A SYSTEMS FRAMEWORK OF BIG DATA DRIVING POLICY MAKING – MELBOURNES WATER FUTURE

Peter Coombes[1,2] and Michael Barry[3]
1. Chief Scientist, Office of Living Victoria, Melbourne, VIC
2. Urban Water Cycle Solutions, Newcastle, NSW
3. BMT WBM, Brisbane, Qld

ABSTRACT

This paper provides a snapshot of the integrated systems analysis of the Greater Melbourne region used to provide evidence for the Ministerial Advisory Council for the development of the Living Melbourne Living Victoria water policy and, the ultimate cabinet approval of the Melbourne's Water Future strategy. The systems analysis was built on local scale (the people) inputs (a "bottom up" process) rather than traditional analysis of metropolitan water resources that commences with regional scale assumptions (a "top down" process). The process using Big Data within a Systems Framework has revealed a range of challenges and opportunities in the Australian water industry that were hitherto obscured by more generalised analysis techniques.

INTRODUCTION

A forensic analysis has been undertaken of the existing biophysical and human systems that are related to the operation of the water cycle throughout Greater Melbourne. The analysis incorporates inputs based on large datasets (Big Data) from many disciplines in a Systems Framework to understand the potential urban futures for Melbourne. This investigation informed the Living Melbourne Living Victoria policies for whole of water cycle reform implemented by the Victorian government (Living Victoria Ministerial Advisory Council, 2011).

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). More flexible strategies utilising multiple sources of water are an appropriate response to the security of urban water supplies (PMSIEC, 2007). The resilience of a city's water cycle will be greatly enhanced by using available water resources from traditional centralised strategies and from within a metropolis in combination with a diverse range of water conservation strategies (Coombes et al., 2002; Coombes, 2005; Knights and Wong, 2008).

These approaches are consistent with the principles of Water Sensitive Urban Design (WSUD) and Integrated Water Cycle Management (IWCM). Moreover, the efficiency of traditional water supply catchments is substantially less than urban areas that include impervious surfaces and are, therefore, largely immune to the losses exhibited by traditional water supply catchments in generation of runoff (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) that is not often considered in the development of water policies. 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 observed throughout urban regions (Coombes and Barry, 2007; Coombes, 2013).

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 and IWCM 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. However, 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. For example, 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 crucial response should to be included in the shaping of water strategies for the future. However, it seems that these lessons about integrated responses from the recent drought have diminished in favour of large scale infrastructure solutions.

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

The existing integrated systems models of the Greater Melbourne region developed by the author over that last decade were updated and enhanced for use in developing the Living Melbourne Living Victoria water policy. These systems frameworks subdivide the region into hierarchies of distributed nodes, or ‘zones’, that represent opportunities, constraints and feedback loops across multiple scales. The systems analysis includes the entire water cycle (water, stormwater, wastewater and environment), incorporates a dynamic economic model and was based on behaviour of people throughout the metropolis. The asset management costs and challenges for operating water cycle infrastructure were included in the analysis.

This investigation included workshops with a wide range of disciplines throughout the Victorian water industry including staff from water authorities, town planners, economists and environmental managers. The systems process included calibration and verification across multiple scales, independent peer review, and scrutiny by water industry, bureaucracy and political processes. This paper provides a snapshot of the analysis and results. The reader is referred to the full report for additional detail (see Coombes and Bonacci Water; 2012) to the Melbourne’s Water Future strategy.

BIG DATA SYSTEMS FRAMEWORK

Development of evidence based policy has garnered substantial interest throughout a range of policy development domains. However, a barrier to the process of developing or implementing evidence based policies can be perceptions of certainty or uncertainty about deterministic data or information from single, partial or limited number of sources.

In contrast, the Systems Framework includes and links multiple layers of temporal and spatial data or information from many different disciplines and from multiple perspectives. Systems Frameworks link and process information across time and space, that include entire data set in Big Data Analysis processes. Big Data Analysis is the term for a collection of large and complex datasets that are difficult to process or understand using traditional database management tools or data processing applications.

A simple example is provided below for the intersection of Economics (A), Environment (B) and Water Resources (C) considerations in the development of state policy. A traditional deterministic policy process can be limited by perceptions of certainty about the data selected to underpin each of the policy elements. This is defined as the “area of deterministic certainty”.

The use of Systems Analysis processes allows and frames the complete Big Data inputs into a system. This results in a wider domain of overlapping data or information from different disciplines. Greater Systems Certainty about policy inputs and influence is provided by the overlapping information.

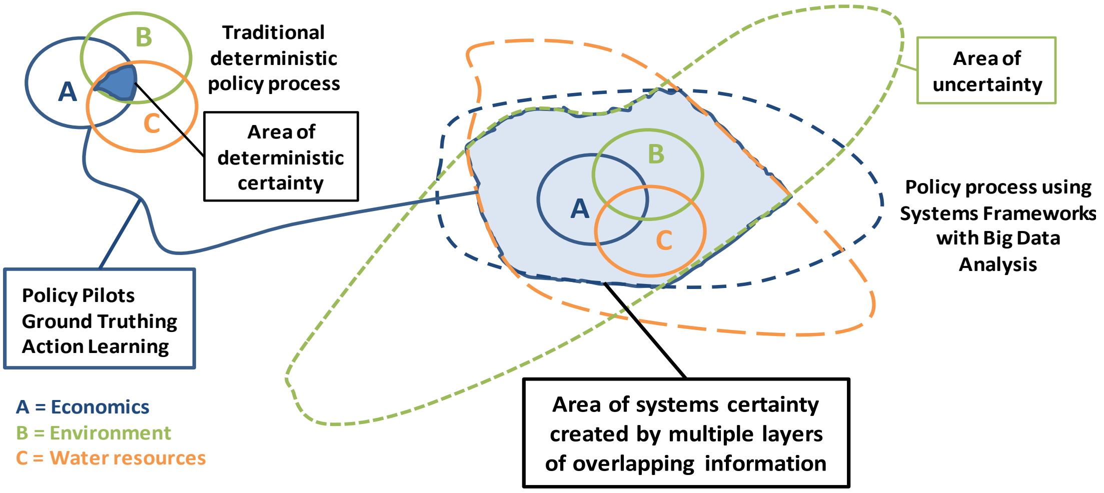

Figure 1: Conceptual diagram of deterministic policy process and the policy process using Systems Frameworks with Big Data

For example, overlapping data from financial costs and economic benefits (A), waterway health and biodiversity (B), and availability of surface water (C) is combined to provide greater understanding of whole of systems outcomes and trade-offs.

The continuing use of the Systems Framework with pilot programs for policy, ground truthing of changes in Big Data in response to actions, and the application of action learning provides a robust process to allow timely application of experimental policy initiatives. This process allows application of feedback loops in the policy process to allow continuous improvement and refinement to maximise value to the whole of society.

METHODS

This study employed an integrated systems approach to analysing the performance of water cycle systems throughout the Greater Melbourne region. 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. The systems analysis was constructed from the basic elements (local scale land uses) 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 the region 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

These elements were incorporated at different spatial, temporal and dimensional scales in the analysis. This includes water use (and linked generation of wastewater) and demographics at the local 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, space 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. Local government areas were chosen as key spatial nodes for reporting of information. This process compiles inputs from a wide range of commonly utilised analysis tools including continuous simulation of local water demands and water balances at 6 minute time steps using PURRS (Coombes, 2006). Key inputs to this framework include:

- Demographic data from the Australia Bureau of Statistics and Department of Planning, Transport and Infrastructure;
- Climate data from the Bureau of Meteorology and stream flow data from the Victoria Data Warehouse and Melbourne Water;
- Water and sewage flows sourced from Melbourne Water, City West Water, South East Water and Yarra Valley Water;
- Local and cluster scale behavioural water demands and water balances simulated in the PURRS model at 6 minute time steps using the longest available climate and demographic records – calibrated using water billing data from Department of Environment and Primary Industries;
- Urban typologies and precincts analysed using a range of models such as PURRS and MUSIC. These smaller scale systems are also analysed in more detailed WATHNET models;
- A biophysical and scale transition framework compiles inputs of the performance of local land uses into Local Government areas (LGA) using non-parametric algorithms that were calibrated to observed data from water and sewage catchments at multiple spatial scales; and
- The Wathnet model was used to collate all inputs into integrated natural and infrastructure networks and to simulate all spatial processes across the entire region.

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

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, stream flows and spatially calibrated water use behaviours that are dependent on climate and demographic inputs. This detailed analysis is a departure from the 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). Water from the current desalination plant was utilised when water levels in dams are less than 65% and water from the north south pipeline is used when dam levels are less than 30%.

To preserve the climatic correlation between the urban and water supply catchments 100 equally likely replicates of stream flow 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). Equally likely replicates of daily climate sequences (rainfall, temperature, evaporation and cumulative days without rainfall) were used to generate water demands within each LGA (see Coombes, 2005). Water restrictions were assumed to be triggered when total water storage in dams is less than 60%. A greater than 10% annual probability of water restrictions was deemed to indicate requirement to augment regional water systems.

Options were created to analyse the performance of alternative water management strategies. The purpose of establishing Options was to test the physical, technical and commercial performance of the system without the influence of opinions, perceptions and agenda. Defining a Base Case (Business as Usual) and Alternative Options facilitates examination, discussion, comparison and understanding of the water cycle throughout Greater Melbourne. This study did not seek to pick an endpoint or to provide a detailed design of the Options. It provides useful insight into systems behaviour that can inform decision making. Four alternative Options were examined for water cycle management within Greater Melbourne and compared to the BAU Option as outlined in Table 1.

Table 1: Summary of Options

Option	Description
Business as Usual (BAU)	Management of water, wastewater and stormwater using centralised infrastructure. Future water security and wastewater treatment is provided by regional infrastructure (such as desalination). Population growth requires expansion of existing networks.
BASIX	Water efficient appliances (Green Star 6 standard) and water efficient gardens in all new and redeveloped buildings. Rainwater harvesting for toilet, laundry and outdoor uses replacing requirement for On-Site Detention for stormwater management.
BASIX1	Water efficient appliances – Green Star 6 standard. Rainwater harvesting for toilet, laundry and outdoor uses replacing on-site detention for stormwater management.
ULT	Precinct scale wastewater treatment and reuse for toilet and outdoor uses. Precinct scale stormwater harvesting for potable water supply. Stormwater is treated and injected into the water supply network. Water efficient appliances and gardens in all new and redeveloped dwellings.
ULT1	Precinct scale wastewater treatment and reuse for toilet and outdoor uses. Local rainwater harvesting for laundry and hot water use. Mains water supply for kitchen and drinking purposes. Water efficient appliances and gardens in all new and redeveloped dwellings.

RESULTS AND DISCUSSION

The systems analysis revealed that significant water savings are achieved by use of alternative water cycle management strategies. The ULT Option that includes water efficient gardens and buildings, wastewater reuse for toilet, laundry and outdoor uses, and stormwater harvesting for potable water demands generates a 27% reduction in cumulative demands for mains water. The cumulative volume of water that is not extracted from the environment or provided by desalination is 5,200 GL. This equates to ten years of avoided mains water supply for Greater Melbourne in comparison to the BAU Option. The ULT1 and the BASIX Options provide similar cumulative reductions in demands for mains water of 20% (3,870 GL and 3,820 GL) and the BASIX1 Option generates a 17% (3,280 GL) reduction in demands for mains water (about 7 years of avoided mains water supply for Greater Melbourne).

The BASIX1 Option does not include water efficient gardens and utilises rainwater for irrigation of gardens which produces less water savings than the BASIX Option. However, the greater demand for rainwater to supply gardens almost overcomes the absence of water efficient gardens in the BASIX1 Option.

In contrast, the ULT1 Option generates significantly diminished water savings than the ULT Option because of omission of water efficient gardens and stormwater harvesting for potable water use is replaced by use of rainwater for laundry and hot water uses. The use of rainwater harvested from roofs for constant indoor uses such as laundry and hot water produces similar yields as stormwater harvesting for potable uses.

Integrated water cycle management strategies also create substantial reductions in cumulative wastewater discharges from the Greater Melbourne region. The use of water efficient buildings and precinct scale wastewater reuse schemes in the ULT Option has produced a 21% reduction (4,150 GL) in the cumulative discharge of wastewater from LGAs. This equates to avoidance of about seven years of wastewater discharges from Greater Melbourne. The ULT1 Option uses less treated wastewater than the ULT Option and generates a 17.5% reduction (3,430 GL) in cumulative wastewater discharges. The BASIX and BASIX1 Options provide reductions in cumulative wastewater discharges of 11% (2,240 GL) and 8% (1,650 GL) respectively. These reductions in cumulative wastewater discharges are created by use of water efficient appliances.

The economic performance of the water, wastewater and stormwater systems for each Option were evaluated from the perspective of the regional water manager using an investment analysis that included the costs of providing, renewing and operating the alternative Options. In addition, the security payments and costs to operate the current desalination plant and any augmentations were included in the cash flows attributed to the regional water, stormwater and wastewater systems. The costs of operating any privately operated water and wastewater treatment plants were included in this analysis. Costs and benefits from water efficiency, decentralised wastewater reuse, rainwater and stormwater harvesting strategies in the alternative Options were attributed to the regional water manager as it allows clarity in the comparison of Options. Note that the alternative precinct water management strategies in the ULT Option can be readily installed and operated by the private sector, and rainwater harvesting is likely to be operated by owners of properties. The analysis of each Option, subject to the high emissions climate change scenario, from the perspective of a regional water manager is presented as a cumulative sum of water and wastewater costs to 2050 in Figure 2.

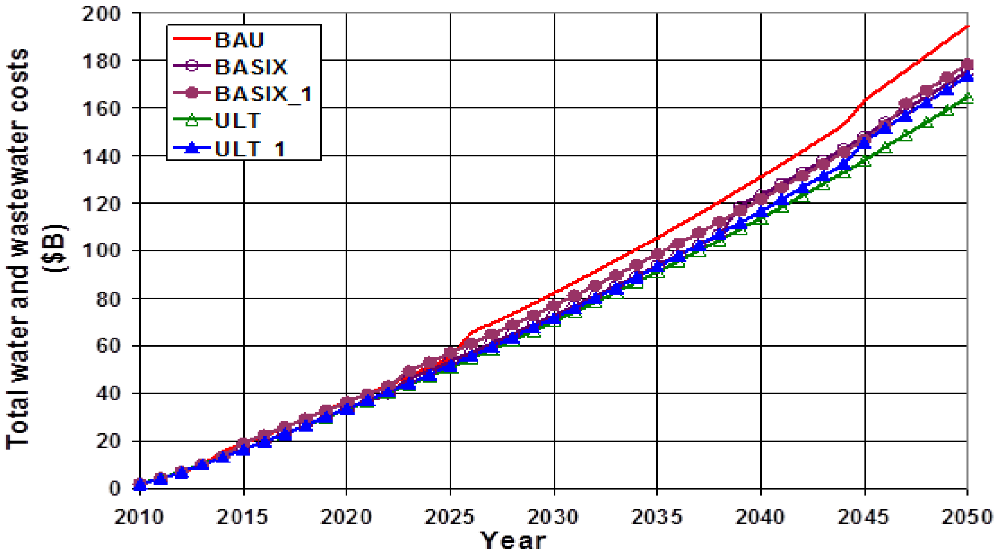

Figure 2: Cumulative costs of water and wastewater services for Options subject to the climate change

A summary of the net present costs for water supply, wastewater and stormwater management for the two alternative Options accepted by the Ministerial Council is provided in Table 2. This analysis uses a real discount rate of 4.24% which was equivalent to the Victorian bond rate.

Table 2: Net present costs to 2050 based on Victorian Bond Rates

Option	NPC ($B) to 2050				
	Water	WW	SW	Total	Diff
BAU	37	24.4	2.1	63	
BASIX1	33	22.6	1.9	57	6
ULT	34	19.8	1.8	55.8	7.2

Table 2 demonstrates that the building scale strategy will reduce the net present costs of water cycle management to 2050 by $6 billion which is 10% of expected discounted future costs. Similarly, the precinct scale strategy will diminish the net present costs of water cycle management by $7 billion which is 11% of expected discounted future costs. An analysis using a real discount rate of 0% was also conducted to understand the cumulative benefit of the options as shown in Table 3.

Table 3: Net present costs to 2050 based on real discount rate of 0%

Option	NPC ($B) to 2050				
	Water	WW	SW	Total	Diff
BAU	78.4	52	4.1	134.5	
BASIX1	68.4	47.5	3.4	119.4	15.1
ULT1	71.5	40.3	3.4	115.2	19.3

Table 3 demonstrates that the Living Victoria policy provides reduced cumulative costs to Victorians of $15.3 billion to $19.3 billion over the planning horizon to 2050. These savings equate to long term annual reductions in costs equivalent to 1% of the Victorian State Budget.

These savings also equate to an average annual saving of 16% of long term annual water costs. Note that the current total annual water expenses (including desalination costs) are about $2.99 billion and the total current revenue is about $2.4 billion.

These economic benefits are derived from reduced requirement for water and wastewater services generated by water efficient buildings and use of local water sources such as rainwater and wastewater. A diminished requirement to transport water, stormwater and wastewater across Greater Melbourne reduces the costs of extension, renewal and operation of infrastructure. In addition, the requirement for regional augmentation of water supplies creates long run economic benefits. The transfer distances for water supply and disposal of wastewater throughout Greater Melbourne are presented in Figures 3 and 4 respectively.

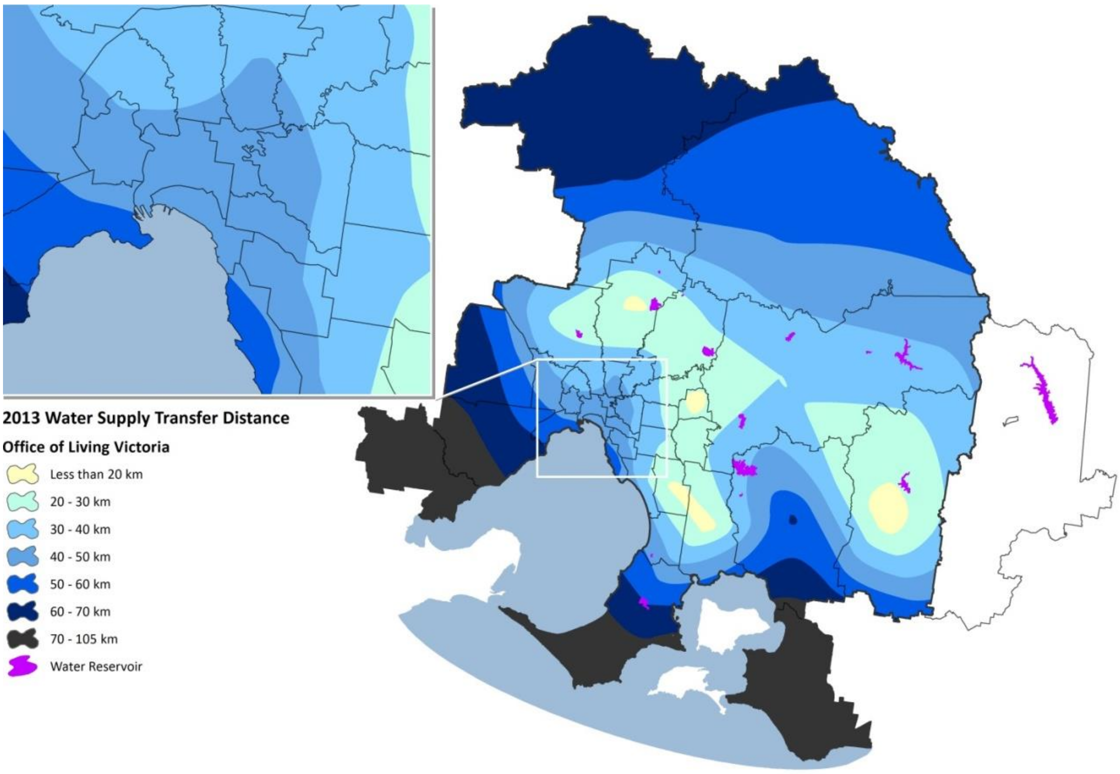

Figure 3: Transfer distance of water supply across Greater Melbourne

Figure 3 reveals that the longest transfer distances for water supply are to inland and western areas that are distant from bulk water external sources located east of Melbourne. The longest transfer distance of 105,000 metres is currently to the Bass Coast LGA. Figure 4 shows that the longest transfer distances for wastewater are from the current urban growth areas and inner city regions. The longest transfer of wastewater of 64,900 metres is currently from Manningham to the Western Wastewater Treatment Plant.

A key insight from this investigation was that reducing the size and connectivity of wastewater catchments reduces the transport of stormwater in the wastewater system. Management of stormwater runoff volumes and peak discharges from urban areas can assist with reducing risks associated with flooding, environmental damage created by higher frequency events and nutrient loads impacting on waterways. The economic analysis of each Option is presented as a cumulative sum of stormwater costs to 2050 in Figure 5.

Figure 5 shows considerable reductions in the cumulative costs of stormwater services to 2050. These economic benefits are generated by changes in the timing, frequency and volumes of stormwater runoff provided by rainwater and stormwater harvesting. The most significant impact of these strategies were reduction in nutrient loads to waterways, avoidance of nuisance flooding in higher density areas and diminished costs associated with requirement for land for stormwater management.

The economic savings revealed by the integrated systems analysis should be considered in the context of the total annual expenses documented in the 2011-12 Victorian budget papers of $47.2 billion.

The alternative water cycle strategies are expected to have a significant positive impact on the State’s finances for the period to 2050 and may allow considerable additional opportunities across different policy portfolios. In any event, the financial costs of the alternative Options are comparable to BAU with a wide range of additional benefits including resilience of water cycle systems and reduced environmental impacts.

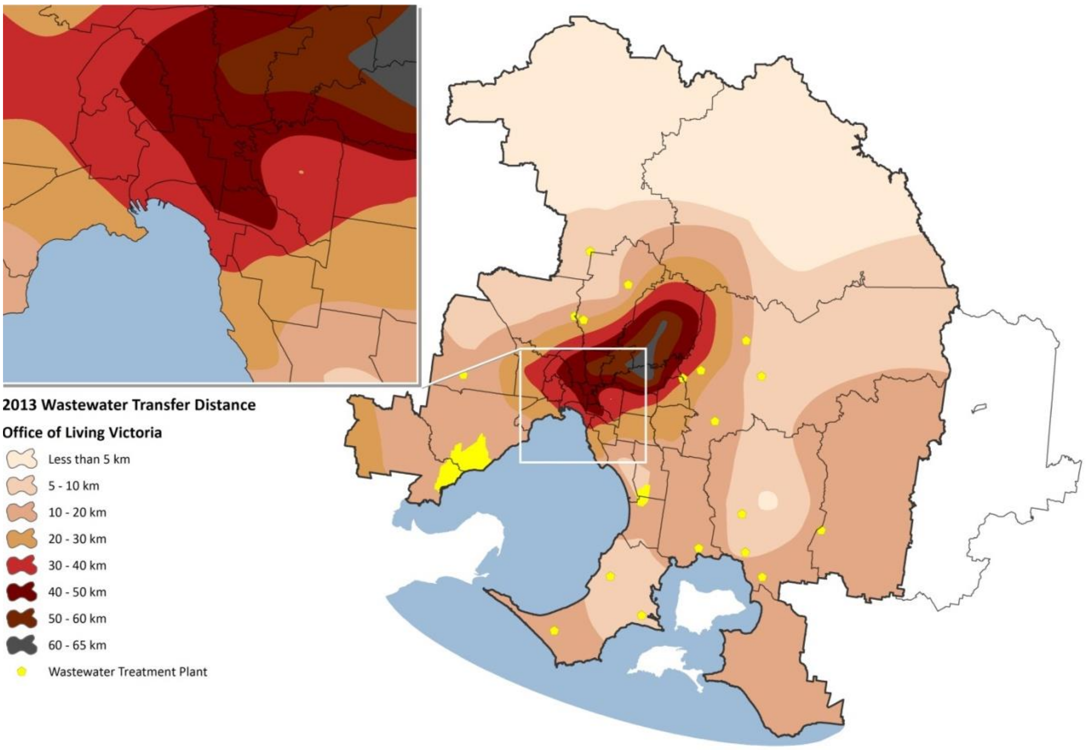

Figure 4: Transfer distance of wastewater management across Greater Melbourne

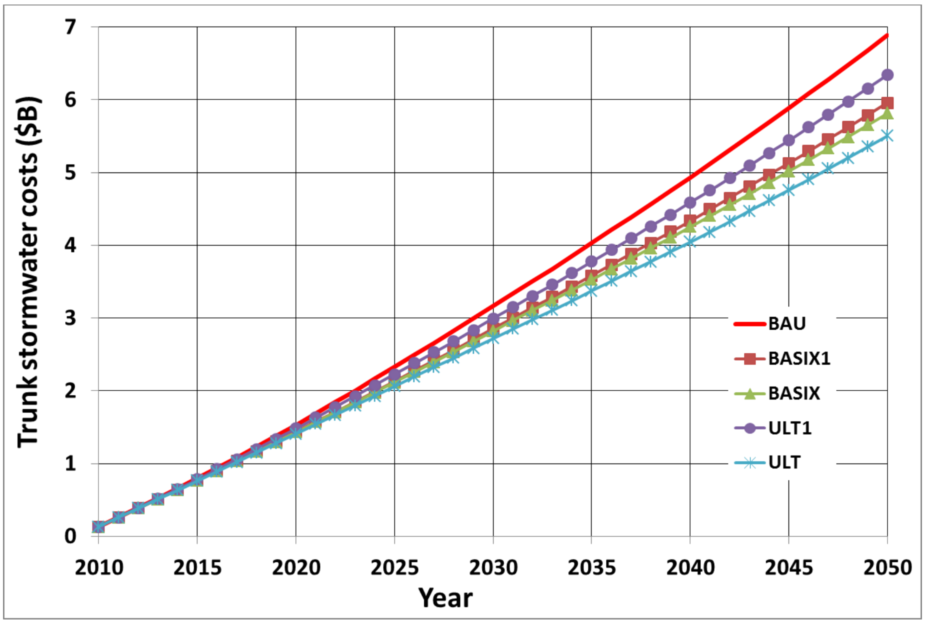

Figure 5: Cumulative costs of stormwater services for Options subject to the high emissions climate change scenario

CONCLUSIONS

An integrated systems approach was employed to analyse the performance of integrated water cycle management Options throughout the Greater Melbourne region. The Options were determined to generate understanding of the response of the water cycle systems within Greater Melbourne to alternative strategies and to subsequently inform decision making for water policy. This process was used to underpin the investigations of the Ministerial Advisory Council as a basis for the implementation of the *Living Melbourne, Living Victoria* policy for water reform and, ultimately, approval of the Melbourne’s Water Future strategy by the Victorian Cabinet. The explorative Options considered in this study provide a range of key insights.

The existing system (BAU) is critically dependent on (or sensitive to) variations in climate and population. Building scale Options (referred to in this study as BASIX and BASIX1) substantially mitigate the challenges of variable population and climate. The precinct scale Options (referred to in this study as ULT and

ULT1) almost eliminate the challenges of variable population and climate. Importantly, the alternative Options operate at multiple spatial, temporal and dimensional scales to generate reductions in water demands, wastewater generation and stormwater runoff, the cost of providing water and wastewater services, and the transfer costs of providing water and sewage services.

The integrated systems analysis was built on local scale (the people) inputs (a "bottom up" process) from multiple layers of Big Data rather than traditional analysis of metropolitan water resources that commences with regional scale assumptions and averages (a "top down" process). This process has revealed a range of challenges and opportunities in the Australian water industry that were hitherto obscured by more generalised analysis techniques. For example, the full cumulative costs (and benefits) of projects for water cycle management across an entire system are not currently considered. There is a need to avoid lumpy investment processes in large scale external infrastructure and to minimise the total distances involved in the transfer of water, stormwater and wastewater throughout Greater Melbourne in water cycle planning and design of infrastructure.

The Systems Framework is currently being applied to the Living Ballarat project for the Office of Living Victoria and for analysis of water cycle management for the Australian Capital Territory.

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