The impact of spatial and temporal averages on prediction of water security using systems analysis – towards understanding the true potential of WSUD.

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ABSTRACT

This study has adopted unique spatially and temporally explicit methods of systems analysis to understand the impacts of average water demands on the security of water supplies for Sydney and Melbourne. The analysis utilised detailed local inputs throughout the systems, such as demographic profiles, human behaviour and climate dependent water demands, and linked systems that account for water supply, sewerage, stormwater and environmental considerations.

Use of average water demands that replace spatial and temporal detail in analysis of regional water systems generates dramatic reductions in certainty about system behaviour that leads to large uncertainty in understanding of the performance of the system. The use of global averages in simulation of regional water systems is unlikely to describe the spatial and temporal contribution provided by WSUD approaches that generate water resources or reductions in water demands within a metropolis.

It is recommended that analysis of regional water resources for cities use spatially and temporally explicit methods of systems analysis to understand the security of urban water supplies. Otherwise, the full potential of alternative water management options including WSUD approaches may not be understood.

KEYWORDS

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Water, security, averages, spatial and temporal

INTRODUCTION

The combined pressures of population growth, a highly variable climate and the potential for climate change challenges the future security of water supplies to Australian cities (Coombes and Barry, 2008). It is now recognised that more flexible strategies utilising multiple sources of water are a more appropriate response to the security of urban water supplies (PMSIEC, 2007). By using available water resources from traditional centralised strategies and from within a metropolis in combination with a diverse range of water conservation strategies the resilience of a city's water supply will be greatly enhanced (Coombes et al., 2002; Coombes, 2005; Knights and Wong, 2008).

These approaches are consistent with the principles of Water Sensitive Urban Design (WSUD). However, the efficiency of traditional water supply catchments is substantially less than urban areas that include impervious surfaces and are, therefore, largely immune to the hysteresis exhibited by traditional water supply catchments in runoff generation (Coombes and Barry, 2008).

Most parameters that describe the characteristics and behaviour of a metropolis are subject to strong spatial and temporal variation (Coombes and Barry, 2009; Coombes, 2005). Water demand is dependent on demographic, climate and socio-economic parameters that vary across a city. Considerable spatial and temporal variation in climate, stormwater runoff and water use behaviours are also expected throughout urban regions (Coombes and Barry, 2007).

The impact of this variability and the opportunity of WSUD approaches throughout a city are not considered by the common use of average water demands in analysis of the security of water supplies.

Until recently water management strategies in Australia were dominated by proposals for large regional infrastructure projects that commonly resulted in dismissal of smaller scale alternative strategies including WSUD approaches. The response to the recent drought and the serious concerns about water security for metropolitan areas continued a preference for large scale traditional projects. It was commonly argued that alternative strategies are not effective.

It is clear that the local and small scale actions of citizens ensured that the majority of Australian cities did not exhaust urban water supplies. Melbourne residents reduced water use by up to 50% using rainwater harvesting, water efficient appliances, reuse of greywater and changes in behaviour. A similar response was commonly experienced across Australia (Aishett and Stienhouser, 2011). The details of this response have been largely ignored in shaping a water supply strategy for the future. Ironically, the very system that had failed to anticipate the recent drought was activated to provide the response to the future in form of large scale infrastructure solutions. Is the prevailing pessimistic view of alternative water management strategies an artefact of average assumptions used in analysis?

This study has adopted unique spatially and temporally explicit methods of systems analysis to understand the impacts of average water demands on the security of water supplies for Sydney and Melbourne. The analysis utilised detailed local inputs throughout the systems, such as demographic profiles, human behaviour and climate dependent water demands, and linked systems that account for water supply, sewerage, stormwater and environmental considerations. The systems analysis was built on local scale rather than traditional analysis of metropolitan water resources that commences with regional scale assumptions.

METHODS

This study employed an integrated systems approach to analysing the performance of water cycle systems in the Greater Sydney and Melbourne regions. This unique analysis is dependent on detailed inputs, such as demographic profiles, and linked systems that accounts for water demands, water supply, sewerage, stormwater and environmental considerations. It is important construct the systems analysis from the basic elements (the lot scale inputs) that drive system behaviours and account for first principles transactions within the system to allow simulation of spatial performance of the system. The water cycle systems for both regions were constructed using three basic components:

- Sources - regional and local demands, water sources, catchments and waterways
- Flux – transport and treatment of water, sewage and stormwater throughout regions
- Sinks – stormwater runoff and wastewater disposal to waterways

This fundamental concept is outlined in Figure 1.

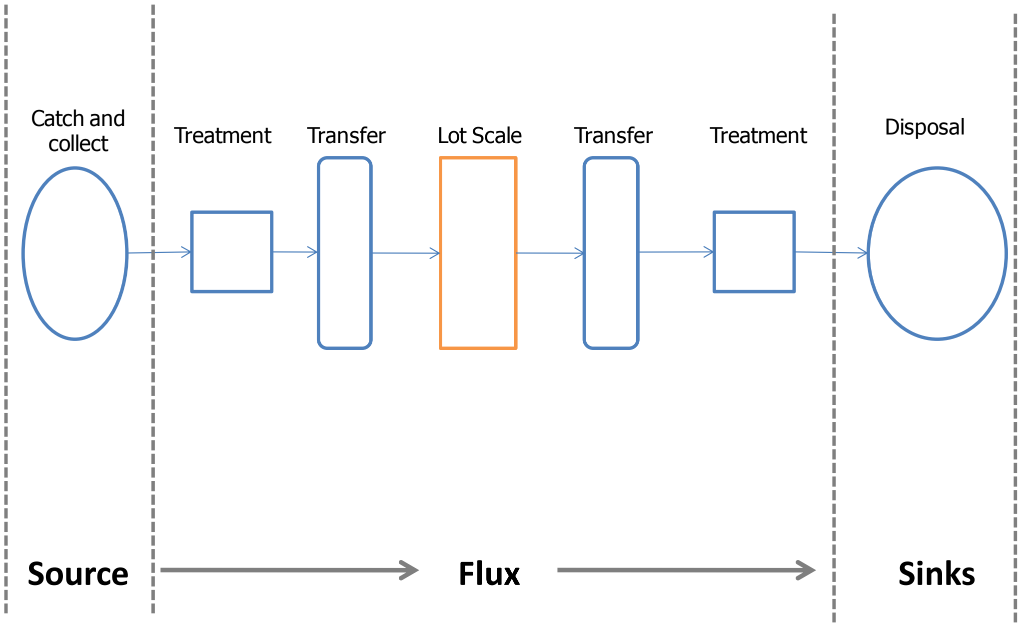

Figure 1: The principles underpinning any water system – Sources, Fluxes and Sinks

Figure 1 highlights the elements that were incorporated at different scales in the analysis. This includes water use and demographics at the lot scale, distribution infrastructure and information at the sub-regional or precinct scale, and regional behaviours and infrastructure such as water extractions from dams and discharges of sewage to wastewater treatment plants.

This process can be described as analysis of systems within systems across multiple scales. A unique biophysical and scale transition framework links the dynamics of the systems with inputs across scales and time. The analysis is anchored by a regional framework of key trunk infrastructure, demand nodes, discharge points, waterways and regional sources of water in the WATHNET systems model by Kuczera (1992). Major water distribution, stormwater, sewage, demographic, climate and topographic zones are combined in this framework.

This process compiles inputs from a wide range of commonly utilised analysis tools, including for local water demands and water balances simulated using PURRS (Coombes, 2006). Key simulation inputs to this framework include:

- Demographic data from the Australia Bureau of Statistics and State Government departments
- Climate data from the Bureau of Meteorology and streamflow data from the Sydney Catchment Authority and Melbourne Water
- Water and sewage flows sourced from Sydney Water and Melbourne Water
- Local and cluster scale behavioural water demands and water balances simulated in the PURRS model at 6 minute time steps using long climate and demographic records – calibrated using water billing data from Department of Sustainability and Environment and Sydney Water.
- Urban typologies and precincts analysed using a range of models including PURRS and MUSIC. These smaller scale systems are also analysed in more detailed WATHNET models.
- A biophysical and scale transition model compiles inputs from PURRS into Local Government areas (LGA) that was calibrated to observed data from water and sewage catchments.
- The Wathnet model was used to collate and simulate all inputs across the entire region

This framework incorporates the movement of water throughout the regions and connectivity to the water supply headworks system. Similarly, this framework includes the movement of sewage throughout the region and connectivity with discharge points or reuse systems. It includes stormwater catchments, conveyance systems and urban streams as shown in Figure 2.

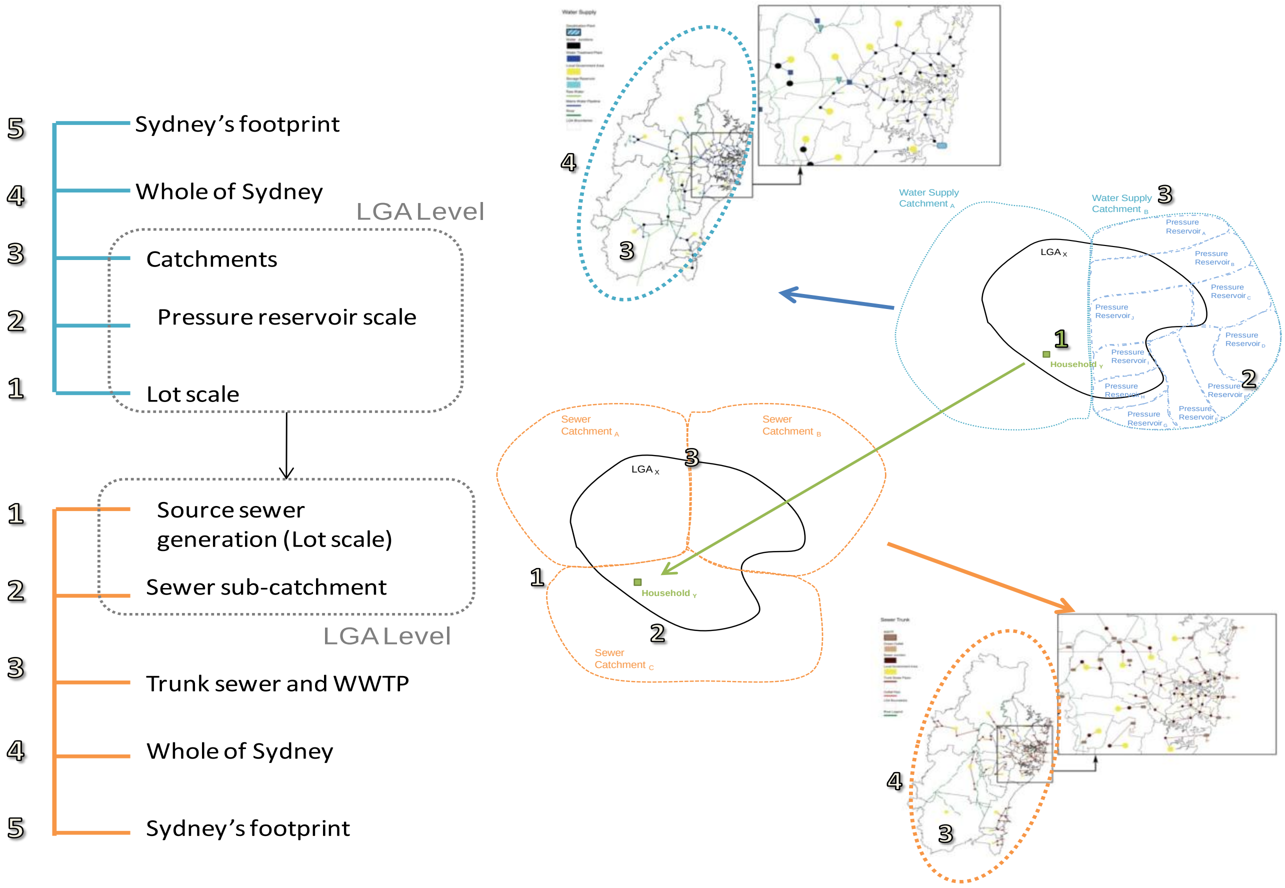

Figure 2: The linked and spatial nature of water and wastewater systems employed in this analysis

This investigation has utilised simulations of the system that employ daily time steps that are based on long sequences of spatially and temporally consistent climate, streamflows and spatially calibrated water use behaviours that are dependent on climate and demographic inputs. This detailed analysis is a departure from the normal water industry practice of using average water demands for the entire system that are varied by population and water use sectors (such as residential, industry, commerce and other). The impacts of different assumptions about water demands on perceived security of regional water supplies were derived in this study. The average water demands were derived from the same data for each city in three ways:

- by multiplying average water demand per person across the entire region by the population in each LGA (Global Average) and applying those demands to each node in the systems model;
- by multiplying the average water demand per person within each LGA by the population in each LGA (LGA Average) and applying those demands to each node in the systems model; and
- by multiplying the average water demand per person within each LGA by the population in each LGA and adjusting the demands for gross seasonal variations (Temporal LGA Average) and applying those demands to each node in the systems model.

All of the above assumptions effectively averaged the spatial and temporal demand patterns generated by the systems analysis with the exception of the third quantity which allowed for seasonal variability. For the Melbourne systems it was assumed that water from the current desalination plant was utilised when dam levels are less than 65% and water from the north south pipeline is used when dam levels are less than 30%. Desalination was used in the Sydney system when total storages in dams were less than 80%.

To preserve the climatic correlation between the urban and water supply catchments 100 equally likely replicates of streamflow and climate in water supply catchments and LGAs were simultaneously generated for the period 2010 to 2050 using a multi-site lag-one Markov model to generate annual values that were then disaggregated into daily values using the method of fragments as described by Kuczera (1992). Replicates of daily climate sequences (rainfall, temperature and evaporation) were used to generate water demands within each LGA (see Coombes, 2005).

Water restrictions were assumed to be triggered when total storage in dams is less than 60% for each region. A greater than 10% annual probability of water restrictions was deemed to indicate requirement to augment regional water systems.

RESULTS AND DISCUSSION

The impacts of different assumptions about average water demands on perceived security of water supplies to the Greater Sydney region are presented in Figure 3. Note that "correct demands" represent spatial and temporal results of continuous simulation (daily time steps) at 45 local government areas (LGA) throughout region (each model was calibrated to local historical data) , the "LGA average" is the long term daily average demand at each LGA as calculated from the high temporal resolution data, the "temporal LGA average" is the same long term average daily demand at each LGA but varied by a seasonal temporal pattern, and the "global average" is the long term daily average water demand for the entire region, again computed from the same data set used to develop and calibrate the high temporal resolution demand model.

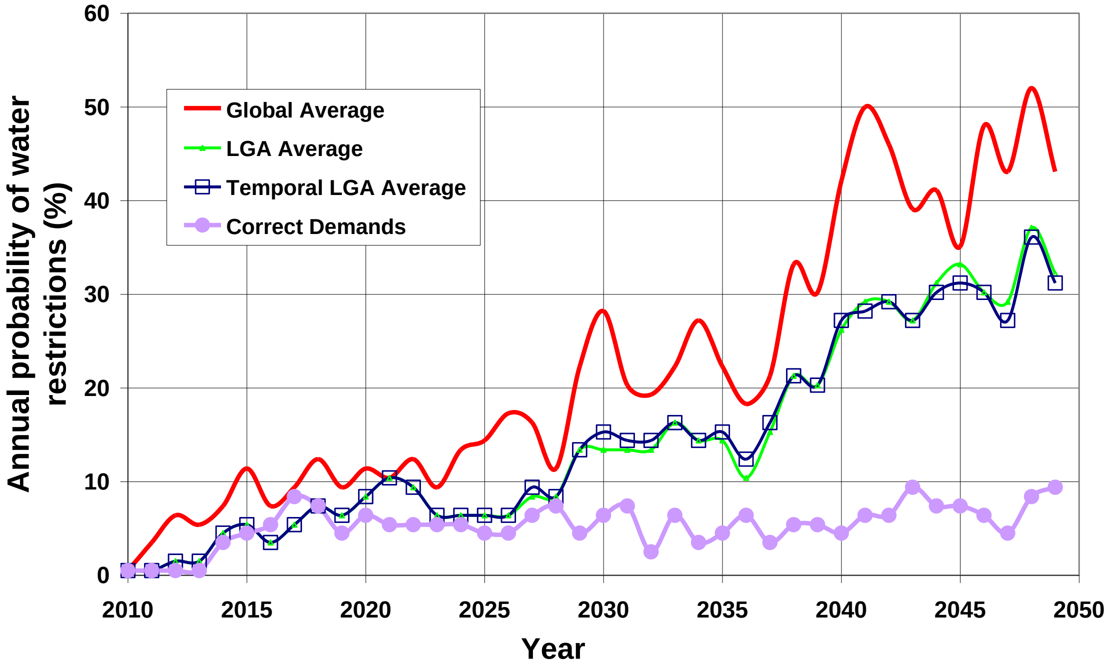

Figure 3: Impacts of using average water demands on the security of Sydney's water supply

Figure 3 reveals that the standard practice of using "global average" water demands in analysis of water resources provides the most pessimistic results for security of Sydney's water supply. Use of spatial average water demands at each LGA generates an improved perception of the security of water supply. The use of spatial averages with a seasonal temporal pattern provides a similar result. Importantly, the more detailed inputs to the simulation generate the highest security for the water supply system. More generally, the figure shows that using boundary condition data derived from the same raw data sets within the same model can produce strong variations in the model predictions. The direction in which these variations occur is less important: the fact that divergent predictions result from forcing a given model with different temporal resolutions of the same underlying data set is the key result.

The impacts of different assumptions about average water demands on perceived security of water supplies to Greater Melbourne as defined by 36 LGA areas were also invested given the above, and are presented in Figure 4. The definitions of the scenarios are as per the above example for Sydney, and it is again noted that the simulations used the same model setup, but with that model forced with boundary conditions computed at different temporal scales.

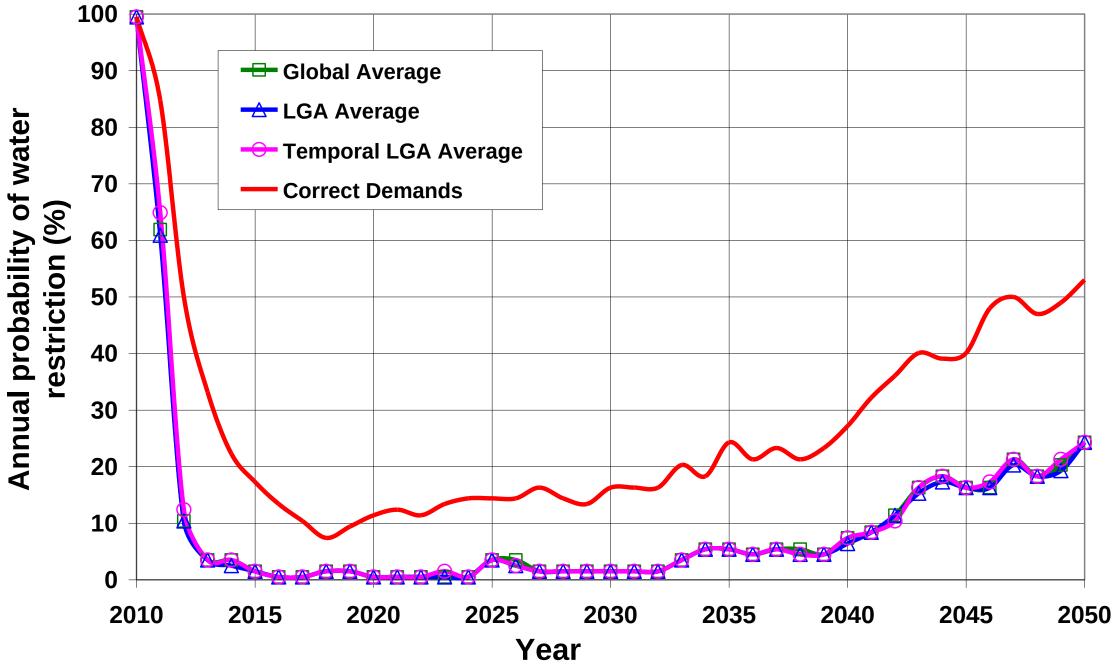

Figure 4: impacts of using average water demands on the security of Melbourne's water supply

Figure 4 shows that the annual probability of water restrictions decreases from 100% in 2010 as expected. It is also revealed that (contrasting to the Sydney case) the use of "global average" water demands provides the most optimistic results for security of Melbourne's water supply. Use of spatial average water demands and seasonal averages at each LGA generates a similar perception of the security of water supply.

Importantly, use of different spatial and temporal assumptions in simulations of regional water resources generates the highly variable perceptions of security for water supply systems. The requirement to augment water supply systems resulting from each assumption is shown in Table 1.

Table 1 reveals that the use of increasingly generalised temporally average water demands has a profound impact on the perceived requirement to augment the water supply system for Greater Melbourne – use of global average water demands changes the perceived security of Melbourne's water supply by 23 years. Alternatively, the use of global average water demands changes the perceived security of Sydney's water supply by 33 years, but in the opposite direction to that of the Melbourne case study. This is the key result of our work, i.e. that one predictor of system performance (water security) from fixed numerical models and underlying base data sets can vary widely as a function of the temporal scale at which demand boundary sets are applied. This variation does not appear to be unidirectional at this early stage of our research program, and this in itself warrants further investigation.

Table 1: Augmentation timing for different assumptions about water demands

Option	**Timing**	
	Sydney	**Melbourne**
Global average	2017	2042
Spatial average	2027	2042
Spatial average with temporal pattern	2027	2042
Detailed water demands	2050	2019

One result that does seem clear to us at this early stage is that the uncertainties about the prediction of water security are most likely driven by the multiple interactions in time and space that are typical for a complex system such as a regional water cycle – interactions that are unlikely to be captured at a scale that involves significant temporal and spatial averaging. Moreover, the relative timing of water demands and streamflows (and other factors) is also a key driver for understanding water security.

Given our initial findings in this regard, it may be the case that the current use of averages and generalisations for analysis of water security is also likely to generate an uncertain view of the capacity of alternative solutions to contribute to the security of water supplies for Sydney and Melbourne. This observation is particularly important for understanding the actual contribution of WSUD approaches that are spatially and temporally variable (and smoothed by averaging) to the security of a city's water supply. The likely characteristics of supporting WSUD policies include time based adoption of measures in response to planning policies and urban development, retention of water within urban landscapes and water supplies from within cities.

This investigation has only considered the impact of using averages and generalisations of water demands in the current water cycle systems for each city. It is likely that also using the generalisations about climate and streamflow inputs embodied in current practice introduce further uncertainty about system behaviours. This is the subject of ongoing collaborative research.

CONCLUSIONS

Use of average water demands that replace spatial and temporal variation in analysis of regional water systems generates dramatic reductions in certainty about system behaviour that leads to incorrect understanding of the performance of the system. This is the major finding of this investigation.

Moreover, the use of averages cannot capture the substantial spatial and temporal variation of the majority of parameters, including climate, demographics, urban form and socio-economics that drive the behaviour of any urban settlement. The use of global averages in simulation of regional water systems is unlikely to describe the spatial and temporal contribution provided by WSUD approaches that generate water resources or reductions in water demands within a metropolis.

It is recommended that analysis of regional water resources for cities use spatially and temporally explicit methods of systems analysis to understand the security of water supplies. This approach is particularly important to realise the value provided by WSUD approaches distributed throughout cities – that are unlikely to be captured at the large temporal and spatial scale. This analysis should utilise detailed local inputs throughout the systems, such as demographic profiles, human behaviour and climate dependent water demands, and linked systems that account for water supply, sewerage, stormwater and environmental considerations. Otherwise, the full potential of alternative water management options including WSUD approaches may not be understood.

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