factor existing rainfall data to reflect likely changes as a result of climate change. The rainfall data should be modified as follows to account for climate change projections:
    - factor up all intensities by the amounts recommended by climate change analysts (such as CSIRO, the Bureau of Meteorology or DSE in Victoria)
    - progressively remove the smallest rainfall events from the data series until the mean annual rainfall is reduced by the amount recommended in the relevant climate change predictions.
- Factor up all evapotranspiration values by the amounts recommended by climate change analysts (such as CSIRO, the Bureau of Meteorology or DSE in Victoria).
- Calculate security of supply and total water harvest of the proposed stormwater harvesting scheme for selected climate change scenarios.
- Review results based on recommendations outlined below.
- Modify the scheme design based on the recommendations outlined below.

2. Reviewing results

When reviewing the results from the water balance model it is important to calculate the security of supply for the system, to check the design is sufficient to meet the irrigation demands. Based on the findings from the two case studies investigated, it is recommended that the security of supply be considered (in order of priority) for:

- top three consecutive demand months
- summer security of supply
- annual security of supply.

It is important to consider each of these three security of supply assessments and determine how they will affect the end use. Simply considering the annual security of supply and/or the summer security of supply may not be enough to paint a complete picture of the impacts of climate change.

Depending on the demand and the end use, it may be necessary to adjust the stormwater harvesting system to maintain a particular security of supply.

3. Impact on design

In both case studies investigated, the security of supply decreased as time progressed. Therefore, to maintain a particular security of supply, it may be necessary to modify the design (using a cost-benefit approach in considering the proposed changes) of the stormwater harvesting system. The following design factors should be considered in this review:

- Uncovered versus covered storage.
- Storage size.
- Buffer tank size.
- Low flow bypass

Climate change will affect all stormwater reuse schemes, such as the two analysed in this paper, to varying degrees. The impacts of climate change on a particular system are likely to vary depending on its location, composition and many other factors.

This paper has highlighted the need for engineers and designers of these systems to consider not just the impact on annual security of supply for a particular scheme, but also the summer security of supply and the security of supply of the three consecutive demand months. If these assessments are done then the likely impacts of climate change may be better understood and system refinements can be made where needed. Following the three steps recommended above will allow us to continue to use stormwater as a viable non-potable resource and to better understand its limitations in a changing world.

References

CSIRO and Bureau of Meteorology (2010). State of the Climate

CSIRO and Bureau of Meteorology (2007). Climate Change in Australia: Observed Changes and Projections. www.climatechangeinaustralia.gov.au

CSIRO and Melbourne Water (2005). Implications of Potential Climate Change for Melbourne's Water Resources.

Department of Sustainability and Environment (2008). Climate Change in Port Phillip and Westernport. www.climatechange.vic.gov.au
Intergovernmental Panel on Climate Change (2007). Climate Change 2007 – the Fourth Assessment Report (AR4)