CLIMATE CHANGE IMPACTS ON STORMWATER HARVESTING YIELDS

Evaluating the impacts of climate change on urban water systems through simulation of a range of climate change scenarios

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ABSTRACT

Stormwater harvesting has significant potential as an alternative water supply, because: a) it is relatively abundant; (b) it is often available in close proximity to urban demands; and (c) it causes environmental harm if *not* harvested.

Climate change is expected to result in increased climate variability, including droughts, which reduces the reliability of inflows into dams. This has led many policy makers to seek a reduced reliance on climate-dependent sources of water. The role of stormwater harvesting in this context is unclear and is often misunderstood. While yields from stormwater harvesting schemes are somewhat rainfall dependent, they are also heavily influenced by demands, which tend to increase with lower rainfall.

Large-scale stormwater harvesting projects in Brisbane have been adopted as case studies. These schemes harvest water from 200 ha urban catchments for sports field irrigation.

An ensemble of climate change scenarios, developed by the Queensland Climate Change Centre of Excellence from downscaled global climate models, have been coupled with MEDLI (Model for Effluent Disposal using Land Irrigation) to assess the impact of climate change on irrigation demands. A catchment runoff is also estimated, and the combined impact on yields is evaluated.

The results help better understand the climate resilience of stormwater harvesting schemes.

Hypothesis: *That climate change is unlikely to have a significant impact on the yields of stormwater harvesting schemes.*

INTRODUCTION

Stormwater harvesting has significant potential as an alternative water supply, because stormwater is relatively abundant, is often available in close proximity to urban demands, and causes environmental harm to waterways if it is not harvested, through increased pollution loads and altered hydrology of urban streams.

Harvested stormwater is primarily used for non-potable purposes, especially irrigation and, in some instances, as a dual-reticulated supply for non-potable domestic use. Support for stormwater use as a water supply appears to be increasing in Australia, according to the *2014 State of the Water Sector Report* (AWA/Deloitte 2014), which found: *Most respondents (92%) strongly agree, agree or somewhat agree that urban stormwater can provide a sustainable source of non-potable water for municipal and industrial use. This figure drops only slightly to around 79% of respondents who also believe that urban stormwater can be treated and managed to a level that is sufficient for safe potable supply. However fewer respondents still believe that it is a cost-effective source of potable water for Australian cities (65%).*

Climate change is expected to result in increased climate variability including droughts, which reduces the reliability of inflows to dams. This has led many policy makers to seek a reduced reliance on climate-dependent sources of water. The role of stormwater harvesting in this context is unclear and often misunderstood. Inflows to stormwater harvesting schemes are clearly rainfall dependent, although urban runoff is less influenced by antecedent dry periods than runoff into dams, due to increased impervious surfaces. Water demands (for irrigation purposes) are also climate dependent, and tend to increase with lower rainfall and higher temperatures.

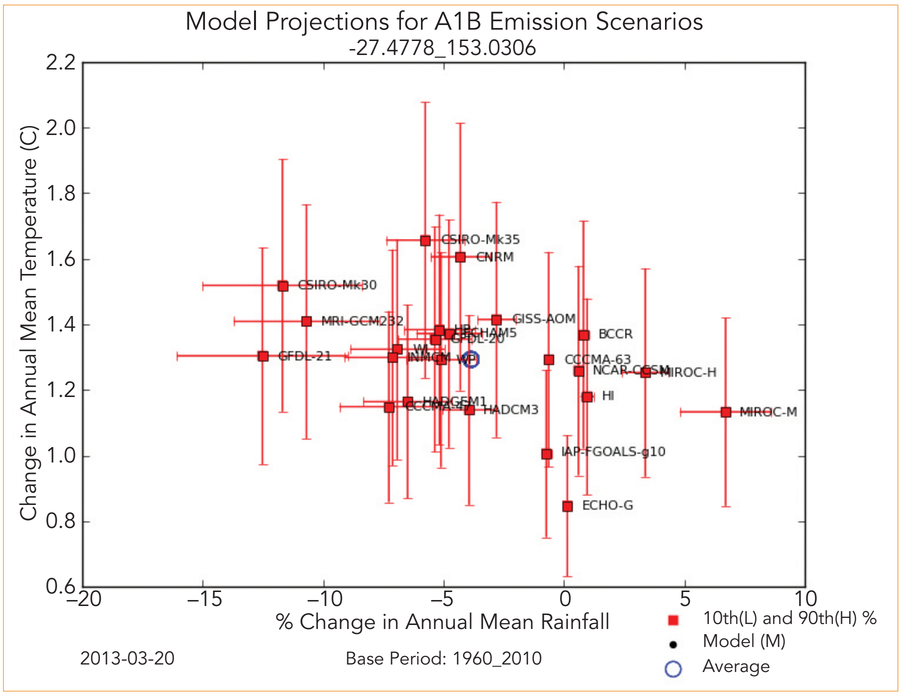

Figure 1. Predicted changes in temperature and rainfall for A1B emissions scenario from a range of models. Most predict lower mean annual rainfall at higher temperatures, but also show significant variability. *Source: Consistent Climate Scenarios, DSITIA Qld.*

The combined impact of changes on the supply of water to, and demand of water from, stormwater-harvesting schemes is complex.

Analysis of climate change impacts is confounded by several factors:

- There are different possible trajectories for global CO_2 emissions;
- There are many different general circulation models (GCMs) that produce different estimates of how the emissions trajectories affect climate (see Figure 1, for example);
- Global climate models have tended to have low resolution and be less useful for understanding local scale impacts;
- Stormwater harvesting yields are generally a function of catchment runoff (affected by climatic parameters of rainfall and evaporation) and catchment parameters such as the impervious fraction, and demand (affected by climatic parameters of rainfall, evaporation, radiation and temperature).

Simplistic estimates of climate change impacts can be derived by scaling historical rainfall data by a nominal factor (say up or down 10%). While this shifts the mean annual runoff, it maintains the historical patterns of rainfall, and that is likely to be a significant deficiency when estimating the performance of stormwater harvesting schemes. Another simplified approach is to transpose rainfall records from another region (for example, adopting a rainfall record from the dry tropics for use in the subtropics). These methods are both subjective and generally lacking a sound theoretical basis.

Recognising that researchers conducting studies of climate change impacts on primary industries have previously not had access to a consistent set of climate change projections in a suitable format for use in biophysical models, the Queensland Government established the Consistent Climate Scenarios Project (CCSP) (Burgess *et al.*, 2012). CCSP has produced a consistent set of model-ready 2030 and 2050 Australia-wide climate change projections data, via the Climate Change Projections web portal. These are downscaled climate scenarios at a local (20km) resolution.

While developed for primary industries, these climate change scenarios provide a means of evaluating the impacts of climate change on urban water systems.

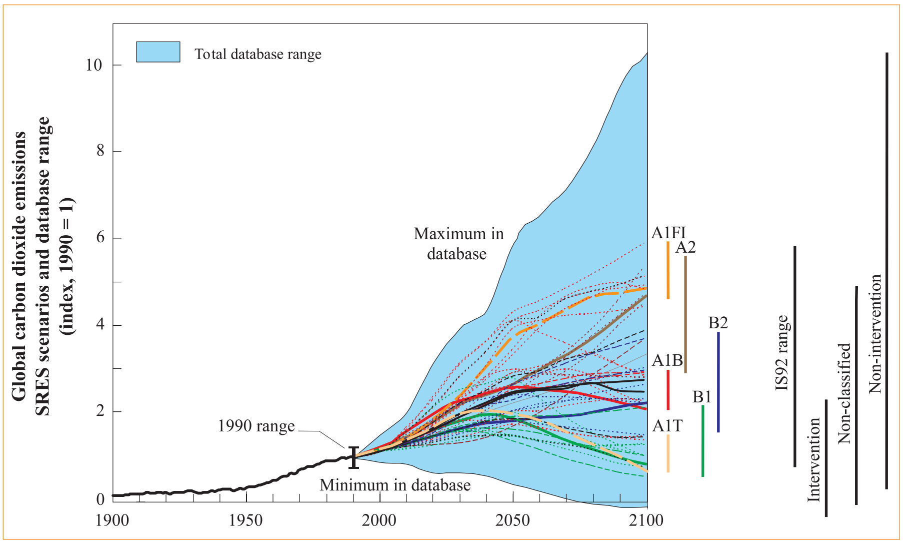

Figure 2. Global CO_2 emission scenarios. In this paper, the A1F1, A1B and B1 scenarios have been adopted for analysis. *Source: IPCC, 2000.*

METHODOLOGY

METHODOLOGY OVERVIEW

The overall approach used in this analysis is to simulate the performance of two stormwater harvesting schemes in Brisbane under a large number of possible climate change scenarios that have been derived from credible emissions scenarios and general circulation models. The resulting dataset is considered a population of equally probable outcomes, similar to a Monte-Carlo simulation.

CLIMATE DATA

Three climate change carbon dioxide emission scenarios have been considered, based on the IPCC Special Report on Emission Scenarios (SRES): A1F1, A2 and A1B scenarios for the year 2050 (IPCC, 2000). These scenarios tend to sit in the mid-to-upper range of emissions scenarios (see Figure 2), spanning a range of potential narratives about future global population, economic, technological and political developments, and according to the IPCC should all be considered equally sound. Lower emission scenarios (such as A1T and B1) were not analysed due to a combination of time constraints (significant data processing is involved in this analysis), and because the intention of this paper is to test stormwater harvesting schemes under quite different climates.

Downscaled climate time series for temperature (max and min), vapour pressure, radiation, pan evaporation and rainfall for Brisbane (latitude -27.4778 longitude 153.0306) were obtained from the Consistent Climate Scenarios Project (CCSP), derived from 21 different general circulation models/model variants (GCMs) representing a range of different institutions and modelling approaches (Burgess *et al.*, 2012). This produces 63 synthetic climate scenarios (three emission scenarios each processed through 21 climate models).

Each time series is for a 50-year period to ensure adequate reflection of the stochastic variability of each model, and assumes static emissions during that period (i.e. there is no additional climate forcing within a scenario and emissions are fixed at the corresponding 2050 SRES level).

A base case climate scenario was also tested using daily climate data from the Bureau of Meteorology station 40214 (Brisbane Regional Office) for the 50-year period 1960–2010.

MUSIC (Model for Urban Stormwater Improvement Conceptualisation, eWater 2014) was used to simulate the performance of the stormwater harvesting schemes, due to its flexibility and accessibility.

MUSIC was configured to reflect two stormwater harvesting schemes which were recently designed in Brisbane, although the MUSIC models were simplified, for the purposes of this analysis, to be straightforward catchment-to-tank to end-use schemes when, in reality, the schemes have complex pumped diversion arrangements and multiple storages. The purpose of this analysis was to assess the general impact of climate change on harvesting yields rather than to precisely assess the impacts on those particular schemes.

Scheme A has a 213.5 ha urban catchment that is 37% impervious (measured from aerial imagery), draining to a 3ML storage, and supplying 16ha of sports fields. This represents a scheme where yield is storage-limited. Scheme B is similar to Scheme A except that it has a 10ML storage, and yield is more limited by demand.

MUSIC climate input files were produced for each climate scenario (based on rainfall and evaporation from the CCSP).

For each scenario, an irrigation demand series was produced using MEDLI (CRC-WMPC, DNR, DPI, 2003). While primarily developed for effluent disposal, MEDLI has an irrigation module that calculates an irrigation demand based on soil water condition and crop water requirements, and is therefore well suited to the task of estimating an irrigation demand from the synthetic climate data (Tmax, Tmin, Rad, Evap and Rainfall).

MUSIC was run on a daily time-step reflecting the time-step of the CCSP data. A shorter time-step would have more accurately reflected the hydrology of the catchment, but would have significantly increased the processing time and volume of data. A comparison of scheme performance using historical rainfall data (1960–2010) at 30-minute and daily time-steps was found to provide yields within 5%, so this was not considered a major limitation. The rainfall runoff parameters in MUSIC were configured in accordance with Water by Design (2010).

In addition to these steps, custom Visual Basic code was written to transform and transpose the data to convert it into the various formats required by the adopted models to make the process more efficient and, therefore, more suited to wider application.

An overview of the models and processes employed is shown in Figure 3.

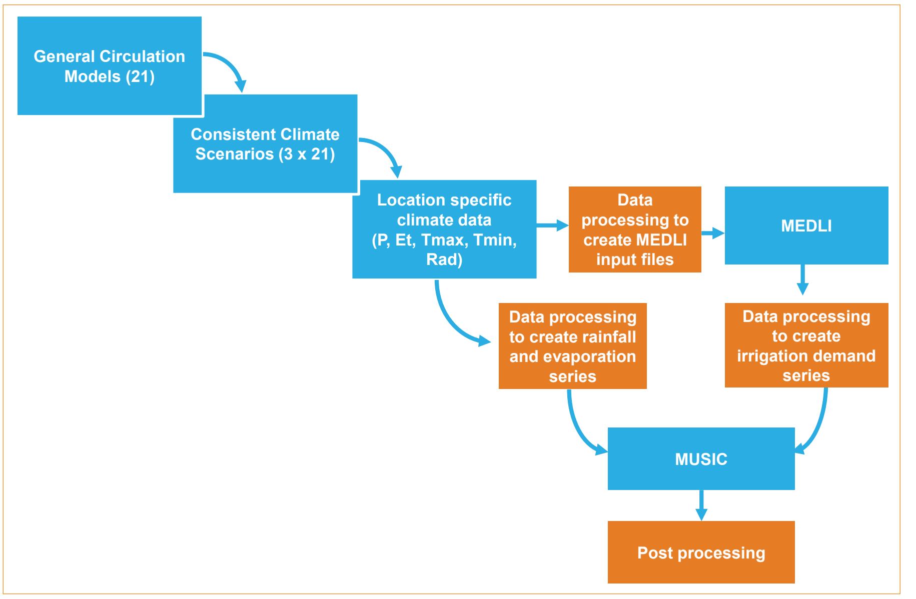

Figure 3. Schematic overview of the adopted models and processes.

RESULTS AND DISCUSSION

For the range of climate scenarios analysed, mean annual runoff from the 200ha catchment ranged from 680 to 1280 ML/yr, compared with 982 ML/yr based on historical climate data. The potential for greatly reduced catchment runoff is notable for an urban catchment with moderate levels of imperviousness (37%) and has significance for runoff into dams from rural/forested catchments.

EMISSION SCENARIOS EXPLAINED

- A1. The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil-intensive (A1FI); non-fossil energy sources (A1T); or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies).
- A2. The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.
- B1. The B1 storyline and scenario family describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures towards a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.
- B2. The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

Table 1. Summary of results.								
	Units	Base case 1960–2010	Synthetic climate scenarios					
			Mean	Median	Max	Min	Cv	Std Dev
Catchment runoff	ML/yr	982	955	930	1282	679	0.147	136.41
Irrigation demand	ML/yr	153	164	163.8	186.8	148.8	0.046	7.49
3ML Storage								
Reuse supplied	ML/yr	64	65	64.7	65.8	61.5	0.011	0.73
% Reuse demand met		42	40	39.6	43	33.9	0.042	1.68
10ML Storage								
Reuse supplied	ML/yr	117	120	121	123.5	115	0.019	2.26
% Reuse demand met		77	74	74	77.5	64.4	0.032	2.38

The demand ranged from 149 to 187 ML/yr, compared with 153 ML/yr based on historical climate data, as shown in Table 1.

As would be expected, there is a relatively strong negative correlation between runoff and demand, with drier climate scenarios tending to have higher irrigation demands and wetter climate scenarios tending to have lower irrigation demands, as shown in Figure 4. However, of interest was the finding that the overall variability in demands (Cv = 0.046) was less than a third of the variability in runoff (Cv = 0.147), so that irrigation demands were relatively stable even under particularly wet or dry climate scenarios.

The reliability of the schemes, defined as the percentage of the reuse demand met, was higher for the larger 10 ML storage (74%) than the 3ML storage (40%), and there was quite low variability in reliability across a wide range of runoff scenarios (see Figure 5). For the 10ML scheme, the variability in reliability (Cv = 0.032) was less than a quarter of the variability in runoff (Cv = 0.147).

Note that most stormwater harvesting schemes are designed as complementary water supplies to a broader water supply network, where the design intent is to produce a cost-effective scheme that reduces but does not eliminate demand on that network.

Each of the schemes was marginally more reliable than when modelled under an historical climate (1960–2010): 42% reliability for a 3ML storage compared with a mean of 40% for the climate change scenarios, and 77% reliability for a 10 ML storage compared with a mean of 74% for the climate change scenarios.

The results show that under a range of possible climate change scenarios, the long-term yields and reliability of schemes that harvest stormwater for irrigation purposes are likely to be relatively stable even though catchment runoff is likely to vary significantly.

So, while inflows are highly climate dependent, yields from stormwater harvesting schemes are much more insensitive to climate, and it appears that stormwater harvesting can play a significant role as part of a portfolio of water supply options under a changing climate.

There are potentially other ways in which the merits of stormwater harvesting schemes may be affected by climate change scenarios that have not been explored in this paper. For example:

- The cost of providing major supply augmentations to centralised supplies is rising, while the costs of stormwater harvesting are anticipated to remain relatively stable;
- Aquatic ecosystems would be under increased stress, and so society may place a greater value on reducing stormwater pollution into those ecosystems;
- Many of the SRES scenarios incorporate significant population growth and so, in an increasingly resource-constrained world, alternative sources of water will likely be of increased value;
- A further benefit of using harvested stormwater for irrigation is that plants

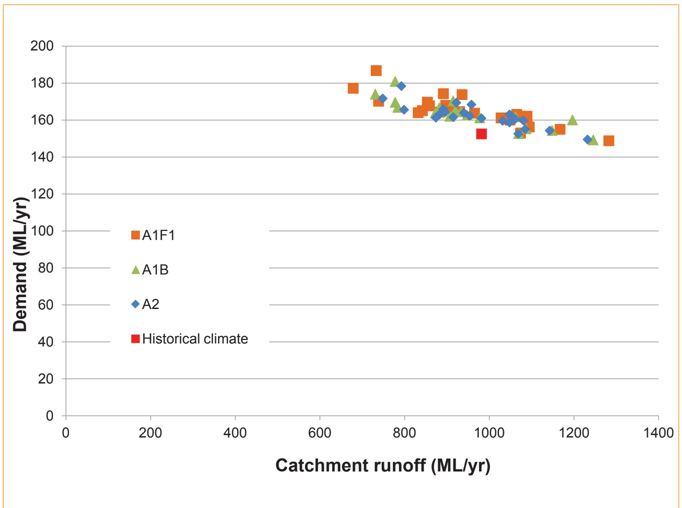

Figure 4. Modelled relationship between catchment runoff and demand.

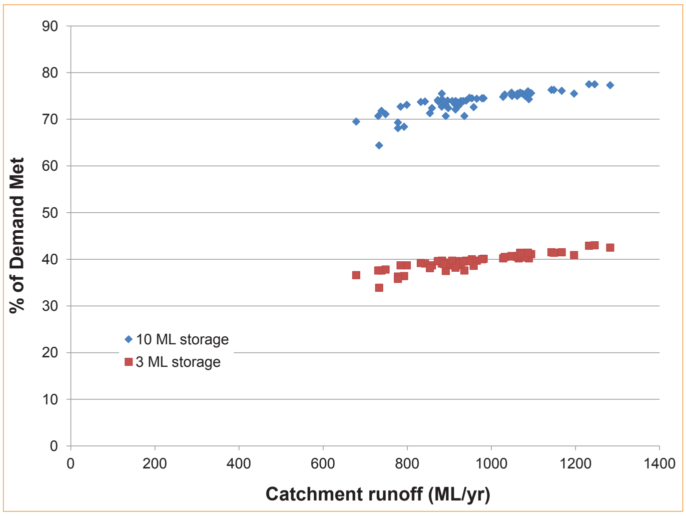

Figure 5. Modelled relationship between catchment runoff and percentage of demand met.

irrigated with stormwater have been found to grow about twice as fast as those irrigated with an equivalent amount of tap water (Denman, 2011).

LIMITATIONS AND FURTHER WORK

Each datum point shown on the graphs in Figure 4 and Figure 5 represent the long-term average of a 50-year simulation. Within each of these simulations there is likely to be significant inter-annual variability, with potentially severe droughts and wet periods (Cai *et al.*, 2012). The analysis of such inter-annual variation for each of the scenarios is a significant computational exercise and beyond the scope of this paper, but may yield important insights into how a portfolio of water supplies (dams, recycling, roof water, stormwater and desalination), might provide best overall resilience in a given area.

Further work in this area could also consider alternative demands profiles, such as would arise from non-potable and potable end uses in addition to irrigation.

In areas other than Brisbane, different climatic patterns may lead to different relationships between climate, runoff, demand and yield.

CONCLUSIONS

- Datasets from downscaled general circulation models are becoming available and provide the ability to assess potential impacts of climate change on urban water systems;
- The potential impacts of climate change on stormwater harvesting yields in Brisbane have been assessed;
- 63 synthetic climate change scenarios in 2050 have been analysed, based on three emission scenarios (A1, A1B and B1) and 21 General Circulation Models;
- Five climatic variables are accounted for to estimate the combined effect on irrigation demands and catchment runoff;
- The results show that, while long-term catchment runoff has the potential to vary quite significantly, yields from the scheme remain relatively constant;
- Yields from stormwater harvesting schemes (for irrigation purposes in SEQ) are likely to be quite resilient (insensitive) to changes in climate over the next 50 years.

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