Living Melbourne, Living Victoria

Greater Melbourne Systems Model – Modelling in support of Living Victoria Ministerial Advisory Council

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Glossary of Terms and acronyms

AAD: **Average Annual Damage.** The average annual damage created by flood events

ABS: **Australian Bureau of Statistics.** Australia's national statistical agency.

BASIX: **The Building Sustainability Index.** A web based planning tool that was introduced by the New South Wales Government during July 2004 to reduce the water and energy use of housing. The planning tool is supported by a state government policy framework that includes state legislation and technical guidelines.

BASIX: **Modelling Option BASIX.** Building scale Integrated Water Cycle Management that includes water efficient gardens.

BASIX1: **Modelling Option BASIX1.** Building level Integrated Water Cycle Management that does not includes water efficient gardens.

BAU: **Business as Usual.** The current state and approach water cycle management. This is the Base Case Option.

Blackwater: Used water generated from the toilet.

BOD: **Biological Oxygen Demand.** A chemical procedure for determining the amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic material present in a given water sample at certain temperature over a specific time period. Widely used as an indication of the organic quality of water.

BWA: **Bulk Water Authority.** The water authority responsible for providing bulk water services to Greater Melbourne. This is Melbourne Water Corporation.

CC: **Climate Change.** A long-term change in the statistical distribution of weather patterns over periods of time.

CPI: **Consumer Price Index.** A social and economic indicator that measures the changes in prices of paid by consumers for goods over time.

CWW: **City West Water.** The Retail Water Authority responsible for providing retail water services to the west of Greater Melbourne.

DPCD: **Department of Planning and Community Development.** The Victorian Government agency responsible for managing the State's planning system.

DSE: **Department of Sustainability and the Environment.** The Victorian Government agency responsible for sustainable management of Victoria's water resources and catchments, climate change, bushfires, parks and other public land, forests, biodiversity and ecosystem conservation.

EC: **Economic Structural Change Scenario.** A modelling scenario that tests restructure in Melbourne's economy from (water intensive) manufacturing into other sectors.

EPA: **Environmental Protection Authority of Victoria.** The Victorian Government agency responsible for the protection, care, and improvement of Victoria's environment.

ESC: **Essential Services Commission.** Victoria's price regulator responsible for determining the prices and charging arrangements for water service provision

EWWTP: **Eastern Wastewater Treatment Plant.** A large centralised wastewater treatment plant operated by Melbourne Water Corporation located at Carrum Downs, in the South-East of Greater Melbourne.

GF: **Greenfield Growth Scenario.** A modelling scenario that tests a situation where all growth occurs on the urban fringes of Melbourne in undeveloped "Greenfield" areas.

Greywater: generated by residential kitchens, bathrooms and laundries.

HE: **High Emissions Climate Change Scenario.** Tests the impact of temperature increases generated by the upper bounds of IPCC's high emissions predictions on Greater Melbourne's water cycle.

IF: **Infill Growth Scenario.** A modelling scenario that tests a situation where all of Melbourne's growth occurs through densification of existing developed areas.

IWCM: **Integrated Water Cycle Management.** A multi-disciplinary and multi-objective approach for the sustainable use of available resources with the objectives of environmental protection and minimising water demands, wastewater discharges and stormwater runoff.

LE: **Low Emissions Climate Change Scenario.** Tests the impact of temperature increases generated by the lower bounds of IPCC's high emissions predictions on Greater Melbourne's water cycle.

LGA: **Local Government Area.** An administrative division defined by the Australian Bureau of Statistics that is a local government jurisdiction.

MBR: **Membrane Bioreactor.** A modular wastewater treatment process which combines a membrane process such as microfiltration or ultra filtration with a suspended growth bioreactor. Widely used for municipal and industrial wastewater treatment.

MWC: **Melbourne Water Corporation.** Greater Melbourne's Bulk Water Authority.

NWC: **The National Water Commission.** A Statutory Authority established by the Australian Government in 2004 to provide advice on and drive progress towards the sustainable management and use of Australia's water resources.

MUSIC: Model for Urban Stormwater Improvement Conceptualisation – a statistical model used to provide conceptual understanding of the potential to improve the quality of urban stormwater runoff.

Option: A strategy for water cycle management. Four alternative options have been examined BASIX, BASIX1, ULT and ULT1.

PURRS: Probabilistic Urban Rainwater and wastewater Reuse Simulator – a model of first principles hydrology and hydraulics that includes climate dependent behavioural water demands at the lot and precinct scale.

Roofwater: Rainfall collected from the roofs of buildings.

RWA: **Retail Water Authority.** The water authorities in Greater Melbourne responsible for providing retail water services. These include City West Water, South East Water and Yarra Valley Water.

RWT: **Rainwater tank**. A water tank which is used to collect and store rainwater runoff, typically from rooftops via rain gutters.

SCADA: **Supervisory Control and Data Acquisition**. Computer systems that monitor and control industrial, infrastructure, or facility based processes.

Scenario: A modelling technique established to provide a more detailed understanding of potential opportunities or threats that are introduced to test the practicality of Options.

SEW: **South East Water.** The Retail Water Authority responsible for providing retail water services to the south-east of Greater Melbourne.

SLA: Statistical Local Area is a small division used by the Australian Bureau of Statistics to understand socio-economics, demographics and other characteristics of Australian society.

Stormwater: Rainfall that runs off all urban surfaces such as roofs, pavements, car parks, roads, gardens and vegetated open space.

TDS: **Total Dissolved Solids.** A measure of the combined content of all inorganic and organic substances contained in a given water sample at certain temperature over a specific time period.

TN: **Total Nitrogen.** The sum of the nitrogen present in all nitrogen-containing components in a given water sample at certain temperature over a specific time period.

TSS: **Total Suspended Solids.** A water quality measurement of the mass of fine inorganic particles suspended in a given water sample at certain temperature over a specific time period.

Two: **Two Percent Population Growth Scenario.** A modelling scenario which tests the implications of 2% annual growth in Melbourne's population to 2050.

ULT: **Modelling Option "Ultimate".** Precinct based Integrated Water Cycle Management which includes stormwater harvesting for potable use.

ULT1: **Modelling Option "Ultimate1".** Precinct based Integrated Water Cycle Management which does not includes stormwater harvesting for potable use.

Wastewater: A combination of Greywater and Blackwater from residential dwellings and includes wastewater from non-residential allotments, trade wastes and stormwater runoff.

WATHNET: A suite of network linear programs for water supply headworks simulation that was modified for use in this investigation.

WSAA: **Water Services Association of Australia**. The industry peak body which represent Australian water authorities. As part of their activities WSAA releases a set of Benchmarking Reports, which are audited annual reports that benchmark Australian water utilities across a range of agreed and consistent parameters.

WSDS: **Water Supply Demand Strategy.**

WSUD: **Water Sensitive Urban Design.** Design principles that aim to reduce the impact of interactions between the urban built form and the urban water cycle as defined by the three urban water streams of potable water, wastewater and stormwater.

WWWTP: **Western Wastewater Treatment Plant.** A large centralised wastewater treatment plant operated by Melbourne Water Corporation located at Werribee, in the west of Melbourne.

YVW: **Yarra Valley Water.** The Retail Water Authority responsible for providing retail water services to the central area of Greater Melbourne.

Zero: **Zero Percent Population Growth Scenario.** A modelling scenario which tests the implications of no change in Melbourne's population to 2050.

Contents

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Executive summary

Key Findings and Recommendations

Key Findings

1. This study has adopted unique spatially and temporally explicit methods of systems analysis to establish that alternative water cycle management embedded within existing centralised water cycle networks can offer technically, commercially and environmentally viable strategies.
2. A stakeholder, review and hindcasting process was utilised to obtain data and information that allowed enhancement of an existing systems model.
3. The integrated systems model was used to support an evidence based policy process.
4. The enhanced systems model successfully reproduced the behaviour of regional storages, water demands and wastewater discharges. The spatial robustness of the systems model was verified for generation of water demands and wastewater discharges throughout Greater Melbourne. Costs and greenhouse gas emissions in the systems model were also successfully verified against all available data.
5. The systems model provided similar or more conservative results for the impacts of expected climate change than estimates provided by CSIRO and IPCC.
6. More than 40 discrete combinations of Options and Scenarios were tested that provided a rich data set for understanding the future challenges and opportunities for Greater Melbourne’s water cycle.
7. The existing system (BAU) is critically dependent on (or sensitive to) variations in climate and population.
8. The expected increases and accumulation of wastewater and stormwater in water cycle networks are significant challenges for Greater Melbourne to 2050.
9. This investigation has found that up to three additional augmentations of the regional water supply system are required for BAU to 2050.
10. The building scale Options (BASIX and BASIX1) substantially mitigate the challenges of variable population and climate.
11. The precinct scale Options (ULT and ULT1) almost eliminate the challenges of variable population and climate.
12. Alternative Options can generate substantial reductions in water demand, wastewater discharges and stormwater runoff.
13. Alternative Options can provide significant reductions in the cost of providing water and wastewater services that include reduced transfer costs of providing water and sewage services.
14. The full costs (and benefits) of projects for water cycle management are not currently considered. This is likely to create bias in decision making processes towards augmentation using large scale infrastructure.

15. The variances and inconsistencies in data highlighted in this investigation indicate that it has been previously difficult to develop accurate spatial understanding of the performance of Greater Melbourne's water cycle. Thus it is unlikely that the actual costs of providing services to discrete spatial locations throughout Greater Melbourne have been considered.
16. One of the most significant outcomes of the MAC process was the large number of individuals who demonstrated significant good will and willingness to generate change across the sector.

Key Recommendations

1. Implement "whole of Melbourne" minimum objectives for water cycle management that include minimum annual reductions in demand for mains water, wastewater discharges and stormwater runoff of 80%, 50% and 30% respectively. These objectives should be combined with spatially relevant building scale targets that include minimum annual reductions in demands for mains water, wastewater discharges and stormwater runoff of 50%, 30% and 20% respectively.
2. Minimise the total distances involved in the transfer of water and wastewater throughout Greater Melbourne in water cycle planning and design of infrastructure.
3. Eliminate "lumpy" expenditure for large scale centralised infrastructure wherever possible. There is significant value in avoiding investment in large scale infrastructure by utilising timely investment in smaller scale local infrastructure as required.
4. Water cycle planning and associated decision making should be derived from the integrated systems analysis methods utilised for this investigation to provide better understanding of the spatial variance and complexity of the water cycle throughout Greater Melbourne.
5. Implement design guidelines that are underpinned by the latest knowledge, understanding and integrated systems processes. The new guidelines must consider the impacts of multiple water sources, water efficiency and local variability on the design of infrastructure.
6. Implement a high quality monitoring and data management system for the entire Greater Melbourne water, sewage and stormwater networks. This system should be implemented and managed independently and in partnership with all water authorities to ensure consistency. The "whole of Melbourne" monitoring and information management systems should also include observations of stormwater runoff volumes and quality.
7. Implement a competitive process for management of water resources throughout Greater Melbourne. An essential element of this process is the structural seperation of planning, approval and operational processes involved in delivering water cycle services. At a minimum this will involve assigning water cycle planning and approval functions to an independent authority.
8. Provide open, transparent, and freely accessible information about the performance of water cycle systems throughout Greater Melbourne to all stakeholders and the community. This information should be managed by an independent authority and be available in a common location and format.

Introduction

The purpose of this investigation was to provide systems analysis of the water cycle for Greater Melbourne and advice in support of the Ministerial Advisory Council (MAC). This process aimed to generate discussion and deeper understanding of the detailed transactions that drive water cycle management throughout the region.

This alternative view was used as a basis for the implementation of the *Living Melbourne, Living Victoria* policy and this report supports the recommendations in the MAC's final Stage II report.

The Ministerial Advisory Council (MAC) commissioned Dr Peter Coombes and Bonacci Water to provide "Modelling in support of the Living Victoria Ministerial Advisory Council work program" using the Greater Melbourne Systems Model utilised during Stage I of the MAC process. This process involved a range of key objectives including:

- Assist in deepening the understanding of the MAC about the Stage I model and outputs.
- Validate and strengthen the model and outputs for the MAC.
- Provide continuing support for investigations and policy processes undertaken by the MAC.

An integrated systems approach was employed by this study to analyse the performance of integrated water cycle management Options throughout the Greater Melbourne region. 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 unique analysis was dependent on detailed local inputs throughout the system, such as demographic profiles and human behaviour, and linked systems that accounts for water supply, sewage, stormwater and environmental considerations. 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).

This project has utilised the powerful framework for detailed systems analysis of the Melbourne region that has been developed over a long period of continuous investigation. Three decades of research, two separate investigations (the previous investigation commenced in 2006) and a year of dedicated analysis have enabled a robust analysis.

Options and Scenarios

Options

Four alternative options were examined for water cycle management within Greater Melbourne. The performance of each Option was compared to the performance of the Business as Usual (BAU) Option.

The purpose of establishing Options was to facilitate testing of 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 enable the testing, comparison and understanding of the behaviour of the Greater Melbourne system. 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.

These Options were established to test, compare and contrast a range of alternative future states. Note that each Option is also subjected to a range of naturally variable climate scenarios. The alternative Options are described in Table E1.

Table E1: Summary of Options

Option	Description
0 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.
1 (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.
2 (BASIX1)	Water efficient appliances – Green Star 6 standard. Rainwater harvesting for toilet, laundry and outdoor uses replacing on-site detention for stormwater management.
3 (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.
4 (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.

Scenarios

Scenarios describe the potential changes in qualitative drivers that may influence the behaviour of the system. These qualitative drivers create behaviours that may be experienced by any Option. The consequent plausible alternative futures test the viability of the Options. The Scenarios applied to each of the Options for water cycle management throughout Greater Melbourne examined in this study are summarised in Table E2.

Table E2: Summary of Scenarios

Scenario	Description
Low Emissions Climate Change (LE)	Lower bounds of high emissions projections by IPCC represented by a 0.025˚C incremental annual change in average maximum temperature.
High Emissions Climate Change (HE)	Higher bounds of high emissions projections by IPCC represented by a 0.05˚C incremental annual change in average maximum temperature.
Greenfield Growth (GF)	All urban growth occurs as Greenfield development at the fringes of Greater Melbourne where development currently does not exist.
Infill Growth (IF)	All urban growth occurs as infill development of existing inner urban areas of Greater Melbourne.
Low Population Growth (0%)	Annual average population growth remains static (0%) across Greater Melbourne from 2011–2050.
High Population Growth (2%)	Annual average population growth of 2% across Greater Melbourne from 2011–2050.
Economic Structural Change (EC)	Structural change in the economy results in the closure of the majority of Greater Melbourne's heavy industry and manufacturing. This results in reduced commercial and industrial water demand.

Methodology

This study employed an integrated systems approach to analysing the performance of alternative water cycle management Options for Greater Melbourne. Options were determined to generate understanding of the response of the water cycle systems throughout Greater Melbourne to alternative strategies.

This unique analysis is dependent on detailed inputs, such as demographic profiles, and linked systems that accounts for water supply, sewage, stormwater and environmental considerations.

The systems analysis was constructed 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. Biophysical systems in the region were constructed using three basic components:

- Sources - Regional and local water sources, catchments and waterways
- Flux – transport and treatment of water, sewage and stormwater throughout the region
- Sinks – Stormwater runoff and wastewater disposal to waterways

The analysis is anchored by a regional framework of key trunk infrastructure, demand nodes, discharge points, waterways and regional sources of water in the systems model.

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 and hydrology. Key inputs to this framework include:

- Demographic data from the Australia Bureau of Statistics and State Government departments including the Department of Planning and Community Development (DPCD)

- Climate data from the Bureau of Meteorology (BOM) and streamflow data from the Victorian Data Warehouse and MWC.
- Water and sewage flows sourced from MWC, CWW, SEW and YVW.
- Local and cluster scale inputs simulated in the PURRS model at 6 minute timesteps using long climate records sourced from the BOM.
- Urban areas and LGAs analysed using a range of models including PURRS and MUSIC. These smaller scale systems are also analysed in more detailed WATHNET models.
- The biophysical and scale transition model compiles inputs from PURRS into zones based on statistical local areas and calibrates 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 region 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.

Details of the analysis, extractions from the data and modelling process have been provided throughout this report to assist with understanding the systems processes used in this study.

Household water consumption for the period 2005 to 2006 was selected in this study as representing base water consumption for the region during a period relatively free of water restrictions. These water demands were then modified by a range of processes including adoption of water efficient appliances in some houses, connection to wastewater reuse systems and changes in demographics. The economic analysis was based on the 2009/10 financial period.

Results

Most parameters relevant to water cycle management are subject to significant spatial variation throughout Greater Melbourne. These include climate, water demands, wastewater generation, stormwater runoff, socio-economic and demographic profiles, and the cost of providing water and wastewater services.

The water cycle for Melbourne cannot be described by homogenous parameters based on a single location or even regional averages. Similarly, this study has shown that the existing performance of the Greater Melbourne system or its response to policy changes cannot be based on single parameters or solutions. In particular, the existing system (BAU) is critically dependent on (or sensitive to) variations in climate and population.

The expected increases and accumulation of wastewater and stormwater in water cycle networks are significant challenges for Greater Melbourne. This investigation has found that up to three additional augmentations of the regional water supply system may be required. A summary of requirements for augmentation are presented in Table E3.

Table E3: Summary of requirements for augmentation of regional water supply

Scenario	Year of regional augmentation versus Option				
	BAU	BASIX	BASIX1	ULT	ULT1
HE	2014, 2026, 2045	2023, 2039	2015, 2023	No	2045
LE	2015, 2032	2034, 2045	2047, 2031, 2045	No	2038
Two	2042	No	2042	No	No

Table E3 demonstrate that alternative Options for water cycle management provide significant improvements in the security of Greater Melbourne's water supply and that the climate change and population growth is likely to have a significant impact of security of water supplies.

The ULT Option that includes multiple sources of water and efficient use of water eliminate requirement to augment regional water supply.

It is noteworthy that the high emissions (HE) and low emissions (LE) generate requirement for additional regional water sources for all Options expect the ULT Option. In addition, the BAU Option includes up to three augmentations and requires continuous operation of desalination plants which the alternative Options require use of desalination when total water storage in regional dams are drawn down below 65%.

In addition, the alternative Options BASIX, ULT and ULT1 eliminate the requirement for additional water supplies.

The results of this study are summarised in Table E4.

Table E4: Summary of the systems analysis (decreases relative to BAU)

Criteria	BAU	BASIX	BASIX1	ULT	ULT1
Water Demand 2050 (GL/annum)	522	378 28% decrease	396 24% decrease	286 45% decrease	321 38% decrease
Cumulative water demand 2010-2050 (GL)	19,210	15,390 20% reduction	15,926 17% reduction	14,010 27% reduction	15,342 20% reduction
Augmentation of water supply	YES – up to 3 (HE) 2014 – 50 GL 2026 – 100 GL 2045 – 50 GL	YES - up to 2 (HE) 2023 – 50 GL 2039 – 100GL	YES - up to 3 (HE) 2015 – 50 GL 2023 – 50 GL 2047 – 50 GL	None required	YES - 1 (HE) 2045 – 50 GL
Reliant on desalination?	YES	YES	YES	NO	NO
Wastewater Discharge 2050 (GL/annum)	552	466 15% decrease	490 11% decrease	378 32% decrease	378 32% decrease
Cumulative wastewater discharges 2010-2050 (GL)	19,625	17,383 11% reduction	17,972 8% reduction	15,477 21% reduction	16,191 17% reduction
Stormwater Runoff 2050 (GL/annum)	527	483 8% decrease	478 9% decrease	306 42% decrease	467 11% decrease
Cumulative stormwater runoff 2010-2050 (GL)	17,487	15,383 12% reduction	15,171 13% reduction	14,919 15% reduction	15,355 12% reduction
Greenhouse Gas emissions 2050 (kT CO^2e/yr)	1,928	1,513 40% decrease	1,215 37% decrease	1,036 46% decrease	1,095 43% decrease
Cost of Carbon 2050 ($M)	48.2	28.8 40% reduction	30.4 37% reduction	25.9 46% reduction	27.4 43% reduction
Water NPC ($B)	23.9	22.7 5% decrease	23.2 3% decrease	23.2 3% decrease	23.5 2% decrease
Wastewater NPC ($B)	13	11.6 11% decrease	11.7 10% decrease	11.6 11% decrease	11.7 10% decrease
Stormwater NPC: Infrastructure, Flooding and Nutrients ($B)	7.35	6.9 6% decrease	6.83 7% decrease	5.37 27% decrease	6.53 11% decrease
Nutrients 2050 (tonnes/annum)	1,110	1,020 8% decrease	1,002 10% decrease	640 42% decrease	882 20% decrease

Table E4 reveals the key findings of this study that include:

- Population growth is a key driver of future water demands, wastewater generation and stormwater discharges. The costs of incorrectly predicting population growth has critical implications for the State of Victoria.
- Future variations in climate regimes will create substantial variations in water demands and availability of water. Higher temperatures drive greater water demands and this concurrently reduces rainfall and streamflow (that drives centralised supply).
- The debate as to whether future urban growth should occur as Greenfield or Infill development does not appear to be significant. These Options do not have significantly different impacts on the system.
- A change in the structure of the Victorian economy could have a significant impact on water demands, security of water supplies and the spatial response of the system.
- Mistaken predictions of water cycle impacts and associated requirement for large scale infrastructure may result in stranded assets – large infrastructure without the demand to pay for it.
- Alternative Options consistently deliver significant reductions in water demands, wastewater generation and stormwater discharges:
  - The ULT Option generates the greatest reductions in water cycle impacts in comparison to BAU.
  - The other alternative Options generate significant (but diminished when compared to ULT) reductions in demands on the water cycle for Greater Melbourne.
- Alternative Options also deliver the greatest resilience and flexibility when subject to future variability:
  - The ULT Option delivers the greatest resilience and flexibility in comparison to BAU due to the use of multiple water sources in combination with water efficiency.
  - The other alternative Options also generate significant (but diminished when compared to ULT) resilience and flexibility.
- Water efficient gardens and public open space are an important component of overall water efficiency for Greater Melbourne. This initiative delivers tangible benefits including reduced water demands and avoids augmentation of infrastructure. Water efficient gardens should form part of future water policies.
- The omission of stormwater harvesting for injection into the mains system for potable use from the ULT Option "leaves significant value on the table". This lost value includes the ability to affect substantial reduction in mains potable demands, improved water security and reduced requirement of regional augmentation.
- Perceived problems that originate from concerns about institutional and governance issues need to be challenged and overcome. Failure to resolve these issues stand in the way of substantial benefits to society.
- Alternative Options generate significant economic and financial benefits. The ULT Option generates the most significant reductions in costs and the other alternatives generate significant (but slightly reduced) benefits, including:
  - Reduce the cumulative total costs of the system by up to $30 B over 40 years

  - This equates to 1% to 2% of State's total expenditure every year to 2050 or 65% of Victoria's 2011-12 budgeted expenditure.
  - This value is equivalent to 30 hospitals or 60 new prisons or 10 new Freeways or 6 Regional Rail Links
- Total water cycle management costs vary significantly in response to different futures. Substantial reductions in total costs are generated by the low growth and economic structural change Scenarios. In contrast, the high growth and climate change Scenarios produce considerable increases in total costs.
- The ULT Option generates the greatest resilience to variations in costs resulting from alternative future states and the other alternative Options generate diminished but still significant resilience.
- The alternative Options generate a range of additional financial, social and environmental benefits, including:
  - Up to a 20% (8,246 tonnes) decrease in nitrogen loads entering waterways
  - Significant reduction in the costs of stormwater infrastructure (up to a 13% decrease), the flooding (up to a 17% decrease) and management of nutrients (up to a 17% decrease)
  - Up to a 30% (34,171 kT) reduction in cumulative GHG emissions. This result challenges the perception that alternative Options consume more energy than BAU. It also highlights the importance of holistic and integrated systems analysis

This study used detailed systems analysis to compare the spatial capacity and potential spatial performance for each Option. These are defined as follows:

- **Capacity**: the definition of the potential of each Option at each building or household or precinct throughout Greater Melbourne
- **Performance**: the definition of the behaviour of each Option within the planning horizon that is modified by population growth, renovation rates, demographic processes and the legacy of existing infrastructure and policies

The study found that buildings and households across Melbourne have the capacity to achieve significant reductions in water demand, wastewater discharges and stormwater runoff. The use of a spatially explicit modelling framework in this study was able to show that this capacity varies across Melbourne. All Options provide reasonably consistent capacity outcomes that result in substantial reductions in water demands, wastewater discharge and stormwater runoff for all locations across Greater Melbourne.

The spatial variation in performance of Options is driven by a multitude of factors including rainfall, proportion of residential and non-residential buildings, the age of suburbs, the condition of existing infrastructure and the distance to and from water supply sources and wastewater treatment facilities:

- The ULT Option achieves consistently greater capacity and higher performance for all measured indicators for all of Greater Melbourne.

- Other alternative Options generate significant (but slightly diminished) capacity and performance for Greater Melbourne.

Conclusions

The Options considered in this study provide the following key outcomes:

- the existing system (BAU) is critically dependent on (or sensitive to) variations in climate and population.
- The 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
- The alternative Options generate reductions in
  - water demand, wastewater generation and stormwater runoff
  - the cost of providing water and wastewater services, and
  - the transfer costs of providing water and sewage services

1 Introduction

Urban settlements are subject to a continuum of change that is influenced by demographic, economic, political, environmental, cultural, and social factors – evolution of a metropolis will vary depending on dominant influences at the time. Greater Melbourne has prospered and grown rapidly since European settlement commenced early in the 19th century.

The last decade has been a transformative period for Greater Melbourne in response to the experience of drought, flood, fire, rapid population growth, urban sprawl and a change of government. The community and civil society of Greater Melbourne has evolved to meet these challenges. For more than a century Melbourne's water services has been a model for water management throughout Australia and the world. Melbourne and its community are in a unique situation to create metropolitan water cycle service systems that respond to future challenges of population growth and a highly variable climate.

Australia's water supplies to cities have until recently been almost completely reliant on single sources of water derived from inland catchments fed by rainfall runoff. The reliability of urban water systems dependent on single centralised sources of water is uncertain. During prolonged periods of drought this dependence has resulted in concerns about water security. The combined pressures of population growth, a highly variable climate and the potential for climate change may create serious problems in the future.[1] 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. By using available water resources from both the traditional centralised (large storage dams) and decentralised supply sources in combination with a diverse range of water conservation strategies the resilience of a city's water supply will be greatly enhanced.[2]

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. The response to the recent prolonged severe drought and the serious concerns about water security for metropolitan areas continued a preference for large scale traditional projects.

Most Australian cities were subject to severe water use restrictions and many interior towns suffered serious water shortages. The drought and associated water restrictions also affected the character of urban areas including managed open space, parks, gardens and streetscapes. The character of a Melbourne and Victoria – the garden city and a garden state was endangered. Water storage in regional water supply dams were at persistent low levels.

During this period of lower rainfall the Australian and Victorian debate within the water industry, consultant and academic circles largely centred on the search for traditional supply solutions. Water authorities and their consulting advisers argued that there was insufficient water available within the established catchment systems for our growing cities and the preferred solutions for urban water supply were desalination, long pipelines into previously untapped (for metropolitan use) rural water resources and large scale wastewater reuse for human consumption. Most of Australia's captured

1 Coombes P.J. and M.E. Barry, 2008. The relative efficiency of water supply catchments and rainwater tanks in cities subject to variable climate and the potential for climate change. Australian Journal of Water Resources. Vol. 12. No. 2. pp. 85 – 100.
2 PMSEIC. 2007. Water for Our Cities: building resilience in a climate of uncertainty. A report of the Prime Minister's Science, Engineering and Innovation Council working group. Australian Government. Canberra.

water resources are used by irrigated agricultural schemes. Water trading between cities and rural users was the subject of considerable debate. Some experts also claimed that climate data from the most recent past pointed to a permanent step change in rainfall regimes. However this assumption could not be sustained as a general rule for metropolitan catchments on the basis of historical time series of rainfall data.

A key element for the management of water supplies during the last decade of drought was the use of traditional demand management techniques that combine traditional water restrictions with marketing of water saving measures, water efficient appliances and targets for maximum household water consumption. More advanced behaviour change programs were directed at households and proved to be effective in Perth. All major cities attempted persuasion campaigns via large scale advertising and various incentive measures that were based on rebates for water saving appliances. Large numbers of households responded to the drought and water restrictions by organising their own supply response by acquiring rainwater tanks and greywater reuse systems. Governments responded by offering small financial incentives for water saving measures.

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. All of these outcomes, however, did not influence discussion amongst decision makers that was dominated by the search for traditional supply responses in favour of extending storage facilities and augmenting supplies by new technical solutions such as desalination.

It is now acknowledged that voluntary water conservation by the Australian community has made a substantial contribution to demand reductions precisely when the need for conservation was greatest.[3] 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.

Clearly on balance there were sufficient water resources available within Australian cities and a stressed and concerned community had managed to exploit some of these water resources during the recent drought. The explosion of demand for rainwater tanks took the supply industry by surprise and water authorities demonstrated reluctance in accommodating these outcomes within their own strategies for the management of scarce water resources.

Do the experiences of the recent drought including these unplanned outcomes indicate a systemic failure of centralised planning and supply? It can be said that an important contributor to urban water shortages has been inadequate institutional arrangements for the management of our urban water resources.[4]

Urban water services are mostly delivered by statutory monopolies with government as a sole shareholder. Dividends are commonly paid to state government and the governance boards of these monopolies are charged with protecting economic viability and compliance with a statement of obligations. Revenue is earned from selling water, treating wastewater and providing a narrow range

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3 Aishett E., and E. Steinhauser, 2011. Does anybody give a dam. The importance of public awareness for urban water conservation during drought. Submission by the Australian National University to the Productivity Commission.
4 Productivity Commission, 2008. Towards urban water reform: a discussion paper. Productivity Commission Research Paper. Australian Government.

of related services. Alternative water management options and water conservation is in direct competition with water monopoly processes. Similarly, the narrow structure of the urban water monopoly framework also creates direct and indirect economic dependence on water authorities throughout the water sector.[5] This process acts to create a sameness of opinion about alternatives within the water sector and reinforces substantial institutional inertia.[6] An overview of the ownership and responsibility for water authorities within Greater Melbourne is presented in Figure 1.1.

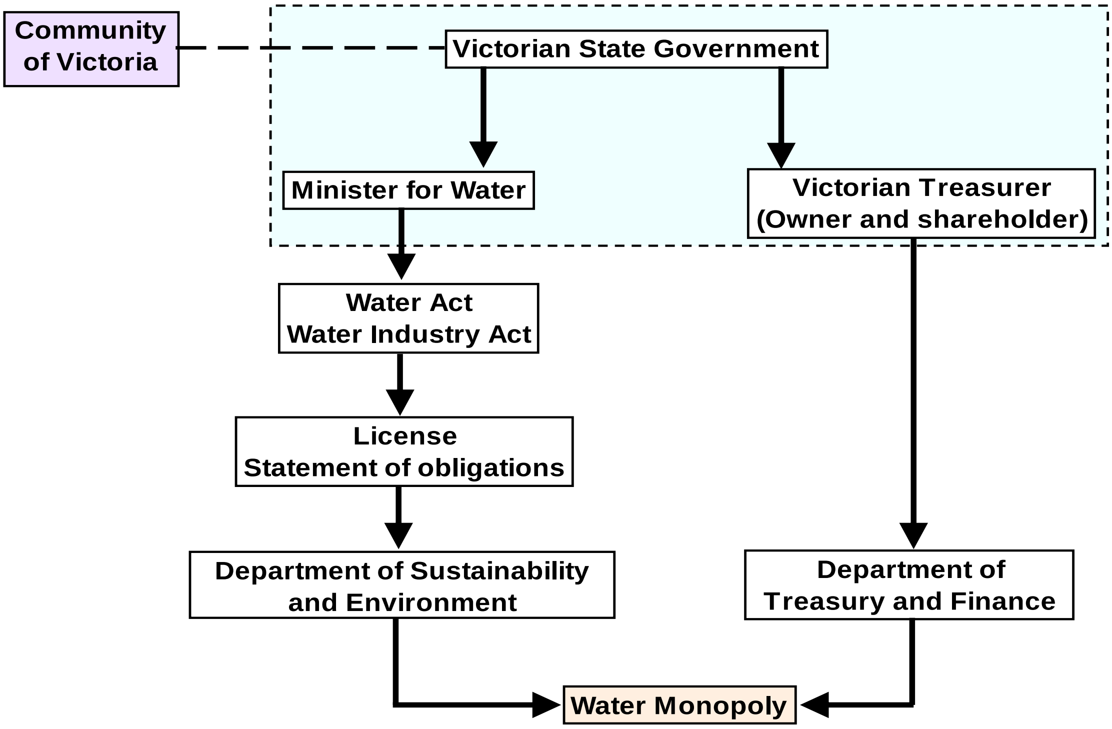

Figure 1.1: Overview of the key ownership and response pathways for water monopolies in Greater Melbourne

Figure 1.1 demonstrates that the ownership and management of urban water resources for Greater Melbourne is remote from perceived public ownership and related public good drivers of performance. Clearly the Victorian bureaucracy has a more direct (albeit delegated) ownership of water monopolies within Greater Melbourne. Urban water authorities with strong feedback links to the aspirations of society and regulation policies are essential to the fabric of a modern city.

An outcome of the experience of recent drought has been increased awareness of the need to protect the liveability of Melbourne in terms of the assets and amenities that have made the Metropolis a garden city. Public open space and private gardens are significant contributors to the liveability of the city. Clearly there are many other aspects of urban form and structure that provide amenity to the citizens of Melbourne. The past use of water restrictions and the absence of strategies to utilise alternative water resources has a negative impact on the liveability of Melbourne.

Recent rainfall variability (from droughts to flooding rains) and government infrastructure decisions

5 Daniell K.A., P.J. Coombes and I. White, 2011. Multi-level governance and politics of innovation uptake in the water sector. 33rd Hydrology and Water Resources Symposium. Engineers Australia.
6 Brown R.R., and N.A. Keath, 2008. Drawing on social theory for transitioning to sustainable urban water management: turning the institutional super tanker. Australian Journal of Water Resources. Vol. 12. No. 2. pp. 73 – 84.

(such as the Desalination Plant and North South Pipeline) have driven an investigation of alternative approaches to achieve secure, resilient and flexible water services. The recently elected Victorian Government's new water policy, *Living Victoria,* seeks to transform urban water policy, planning and implementation in Greater Melbourne.

The Minister for Water has taken responsibility for the *Living Victoria* policy. A Ministerial Advisory Council (MAC) has been established and delivered the *Living Victoria Road Map* during Stage I of the government's metropolitan reform process. Dr Peter Coombes supported by Bonacci Water provided technical expert advice to the MAC during Stage I. The *Study 1 - Transitioning to a resilient, liveable and sustainable greater Melbourne* provided the first comprehnesive systems analysis of the water cycle throughout Greater Melbourne and the associated assessment of the ability to achieve the objectives of the MAC.

During Stage II of the reform process the Ministerial Advisory Council (MAC) again commissioned Dr Peter Coombes and Bonacci Water to provide "Modelling in support of the Living Victoria Ministerial Advisory Council work program" using the established Greater Melbourne Systems Model which had been utilised during Stage I of the MAC process. Key objectives of this assignment were:

- Validate and strengthen the model and outputs for the MAC.
- Assist in deepening the understanding of the MAC about the Stage 1 model and outputs.
- Provide continuing support for investigations and policy processes undertaken by the MAC.

Obviously these objectives involved continuous and interactive dialogue between the MAC and consultants that required a high degree of flexibility. Bonacci Water proposed a transparent "open door" policy for the project with an aim to maximise understanding of the work as well as providing fast and often instant technical and policy responses for the discussions within the MAC process. The analysis and modelling was to be further improved utilising the inputs of the water industry. An unusually high level of co-operation and collaboration with the various water authorities was requested to overcome limited time lines and the necessary depth of analysis. The components of this agreed process and the ongoing interaction with the MAC included:

- Data gathering and subsequent verification of the systems model by Bonacci Water.
- Expansion of the systems model to include Barwon Water, Western Water, South Gippsland Water and other external water demands.
- Calibration and verification of the model using the data provided by water authorities and associated government agencies.
- Generation and simulation of relevant scenarios to test future Options.
- Testing of the sensitivity of the model.
- Engage in workshops and meetings with stakeholders.

It was understood that the role of Dr. Peter Coombes and Bonacci Water was to provide independent advice and support to the MAC. The previous reports by Bonacci Water namely, "Study 1 – transitioning to a resilient, liveable and sustainable Greater Melbourne (system wide study)" and "Rainwater tank evaluation study for Greater Melbourne" are not fully included herein and should be read in conjunction with this report.[7,8] The analysis for the Stage I report has been carried further in this study including:

- More information provided by water authorities and the bureacracy has enabled a greater insight and understanding for the water cycle throughout Greater Melbourne.
- Evolution of alternative Options in response to feedback.
- Evolution of Scenarios in response to feedback.
- Greater consultation, stakeholder engagement, awareness and understanding.

The systems analysis undertaken for this study is substantially different to traditional analysis of water resources in many key areas. The process adopted for this study includes detailed forensic analysis of a wide range of biophysical parameters throughout Greater Melbourne. The existing integrated systems model of the Greater Melbourne region has been updated and enhanced for use in this project incorporating the latest results from ongoing independent research into analysis of water cycle systems.[9] These systems models subdivide the Greater Melbourne region into hierarchies of distributed linked zones that represent opportunities, constraints and feedback loops across multiple scales.

Long sequences of spatial climate data were combined with local water use and demographic information across the entire region. Daily time steps were employed to increase the depth of analysis. This process maintains the long term climatic correlation between urban and water supply catchments. This ensures that urban water demands are temporally and spatially consistent with the rainfall and streamflows in water supply catchments. This systems framework is substantially different to the current practice of separate derivations of water demands and yields from water resources that utilise monthly or annual assumptions. Importantly, this analysis combines the entire water cycle including water demands, wastewater discharges, stormwater runoff, waterways, energy and the environment at multiple locations throughout Greater Melbourne in a single integrated system. This unique process provides a powerful numerical framework that allows understanding of trade offs, costs and benefits of current and alternative strategies across the entire water cycle. The systems analysis includes a dynamic financial and economic investment framework.

In addition, the systems analysis includes climate dependent behavioural models of water demands that also respond to a range of socio-economic and demographic drivers. Rather than using average water demands for households with average responses to alternative strategies, the systems framework evaluates the temporal and spatial performance of alternatives throughout the system. Note that the analysis includes over 2,700 combinations of dwelling types and households at 36 locations throughout Greater Melbourne.

For clarity, a timeline of the ongoing development of the systems analysis framework of the region by Dr. Peter Coombes and colleagues with various inputs to the MAC processes is provided in Figure 1.2.

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[7] Coombes P.J. and Bonacci Water (2011). Study 1 – transitioning to a resilient, liveable and sustainable Greater Melbourne (system wide study). Report to the Ministerial Advisory Council for the Living Melbourne Living Victoria water policy.
[8] Bonacci Water and Urban Water Cycle Solutions (2008). Rainwater tank evaluation study for Greater Melbourne. Report for the Department of Sustainability and Environment.
9 Coombes, P.J., 2005. Integrated Water Cycle Management – analysis of resource security. WATER. Australian Water Association (AWA). Sydney.

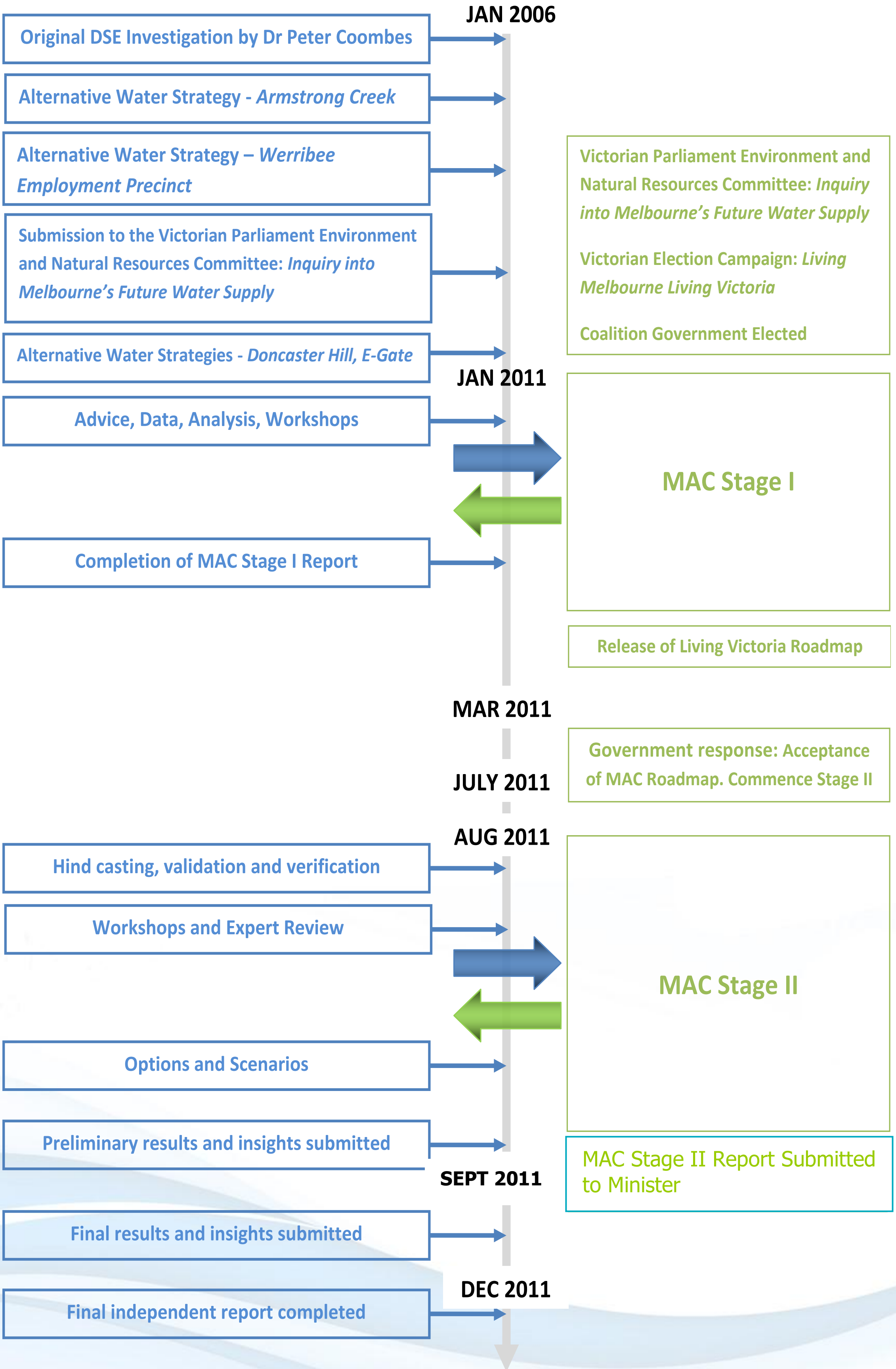

Figure 1.2: Summary of Living Victoria policy development process

Bonacci Water has also recently completed a similar analysis for Greater Sydney that was subject to comprehensive peer review and feedback.[10] The quasi parallel processes of refining the first principles systems analysis for the water cycles in Greater Sydney and Greater Melbourne has also contributed and enriched the processes utilised in both investigations.

Figure 1.2 highlights that development of systems models and associated analysis of the Greater Melbourne systems by Dr. Peter Coombes commenced well before the Living Victoria MAC process and has benefited from a series of Victorian and NSW studies. This work will continue after completion of the enquiry. This process was also underpinned by an ongoing parallel research and development effort.

The first investigation of alternative water strategies for the Department of Sustainability and Environment (DSE) by Dr. Peter Coombes commenced in 2006.[11] This project combined data from DSE, DPCD and water authorities with a series of workshops to refine the systems model for Greater Melbourne.

This process was further underpinned and complemented by analysis of integrated water cycle management (IWCM) Options for new growth areas in the Geelong region.[12] This project included comprehensive engagement with the development industry and local government resulting in further development of the demographic, socioeconomic and economic processes in the systems methodologies. This process was enhanced by interaction with real development issues on a large scale.

This process led to an invitation and subsequent submission to the Victorian Parliament's Environment and Natural Resources Committee. The submission involved further refinement of the systems analysis to extract more detailed understanding of water resources available within Greater Melbourne and barriers to alternative business models that can facilitate the use of these resources.

Methodologies for systems framework were extended for the analysis of a wide range of major projects including the Werribee Employment Precinct [13], Doncaster Hill [14] and Egate. This knowledge assisted with the development of alternative water policy for Greater Melbourne and was combined in the provision of systems analysis and advice for Stage I of the MAC. The process involved a cycle of feedback with the MAC and a range of stakeholders.

Bonacci Water completed the report for Stage I of the MAC and the MAC produced and published a "Living Victoria Roadmap". The government accepted the roadmap and Stage II of MAC process commenced.

Stage II of the MAC process involved a wide range of interactions with Bonacci Water including ongoing provision of the latest results from the systems model. Regular detailed discussions with the MAC members allowed continuous and ongoing testing of model results against issues of policy formulation and systems responses to potential implementation opportunities. This close interaction

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10 Bonacci Water, 2011. Sydney Water alternative water strategy. A vision of what is possible and a roadmap to get there. Report of the Board of Sydney Water Corporation.
11 Bonacci Water and Urban Water Cycle Solutions, 2008. Rainwater tank evaluation study for Greater Melbourne. Report for the Department of Sustainability and Environment.
12 Bonacci Water, 2008. Responsible water use at Armstrong Creek. Report for City of Greater Geelong.
13 Bonacci Water, 2010. Werribee City Infrastructure Planning. Integrated water cycle management – planning for the productive use of stormwater. Report for the Department of Planning and Community Development.
14 Coombes P.J., A. Cullen and K. Bethke, 2011. Toward sustainable cities – Integrated water cycle management (IWCM) at an existing principal activity centre at Doncaster Hill. 33rd Hydrology and Water Resources Symposium. Engineers Australia.

allowed the MAC to provide early feedback and ongoing access to current analysis throughout the project. Finally, the MAC was provided with the ultimate set of results from the systems analysis for inclusion in the Stage II report.

This report provides an explanation of the processes that led to the ultimate results provided to the MAC and includes the following Chapters:

- Chapter 2 describes the base case (Business as Usual) and alternative Options utilised to enable testing, comparison and understanding of the behaviour of the Greater Melbourne system.
- Chapter 3 presents the Scenarios used to describe the potential changes in qualitative drivers that may influence the behaviour of the system and to test the performance of the Options
- Chapter 4 provides an overview of the integrated systems methods used to analyse the performance of alternative water cycle management Options and responses to Scenarios for Greater Melbourne.
- Chapter 5 provides an overview of the processes used to calibrate, validate and enhance the biophysical systems model that was utilised by the Ministerial Advisory Council (MAC).
- Chapter 6 describes the processes of engagement with stakeholders, education and data gathering experienced throughout the project.
- Chapter 7 presents an overview of the results of the systems analysis of climate, demographic and water cycles throughout Greater Melbourne. Key insights and discussions generated by the analysis are also provided.
- Chapter 8 summarises the conclusions and recommendations of this investigation.
- Chapter 9 provides an overview of some of the questions and answers generated by this study to enlighten the reader, share part of the journey of the investigation and provide a taste of the rich and robust discussion that was generated by the policy development process.

2 Options

This study has focused on opportunities to reduce mains water demands, sewage discharges and impacts on waterways from urban development throughout Greater Melbourne. This approach is consistent with the objectives of the *Living Melbourne, Living Victoria* policy for Greater Melbourne. It is a key objective of this policy to minimise the impacts of droughts, floods and climate change on Greater Melbourne whilst reducing impacts on dependent ecosystems and liveability.

The purpose of establishing Options is to facilitate testing of 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 enables testing, comparison and the development of understanding of the behaviour of the Greater Melbourne system. This study did not seek to pick an endpoint or to provide a detailed design of the Options but rather, it provides insight into systems behaviour that can then inform subsequent decision making.

Four alternative options were examined for water cycle management within Greater Melbourne. The performance of each Option was compared to the Business as Usual (BAU) Option. These Options were established to test, compare and contrast a range of alternative future states. Note that each Option was also subjected to a range of naturally variable climate scenarios. The alternative Options are outlined in Table 2.1 and expanded in subsequent Sections.

Table 2.1: Summary of Options

Option	Description
0 Business as Usual (BAU)	• Management of water, wastewater and stormwater using centralised infrastructure. • Future water security and wastewater treatment is provided by large scale regional infrastructure (such as desalination). • Population growth requires expansion of existing networks.
1 (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.
2 (BASIX1)	• Water efficient appliances – Green Star 6 standard. • Rainwater harvesting for toilet, laundry and outdoor uses replacing requirement for on-site detention for stormwater management.
3 (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.
4 (ULT1)	• Precinct wastewater 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.

2.1 Option 0: Base Case - Business as Usual (BAU)

Option 0 (BAU) is the base case which assumes that the majority of mains water will be supplied to Greater Melbourne from the existing headworks system that includes a network of dams and weirs (including Thomson Dam) that are supplemented by the Wonthaggi desalination plant and the Food Bowl Modernisation project (see Figure 2.1).

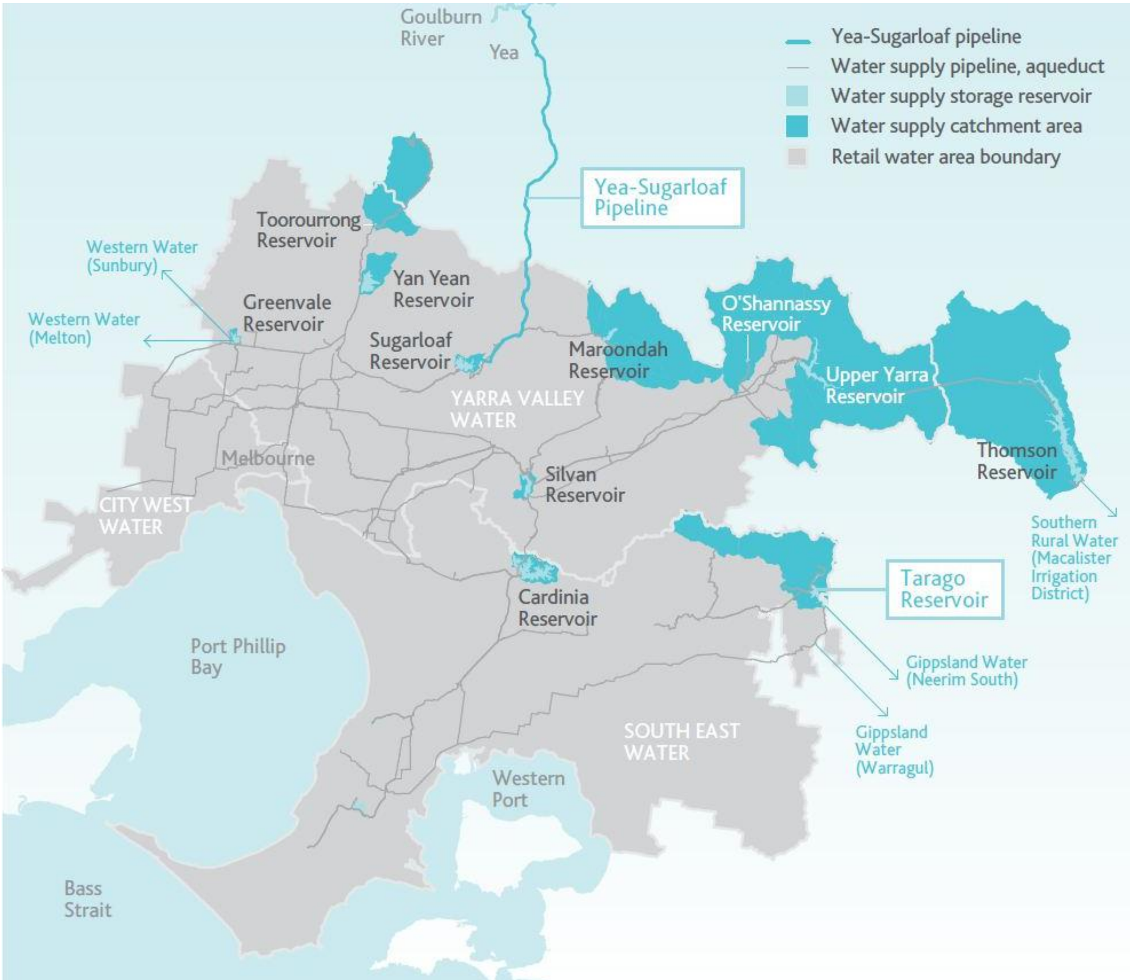

Figure 6.1: Water Supply system for Greater Melbourne[15]

The BAU Option also assumes additional water security is provided by desalination plants and further extraction from Victorian rivers. A majority of wastewater will continue to be conveyed in large centralised infrastructure networks to the Eastern and Western treatment plants. Effluent from these major systems and smaller inland systems is discharged to waterways such as Bass Strait, Yarra River and Port Phillip Bay (see Figure 2.2).

[15] Melbourne Water Corporation, 2010. Annual Report 2009/10.

Figure 2.2 Wastewater system servicing Greater Melbourne[16]

In addition, the existing system includes a range of wastewater reuse strategies that are mostly sourced from the major eastern and western wastewater treatment plants. A dominant proportion of treated wastewater is used at the major treatment plants. In the west, a significant volume of recycled water is used for irrigation purposes and a smaller proportion of recycled water used for other schemes including housing estates. In the east, most of the recycled water is utilised in the Eastern Irrigation Scheme. In addition, smaller volumes of treated wastewater is supplied for outdoor and toilet uses in residential estates. Accordingly, the BAU Option includes reuse of wastewater in a range of urban and commercial developments supplied by the water retail authorities (Yarra Valley Water, South East Water and City West Water) such as the Aurora scheme in the Whittlesea local government area.

The BAU Option assumes that the growth and spatial expansion of Greater Melbourne will require provision of additional wastewater treatment facilities throughout the region. An additional driver for this outcome is the wastewater quality levies imposed on the water retailers by the bulk supplier. Stormwater is, mostly, managed in the BAU Option using a centralised system of drains which flow into key waterways such as the Yarra River, Moonee Ponds Creek and Port Phillip Bay (See Figure 2.3).

[16] Melbourne Water Corporation, 2010. Annual Report 2009/10

Figure 2.3 Major Stormwater catchments and waterways within and surrounding Greater Melbourne[17]

Some of the stormwater runoff from urban development is mitigated using onsite detention and regional detention basins. Stormwater quality is addressed by provision of end of line wetlands and Gross Pollutant Traps (GPTs). A small proportion of urban development incorporates Water Sensitive Urban Design (WSUD) or Integrated Water Cycle Management (IWCM) strategies that holistically manage impacts of development on waterways. However, the majority of stormwater will continue to discharge untreated into waterways at a highly altered regime of flows.

Population growth and associated water demand is mainly accommodated by augmentation and expansion of existing centralised networks rather than precinct based local solutions. This Option also includes a moderate level of water efficiency in all new and renovated buildings which was assumed to be equivalent to a Green Star 2 rating.

[17] Melbourne Water Corporation, 2010. Annual Report 2009/10.

2.2 Option 1: building scale water efficiency and harvesting (BASIX)

Option 1 includes buildings with a high level of water efficiency – all new and renovated buildings and dwellings include the equivalent of Green Star 6 appliances and local rainwater harvesting. Note that this Option involves the gradual uptake of water efficient buildings and rainwater harvesting in accordance with the temporal and spatial variation of increases in dwelling stock and renovation rates throughout Greater Melbourne. All renovations with a value greater than 50% of average value of dwellings in each area include the BASIX Option. It is also important to highlight the variable response of rainwater harvesting systems throughout the Greater Melbourne region.[18]

Rainwater collected from roofs of all buildings will supply toilet flushing, laundry, cooling and outdoor uses. Rainwater harvesting systems are designed to replace on-site detention (OSD) systems assisting with the management of flooding and waterway health.

This Option will be implemented and regulated by government as a similar but enhanced form of the NSW "BASIX" state planning policy. This Option was constructed to demonstrate the benefits of a planning based source control strategy which captures the benefits of a greater level of sustainable building design and water use.

2.3 Option 2: BASIX without water efficient gardens (BASIX1)

Option 2 is a version of BASIX that does not include water efficient gardens in the water efficiency policy. This Option was created by the MAC and is based on an assumption that the community may remove water efficient gardens (and replace them with more water intensive gardens) during periods of higher rainfall and greater water security.

2.4 Option 3: (ULT)

In this Option, all new developments and redevelopments will form part of Precinct scale IWCM strategies (Figure 2.4) and each Precinct will become part of a polycentric cluster of Precincts that provide resilient water strategies (Figure 2.5). Note that Option 3 involves the gradual uptake of IWCM strategies in accordance with the temporal and spatial variation of increases in dwelling stock and renovation rates throughout Greater Melbourne. All renovations with a value equivalent to 100% of average value of dwellings in each area include the ULT Option.

Stormwater is harvested from impervious surfaces, stored at a local scale, treated and injected into water distribution networks for potable uses. Wastewater is collected and treated at a local scale to better than class A standards using small scale modular wastewater treatment technology (such as Membrane Bioreactors). Treated wastewater is used for non-potable purposes such as toilet flushing, laundry, cooling, commercial processes and outdoor uses.

18 Coombes P.J., 2008. Rainwater tank evaluation study for Greater Melbourne. Report for DSE by Urban Water Cycle Solutions and Bonacci Water.

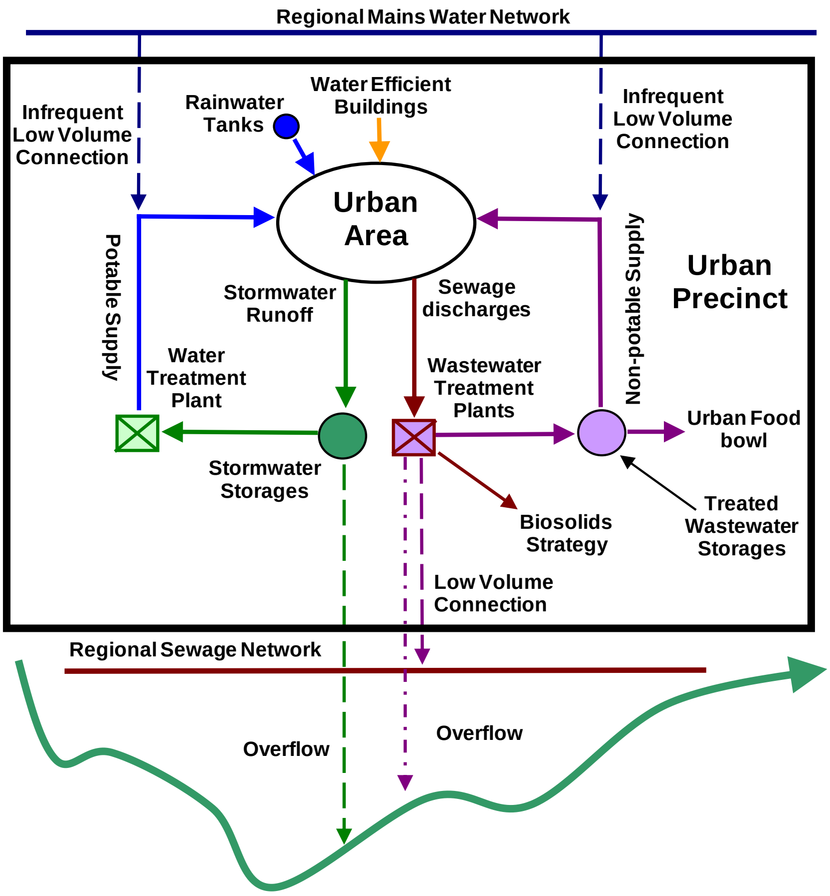

Figure 2.4 The urban precinct with an IWCM strategy[19]

Figure 2.4 shows that the urban Precinct provides water cycle services that originate from resources generated within the Precinct including reduced demands created by more water efficient buildings. The requirement for storages within the Precinct is optimised by replacing stormwater detention facilities with stormwater harvesting storages. The provision of multiple smaller storages that are closer to the source of stormwater runoff and generation of wastewater also optimises the requirement for storage.

Similarly, the use of smaller wastewater catchments minimises the accumulation of stormwater and conveyance within sewage systems which also decreases the requirement for wastewater storages and treatment capacity. Note the costs and resources required from the regional networks are dynamically included in the systems analysis as extension, renewal, transfer and treatment costs that are activated by increases in daily demands that the Precincts require from the centralised systems. For example, a requirement for increased mains water supply due to lower than expected yields from a stormwater harvesting facility will generate increased expenses to augment the water supply system.

A local IWCM strategy is established when a development is of sufficient scale (such as Greenfield developments, substantial infill redevelopment, or a very large building or commercial complex). In situations where developments do not have sufficient scale (a single house, apartment block,

[19] Melbourne Water Corporation, 2010. Annual Report 2009/10

commercial or industrial facility) the development will implement the individual elements of a Precinct approach consistent with a "master plan" to enable integration into a Precinct at a later stage.

In this Option new developments will still have access to regional mains water and wastewater connections. The reliance on this connection may be significantly diminished in comparison to the BAU option as determined by climate and demographic variables. The Precinct scale IWCM solution represents a local system that forms part of a polycentric cluster of Precincts within the larger centralised system as shown in Figure 2.5.

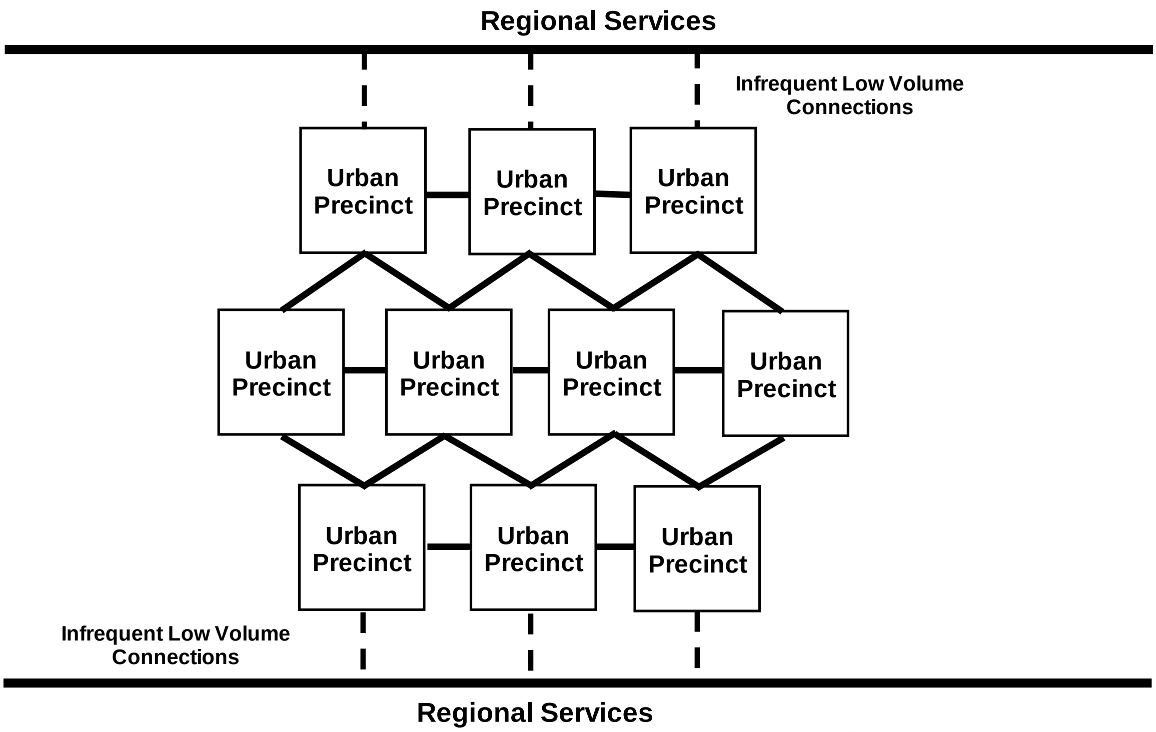

Figure 2.5: A polycentric cluster of Precincts with IWCM strategies that provide resilient water cycle services

Figure 2.5 reveals that each urban Precinct in this Option is located within a polycentric network of Precincts with local IWCM strategies. The network of local strategies combines optimum use of local resources with multiple interconnectivity to maximise the resilience of the local strategies.

Option 3 is designed to minimise augmentation of regional water cycle networks, to supplement the capacity of existing infrastructure and to eliminate disposal of wastewater to waterways.

In this Option, all new buildings would implement sustainable (water, energy and design) building practices into all new residential, commercial and industrial projects. All new and renovated buildings will include a higher level of water efficiency equivalent to Green Star 6 standards and local harvesting.

Stormwater harvesting storages are designed to replace the current requirement for stormwater detention basins, onsite detention (OSD) systems and large scale constructed wetlands. Local bio-retention facilities assist with the management of waterway health.

2.5 Option 4: (ULT1)

Option 4 is a version of ULT Option that does not include treatment and injection of harvested stormwater into mains water networks. The MAC decided not to include this Option as it may not be feasible for treated stormwater to be injected in the mains water system.

This Option uses rainwater harvesting from roofs for hot water and laundry uses. Treated wastewater is used for toilet flushing, cooling and outdoor uses. Mains water is used for drinking and kitchen uses.

3 Scenarios

Scenarios do not seek to predict the future. Predicting the future often conceals risks and opportunities. A focus on apparent certainties often results in singular point or linear outcomes which may provide quantitative comfort or alternatively overly pessimistic futures. In complex systems such as the evolution of a city either qualitative comfort or gloom can be unrealistic.

The scenarios derived for this investigation describe the potential changes in qualitative drivers that may influence the behaviour of the system that can impact on any Option. The Scenarios applied to each of the Options for water cycle management throughout Greater Melbourne examined in this study are summarised in Table 3.1 and described in subsequent Sections.

Table 3.1: Summary of Scenarios

Scenario	Description
Low Emissions Climate Change (LE)	• Lower bounds of high emissions projections by IPCC represented by a 0.025˚C incremental annual change in average maximum temperature.
High Emissions Climate Change (HE)	• Higher bounds of high emissions projections by IPCC represented by a 0.05˚C incremental annual change in average maximum temperature.
Greenfield Growth (GF)	• All urban growth occurs as Greenfield development at the fringes of Greater Melbourne where development currently does not exist.
Infill Growth (IF)	• All urban growth occurs as infill development of existing inner urban areas of Greater Melbourne.
Low Population Growth (0%)	• Annual average population growth remains static (0%) across Greater Melbourne from 2011–2050.
High Population Growth (2%)	• Annual average population growth of 2% across Greater Melbourne from 2011–2050.
Economic Structural Change (EC)	• Structural change in the economy results in the closure the majority of Greater Melbourne's heavy industry and manufacturing. This results in reduced commercial and industrial water demand.

3.1 Scenario 1: Low Emissions Climate Change (LE)

Scenario 1 represents the lower bounds of IPCC's high emissions climate change projections [20,21] by application of a 0.025˚C annual incremental change in average maximum temperatures.

3.2 Scenario 2: High Emissions Climate Change (HE)

Scenario 2 represents the higher bounds of IPCC's high emissions climate change projections by application of a 0.05˚C annual incremental change in average maximum temperatures.

[20] DSE, 2008. Climate change in the North East region. Department of Sustainability and Environment.
[21] IPCC,2007. IPCC Fourth Assessment Report: Climate Change 2007.

3.3 Scenario 3: Greenfield Growth (GF)

Scenario 3 assigns all urban growth as Greenfield development in the fringe areas of Greater Melbourne where development currently does not exist (see Figure 3.1).

3.4 Scenario 4: Infill Growth (IF)

Scenario 4 assigns all urban growth as Infill development and densification of existing inner urban areas of Greater Melbourne where development currently exists (see Figure 3.1).

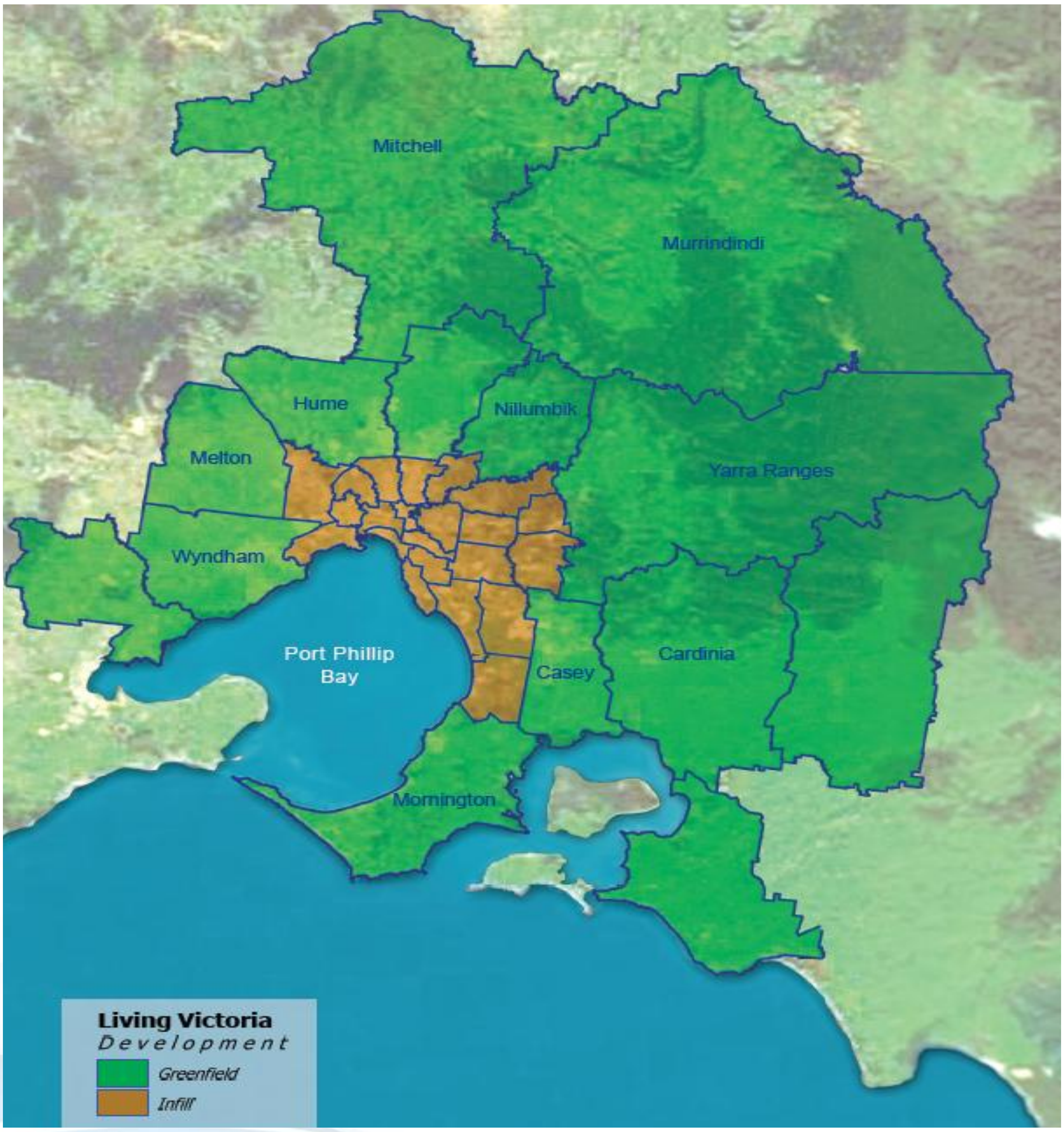

Figure 3.1: Schematic of Greenfield and Infill areas

3.5 Scenario 5: Low Population Growth (0%)

Scenario 5 is lower than projected average annual population growth for Greater Melbourne from 2010 to 2050. This is characterised by an annual average population growth of 0%.

3.6 Scenario 6: High Population Growth (2%)

Scenario 6 is higher than projected annual average population growth for Greater Melbourne from 2010 to 2050. This is characterised by annual average population growth of 2%.

3.7 Scenario 7: Economic Structural Change (EC)

Scenario 7 represents a structural change in the economy of Greater Melbourne resulting in reduced commercial and industrial water demand. This scenario includes partial closure of major industry and manufacturing in the Hobsons Bay, Wyndham, Gippsland, Westernport, Geelong and other regions as shown in Figure 3.2. This impact is characterised by a halving of non-residential water demands in the areas highlighted in Figure 3.2.

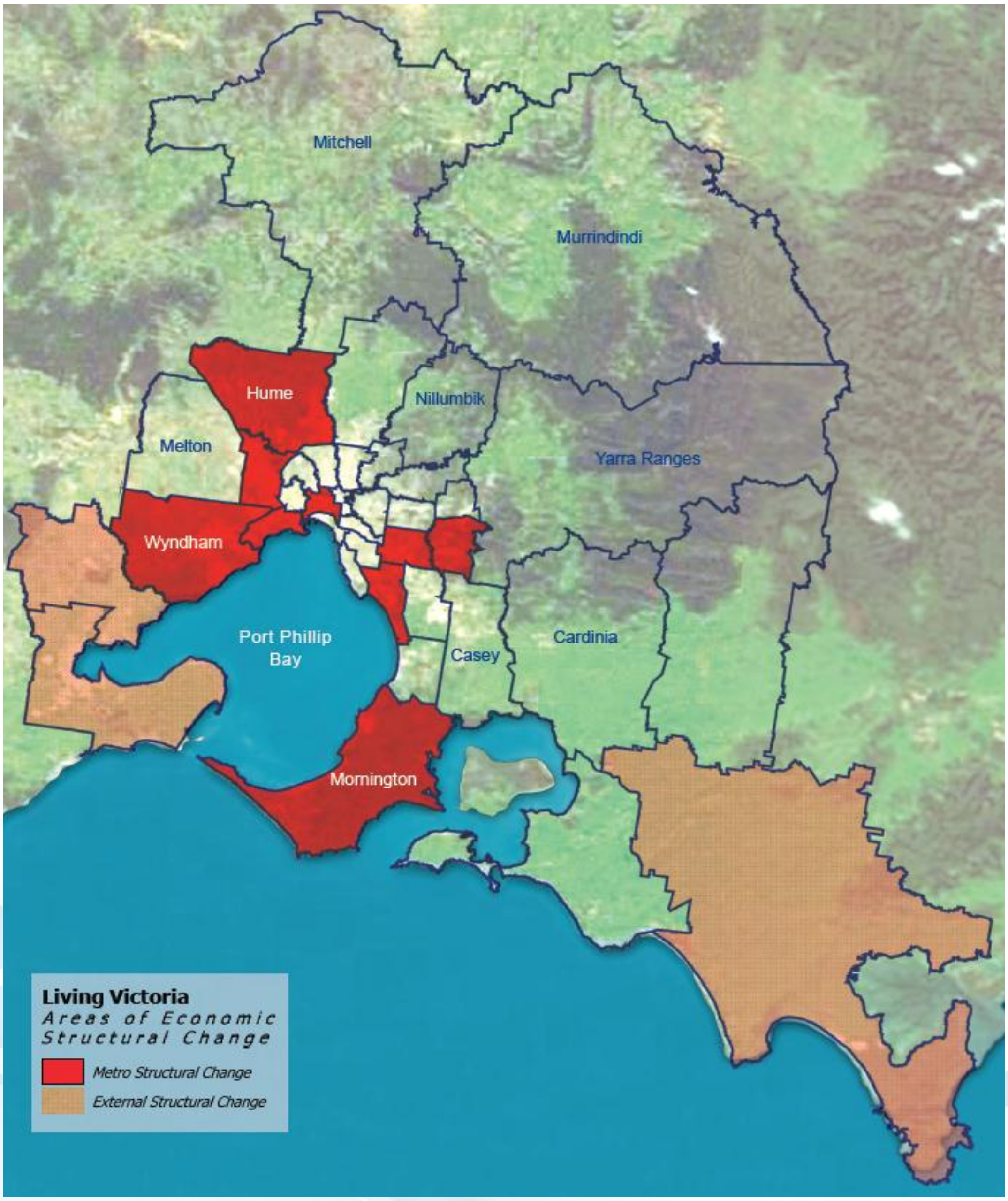

Figure 3.2: Schematic of regions impacted economic structural change

4 Methods

This study employed an integrated systems approach to analysing the performance of alternative water cycle management Options for Greater Melbourne. The Options were determined to generate understanding of the response of the water cycle systems throughout Greater Melbourne to alternative strategies. This unique analysis is dependent on detailed inputs, such as demographic profiles, and linked systems that accounts for water supply, sewage, stormwater and environmental considerations. This section describes the additional key assumptions and methods used in this analysis.

The previous reports by Bonacci Water namely, "Study 1 – transitioning to a resilient, liveable and sustainable Greater Melbourne (system wide study)" and "Rainwater tank evaluation study for Greater Melbourne" should be read in conjunction with this Chapter.[22,23] These reports provide an essential overview of the historical development of the biophysical systems model, and a range of existing key inputs and processes in the systems model.

It is important construct the systems analysis from the basic elements (the lot scale inputs) that drive system behaviours. It is also critical to understand and account for first principles transactions within the system to allow simulation of spatial and temporal performance of the system. This allows simulation of the response of the system to perturbations such as analysis of Options and Scenarios. Biophysical systems in the region were constructed using three basic components:*

- **Sources** - Regional and local water sources, catchments and waterways
- **Flux** – transport and treatment of water, sewage and stormwater throughout the region
- **Sinks** – Stormwater runoff and wastewater disposal to waterways

The fundamental construct of this novel approach is outlined in Figure 4.1.

Figure 4.1 shows that the foundation principles used as the basis of the systems analysis in this project – the system is driven by demands at the lot scale (including water, sewage, stormwater and environmental demands or discharges) that require movement of water (Fluxes) from a range of sources and disposal of water (such as sewage and stormwater) to a range of sinks.

The framework for analysis of the Greater Melbourne system was compiled from the lot scale to regional scale as presented in Figure 4.2.

22 Coombes P.J. and Bonacci Water (2011). Study 1 – transitioning to a resilient, liveable and sustainable Greater Melbourne (system wide study). Report to the Ministerial Advisory Council for the Living Melbourne Living Victoria water policy.
23 Bonacci Water and Urban Water Cycle Solutuions (2008). Rainwater tank evaluation study for Greater Melbourne. Report for the Department of Sustainability and Environment.

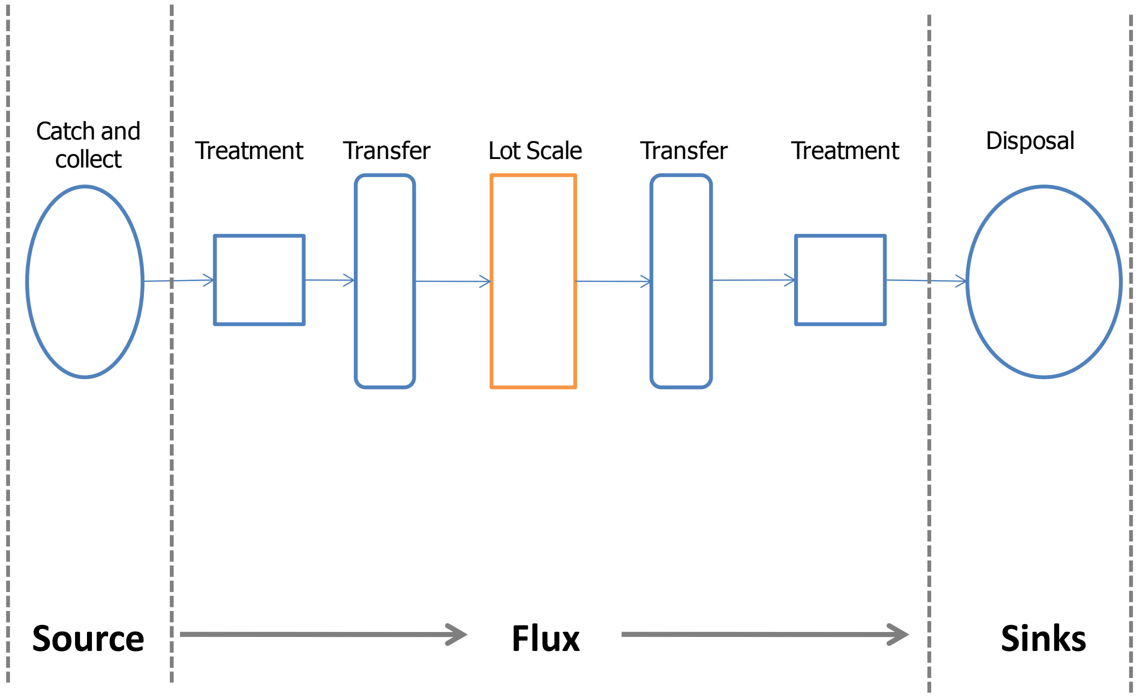

Figure 4.1: The principles underpinning any water system – Sources, Fluxes and Sinks

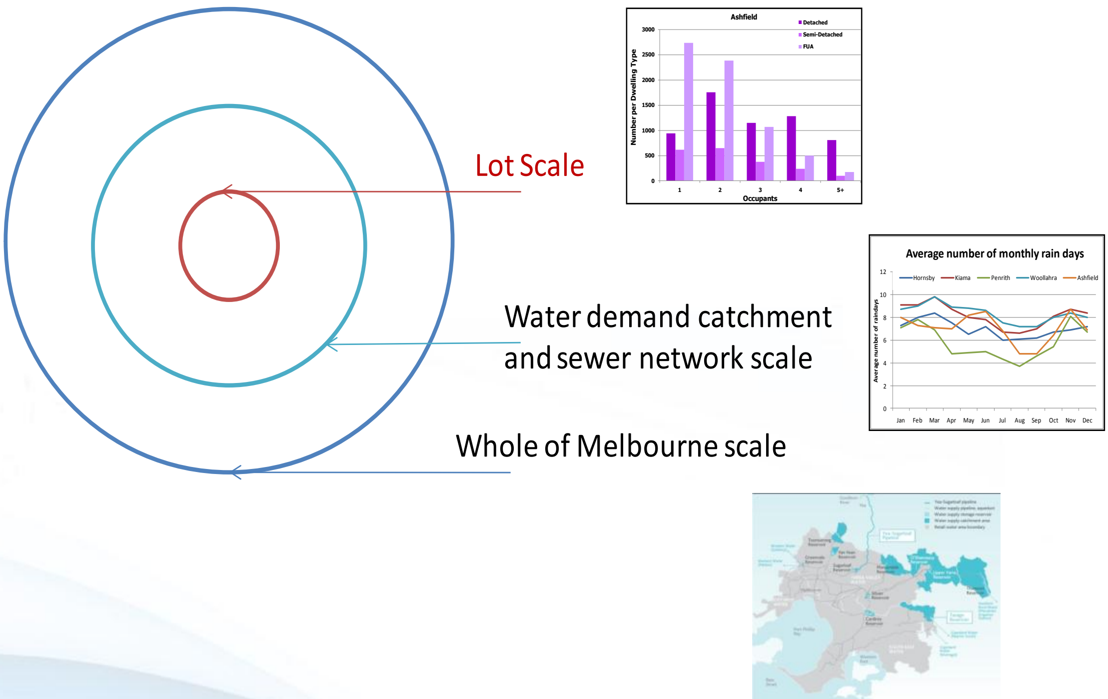

Figure 4.2: Three linked spatial scales used in the analysis and in calibration

Figure 4.2 shows the foundation principle used as the basis of the systems analysis in this project, namely that the overall system is driven upwards by demands at the lot scale (including water, sewage, stormwater and environmental demands or discharges). Further, it shows that these demands require both movement of water (fluxes) from a range of sources and disposal of water (such as sewage and stormwater) to a range of sinks. The methods used to implement this upwards focussed analysis framework of the Greater Melbourne system is presented in Figure 4.3.

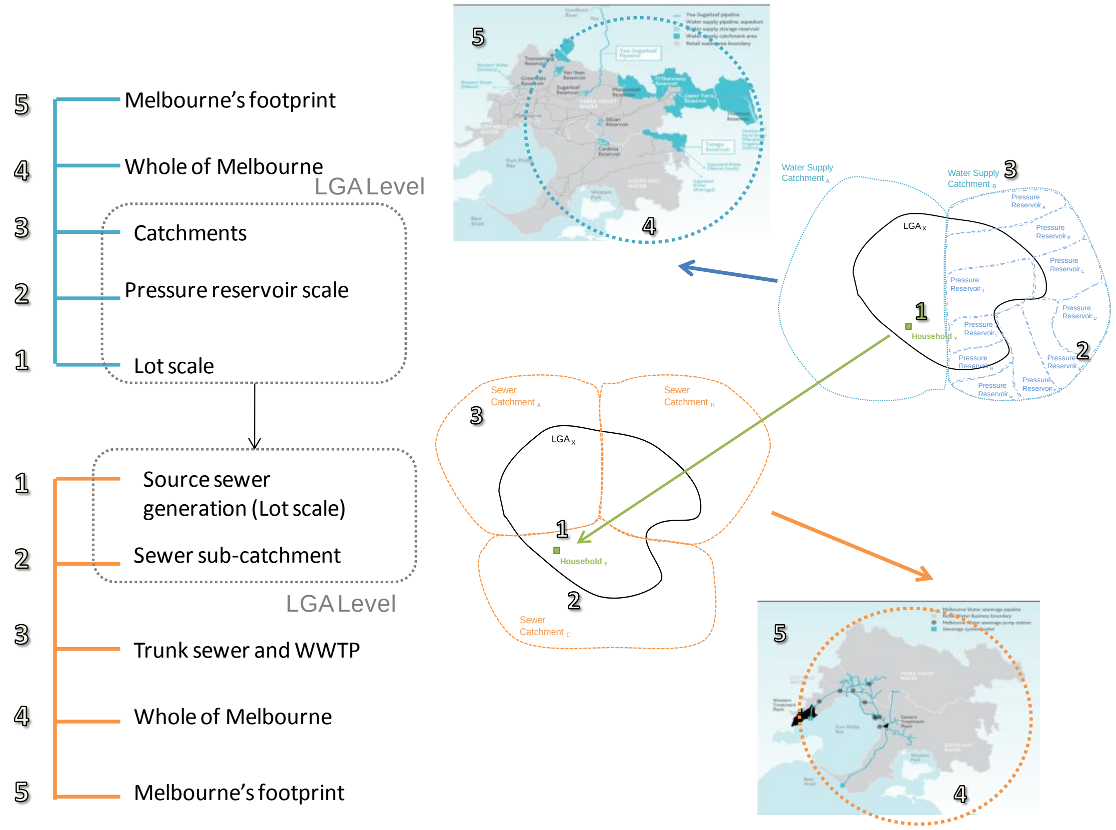

Figure 4.3: The linked nature of water and wastewater systems employed in this analysis

Figure 4.2 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 LGA scale (the middle scale), and regional behaviours or infrastructure such as water extractions from and discharges of sewage to wastewater treatment plants. This process can be described as analysis of systems within systems across multiple scales. Our 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. 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 (such as PURRS) and hydrology. Key simulation inputs to this framework include:

- Demographic data from the Australia Bureau of Statistics and State Government departments including DPCD
- Climate data from the Bureau of Meteorology and streamflow data from the Victorian Data Warehouse and MWC.
- Water and sewage flows sourced from MWC, CWW, SEW and YVW.

- Local and cluster scale inputs simulated in the PURRS model at 6 minute timesteps using long climate records.
- Urban areas and LGAs analysed using a range of models including PURRS and MUSIC. These smaller scale systems are also analysed in more detailed WATHNET models.
- The biophysical and scale transition model compiles inputs from PURRS into the zones based on statistical local areas and calibrates 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 region 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 4.3.

Importantly, the framework shown in Figure 4.3 is driven by long sequences of spatially and temporally consistent input data that captures the spatial and temporal variation in climate (rainfall, temperature and frequency of rainfall), demographics, water demands and water management strategies across the Greater Melbourne region. This ensures that the impact of the considerable spatial and temporal variation and connectivity across the region is robustly incorporated in the framework leading to accurate understanding of internal and external augmentation requirements. Clearly the region does not respond "on average" and this process captures the dynamics of feedback loops from sources to sinks throughout the region. This is a contrast to traditional analysis that assumes that the system response is top down to spatial or temporal averages.

For example, this framework provides comprehensive systems understanding of the dynamics of sewage discharges, including interaction with stormwater systems, to sewage treatment plants and the impact of reusing treated effluent from the contributing sewage catchments. It promotes an understanding of the changes in sewage flows, demands for recycled water and requirement for reuse infrastructure throughout the region with the consequent changes in distribution of water from external sources (such as desalination and the north south pipeline throughout the region). This allows understanding of the changed energy profiles, the extent of reuse required and the operating costs of any strategy. In addition, this connectivity allows understanding of the regional water security and resilience to climate change provided by an alternative Options – a proportion of Greater Melbourne's water security will be provided by internal sources.

Wherever possible the analysis incorporates first principles information and sequences of inputs rather than averages. Smaller scale inputs to the regional framework involve more detailed analysis of residential, commercial, industrial and agricultural areas. This analysis includes the dynamic inputs of local infrastructure and building form to the regional framework.

Details of the analysis, extractions from the data and modelling process have been provided throughout this Section to assist with understanding the systems processes used in this study. Household water consumption for the period 2005 to 2006 was selected in this study as representing base water consumption for the region during a period relatively free of water restrictions. These water demands were then modified by a range of processes including adoption of water efficient appliances in some houses, connection to wastewater reuse systems and changes in demographics. The year used for the economic analysis is the 2009/10 financial period.

4.1 The hindcasting, data gathering and review processes

A stakeholder, review and hindcasting process (see Sections 5 and 6) was undertaken as an essential part of the methodology for this investigation and to obtain data and information that was not made available during the previous Stage 1 of the MAC investigation. This process involved a large number of stakeholders and assisted the enhancement of the systems model by inclusion of a considerable amount of additional data, local knowledge and operational rules.

4.2 Selection of zones

Zones across Greater Melbourne were selected with sufficient spatial resolution to allow analysis of spatial variation in water demand behaviour and, as a consequence, the performance of alternative water cycle management strategies across the region. In addition, the spatial zones were required at a resolution that will allow analysis of impacts on trunk water distribution, sewage disposal processes and stormwater management.

This project analysed demographic, water demand and climate data within statistical local areas (SLA) to select 36 zones for water demands, sewage and stormwater discharges across Greater Melbourne. Information about Melbourne's water and sewage distribution network; and major waterways was also considered in the selection of zones.

The Greater Melbourne region includes 87 SLAs that were combined into 36 significant locations (see Figure 4.4) using the following data:

- Boundaries, demographics and socio-economics from ABS "Local Government Areas" and "Statistical Local Areas".
- Stormwater catchments
- Local government boundaries
- Water and sewage networks provided by Melbourne Water (MWC), City West Water (CWW), South East Water (SEW) and Yarra Valley Water (YVW)
- Climate data from the BOM

The zones presented in Figure 4.4 are also described in Table 4.1.

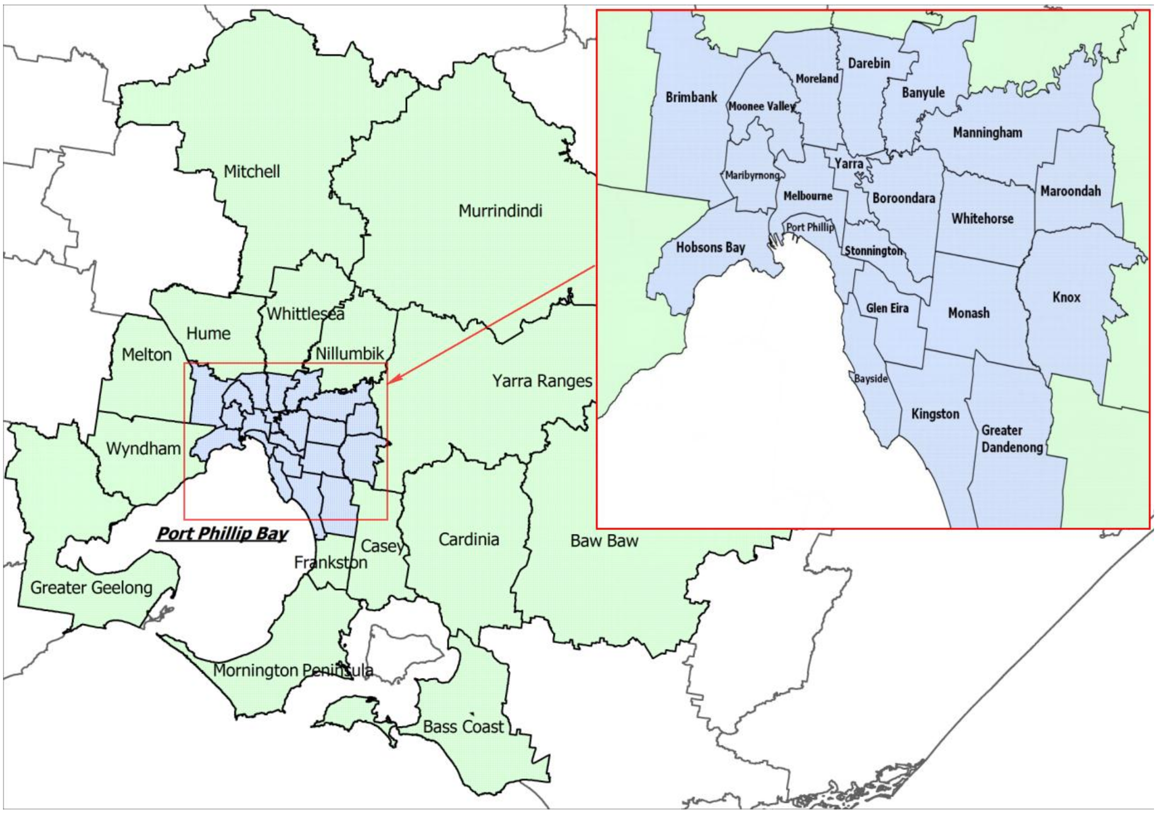

Figure 4.4: Spatial Zones used in analysis

Table 4.1: Spatial Zones used in analysis

Spatial zones			
Banyule	Frankston	Maribyrnong	Murrindindi
Bass Coast bal	Glen Eira	Maroondah	Nillumbik
Baw Baw Pt. B West	Greater Dandenong	Melbourne	Port Philip
Bayside	Greater Geelong Pt. C	Melton	Stonnington
Boroondara	Hobsons Bay	Mitchell	Whitehorse
Brimbank	Hume	Monash	Whittlesea
Cardinia	Kingston	Moonee Valley	Wyndham
Casey	Knox	Moreland	Yarra
Darebin	Manningham	Mornington	Yarra Ranges

Water use and demographic considerations

A combination of average household water use, demographic and climate data was used to develop water use profiles for a variety of household sizes in each zone. Long daily records of temperature and rainfall at each location were combined with pluviograph (6 minute) rainfall records to create synthetic pluviograph records of suitable length for robust simulation of alternative water cycle Options in the PURRS (Probabilistic Urban Rainwater and wastewater Reuse Simulator) model. A diurnal pattern was employed to disaggregate household water use into sub-daily time steps. The use of long climate records and sub-daily time steps was required for reliable simulation of rainwater and stormwater harvesting scenarios.

The water use and sewage disposal profiles derived for each location were calibrated using the selected climate information in the PURRS model and quarterly billing records from water authorities. A range of Options was simulated using PURRS that account for different household sizes, types of dwellings and alternative water management strategies. These results are used to determine household responses to a range of drivers including alternative water strategies, impacts on stormwater, sewage and mains water systems, and economics at each location.

Average water usage data (Litres/household/day) were provided for most postcode areas throughout Metropolitan Melbourne by the Department of Sustainability and Environment (DSE). Over 250 postcode locations were identified. However, the usefulness of this data for understanding local household water use behaviour was limited because each postcode area has different demographic and socioeconomic components.

The Australian Bureau of Statistics (ABS) provides information about household size and distribution of dwelling types for each postcode location. This data provided an opportunity to unlock the characteristics of water use for each household type and for various household sizes within a given area. However the boundaries of postcode areas are mobile which creates uncertainty about the true characteristics of an area and actual household water use.

A more stable spatial characterisation of demographic and socioeconomic criteria was provided by Statistical Local Areas (SLA). Average household water use data was also available for the SLAs. Information from SLAs was combined to derive household water use in each zone.

4.3 Climate

The performance of alternative water use strategies is primarily dependent on climate processes at a given location. Water demands are also influenced by the local climate variables rainfall and temperature which are subject to considerable temporal and spatial variation across the region. This Section presents the process of including the spatial variation of climate processes across Greater Melbourne in the modelling framework.

Selection of rainfall and temperature Records

Reliable analysis of the performance of alternative water systems is dependent on the use of realistic water demand and local rainfall sequences. The physical processes involved in rainwater and stormwater harvesting including collection of roof runoff and rainwater supply to households can only be accurately simulated using sub-daily time steps and the longest available rainfall records.[24]

Daily rainfall and temperature records containing greater than 30 years of data that also include the recent drought were obtained from the Bureau of Meteorology for locations throughout Greater Melbourne. In addition, pluviograph (6 minute) rainfall records containing greater than 10 years of data were obtained from the Bureau of Meteorology for the region. More than 86 daily rainfall and 20 pluviograph records were identified and some of these records were used to derive long synthetic pluviograph records at each location.

Development of long term pluviograph rainfall records

Synthetic pluviograph (6 minute) rainfall records were derived at locations with long daily rainfall records using a non-parametric nearest neighbourhood scheme.[25] At a given site with a daily rainfall record, data from pluviograph rainfall records with different time periods in surrounding areas can be utilised to disaggregate daily rainfall into a synthetic pluviograph rainfall record. A diagram of the concept is shown in Figure 4.5.

The non-parametric scheme utilises climate and seasonal parameters (daily rainfall depth, month, count of days since last rain event) at the daily rainfall and nearby pluviograph rainfall sites to select a day of pluviograph rainfall from the most appropriate nearby pluviograph record. For each day in the daily rainfall record a day of pluviograph rainfall record is chosen using climate and seasonal parameters, and a ranking scheme. The nearby pluviograph records can be ranked on the basis of proximity to the location of the daily rainfall record and similarity of annual rainfall depths, topography and distance from the coast. This allows disaggregation of the daily rainfall records into a series of storm events and dry periods that constitute a continuous synthetic pluviograph rainfall record.

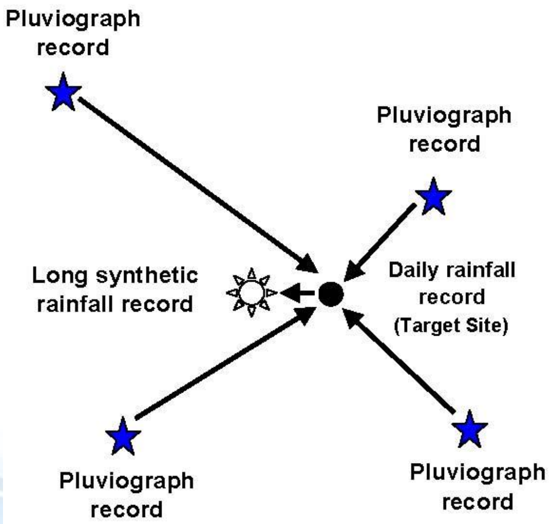

Figure 4.5: Diagram of the non-parametric nearest neighbourhood scheme for development of synthetic pluviograph records

[24] Coombes P.J., and M.E. Barry, 2007. The effect of selection of time steps and average assumptions on the continuous simulation of rainwater harvesting strategies. Water Science and Technology. Vol. 55 No. 4. pp. 125 – 133.

[25] Coombes P.J., 2004. Development of Synthetic Pluviograph Rainfall Using a Non-parametric Nearest Neighbourhood Scheme. WSUD2004 conference. Adelaide.

This process ensures that the synthetic continuous rainfall record will have similar rainfall patterns to the chosen site whilst the total daily rainfall depths in the synthetic rainfall record are conditioned on the daily rainfall record. In the non-parametric nearest neighbourhood scheme a rank is used to prioritise the search process for a continuous rainfall pattern that best matches the climate characteristics of the daily rainfall record on any given day.

Example from the Knox zone

A synthetic pluviograph rainfall record with a length of 59 years and average annual rainfall depth of 875 mm was constructed for the Knox area using daily rainfall from Scoresby with pluviograph rainfall from Croydon, Mitcham, Dandenong and Melbourne Regional Office. These pluviograph records were chosen as the closest available long records to the site and to account for the spatial influence of weather events on the area.

Rainfall

Average annual rainfall at each of the zones used in this study is presented in Figure 4.6 to highlight the spatial distribution of rainfall throughout the region.

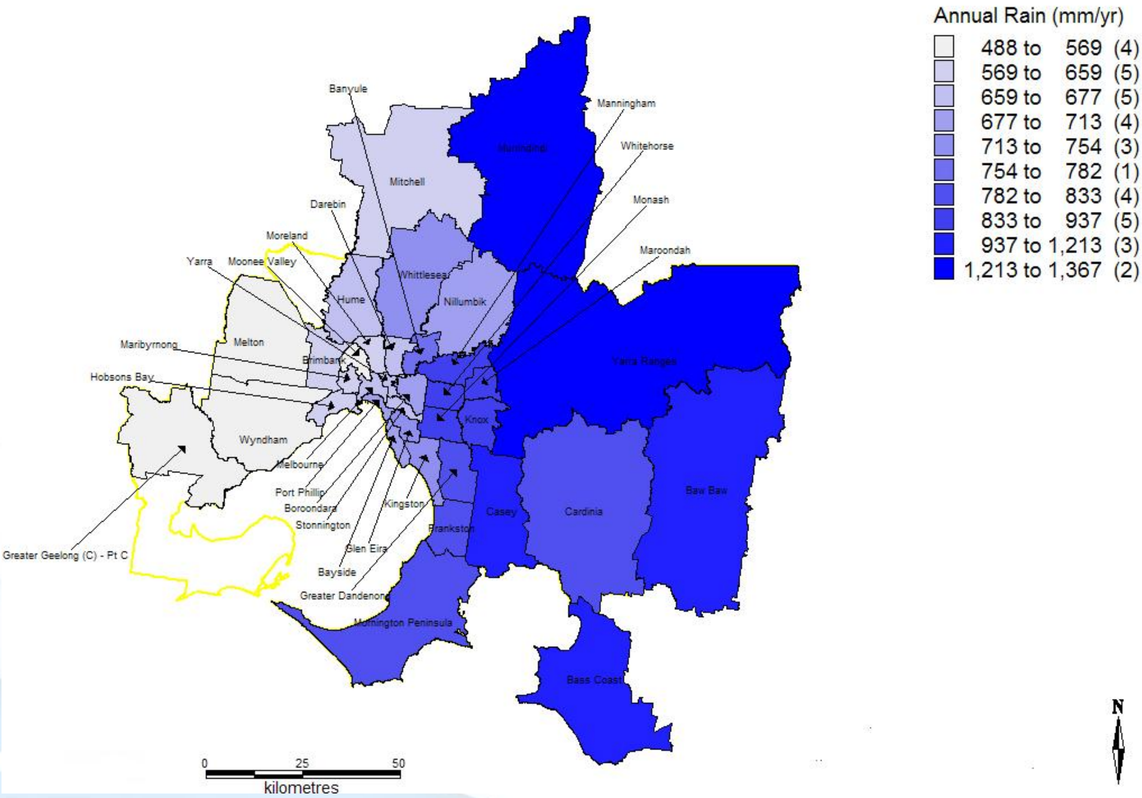

Figure 4.6. Spatial distribution of average annual rainfall across the Greater Melbourne region

Figure 4.6 shows considerable spatial variation in average annual rainfall across the Greater Melbourne region with the highest rainfall of 1,336 mm experienced at the Murrindindi area with the lowest rainfall of 485 mm occurring in the Melton area. The majority of the region is subject to relatively high annual average rainfall depths with only a small proportion of the region experiencing average annual rainfall depths less than 569 mm. The daily rainfall observations from the Bureau of Meteorology (BOM) used to derive rainfall records for each LGA are shown in Table 4.2.

Table 4.2: Annual rainfall statistics from each Statistical Local Area used in the systems analysis

Location	Daily rainfall record	Length (yrs)	Average (mm/yr)	Average over last 11 yrs (mm/yr)	Difference (%)
Banyule	Eltham	105	750.6	616.1	-17.9
Bass Coast	Wonthaggi	100	936.2	933.9	-0.2
Baw Baw	Warragul	124	1018.0	844.3	-17.1
Bayside	Brighton	87	672.0	597.2	-11.1
Brimbank	Greenvale Res	40	599.4	557.9	-6.9
Cardinia	Kooweerup	53	774.0	705.9	-8.8
Casey	Narrewarren Nth	145	919.9	767.7	-16.5
Darebin	Preston Res	119	651.7	572.0	-12.2
Boroondara	Hawthorn	39	657.5	590.1	-10.3
Moreland	Essendon	82	593.6	493.6	-16.8
Stonnington	Prahran	119	653.2	564.5	-13.6
Frankston	Cranbourne Sth	46	776.4	725.6	-6.5
Glen Eira	Caulfield	123	721.3	619.3	-14.1
Greater Dandenong	Dandenong	50	773.4	749.3	-3.1
Greater Geelong Pt. C	Little River	105	495.0	513.0	3.6
Hobsons Bay	Altona	43	550.7	445.0	-19.2
Hume	Epping	105	641.2	560.3	-12.6
Kingston	Bon Beach	55	693.5	631.0	-9.0
Knox	Scoresby	64	861.7	747.6	-13.2
Manningham	Warrandyte	44	814.9	739.8	-9.2
Maribyrnong	Flemington	106	583.8	528.1	-9.6
Maroondah	Croydon	101	886.1	799.2	-9.8
Melbourne	Melbourne RO	160	648.2	537.6	-17.1
Melton	Melton	128	485.9	448.9	-7.6
Mitchell South	Heathcote	130	572.2	520.5	-9.0
Monash	Glen Waverley	40	832.1	780.2	-6.2
Moonee Valley	Melbourne AP	41	536.1	482.5	-10.0
Mornington	Mornington	143	763.5	690.6	-9.5
Murrindindi	Toolangi	58	1336.6	1105.1	-17.3
Nillumbik	Yan Yean	135	664.4	599.0	-9.8
Port Phillip	Botanical Gdns	46	652.9	524.5	-19.7
Whitehorse	Mitcham	75	856.0	736.9	-13.9
Whittlesea	Whittlesea	109	688.7	599.9	-12.9
Wyndham	Werribee	53	517.9	441.7	-14.7
Yarra	Melbourne RO	160	1171.3	958.0	-18.2
Yarra Ranges	Silvan	91	832.1	780.2	-6.2

Table 4.2 shows that the length of rainfall records used ranged from 40 years to 160 years with a corresponding range of average rainfall depths of 485 mm to 1336 mm across the Greater Melbourne region. The length of rainfall records used in this study is sufficient to allow understanding of the performance of alternative water management strategies subject to low rainfall during droughts and higher rainfall during more bountiful years.

The recent drought as represented by the last eleven years (2000 to 2010) produced average annual rainfall depths that range from 442 mm to 1,105 mm. The recent drought is shown to have a highly variable impact ranging from a 3.6% increase to a 19.7% decrease in annual rainfall across the Greater Melbourne region. This result highlights that the impacts of the recent drought on rainfall cannot be generalised across the region.

Seasonal distribution of rainfall

The seasonal distribution of rainfall at selected locations is presented in Figure 4.7.

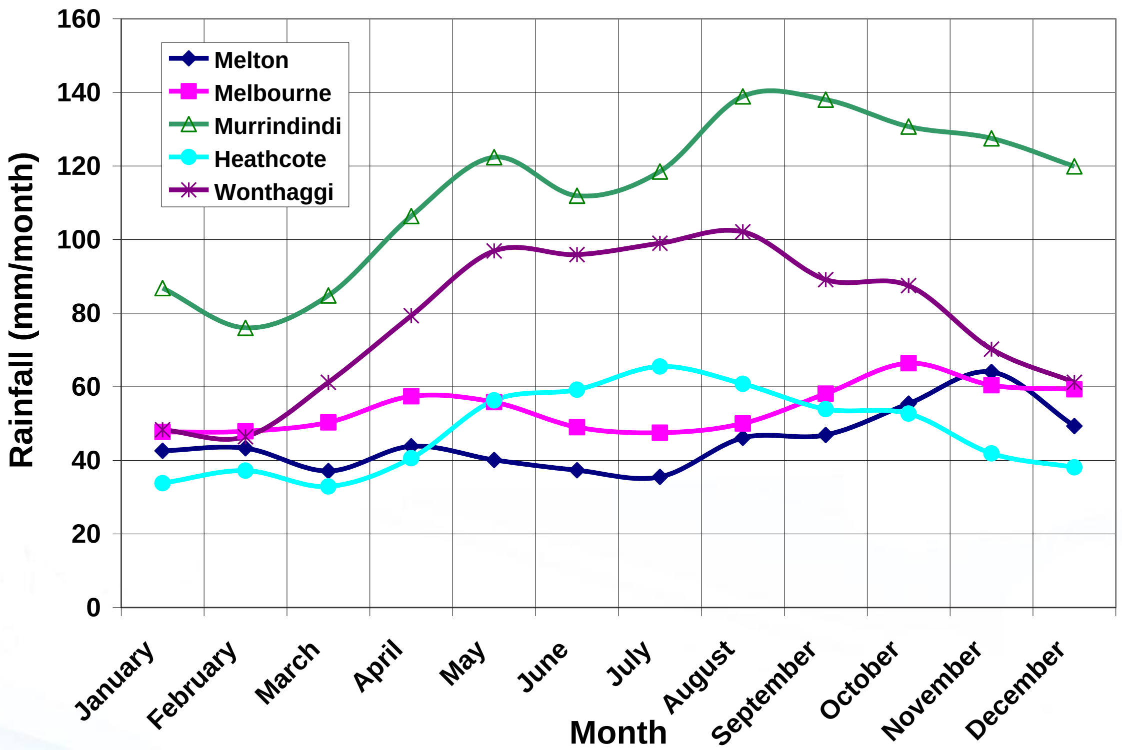

Figure 4.7: Mean monthly rainfall at selected locations across Greater Melbourne

Figure 4.7 demonstrates that the seasonal distribution of rainfall varies throughout the region. Melbourne and Melton are subject to a relatively even seasonal distribution of rainfall. Heathcote experiences generally even distribution of lower rainfall with a tend to higher rainfall during Winter and Spring. The dominance of Winter and Spring rainfall in the seasonal distribution is more significant in areas with higher rainfall and elevations or near the ocean such as Murrindindi and Wonthaggi.

Greater Melbourne experiences considerable variation in the seasonal distribution of rainfall which highlights the importance of using local data in analysis of water resources rather than from a single location or use of a spatial average. The behaviour of rainfall throughout the region cannot be generalised using a single rainfall location such as at Melbourne RO which is the current practice for analysis of water resources.

Average annual rain days

The frequency of rain events is also an important indicator of water demands and the potential of strategies that include rainwater and stormwater harvesting. Average annual number of days with rainfall greater than 1 mm at each of the zones used in this study is shown in Figure 4.8.

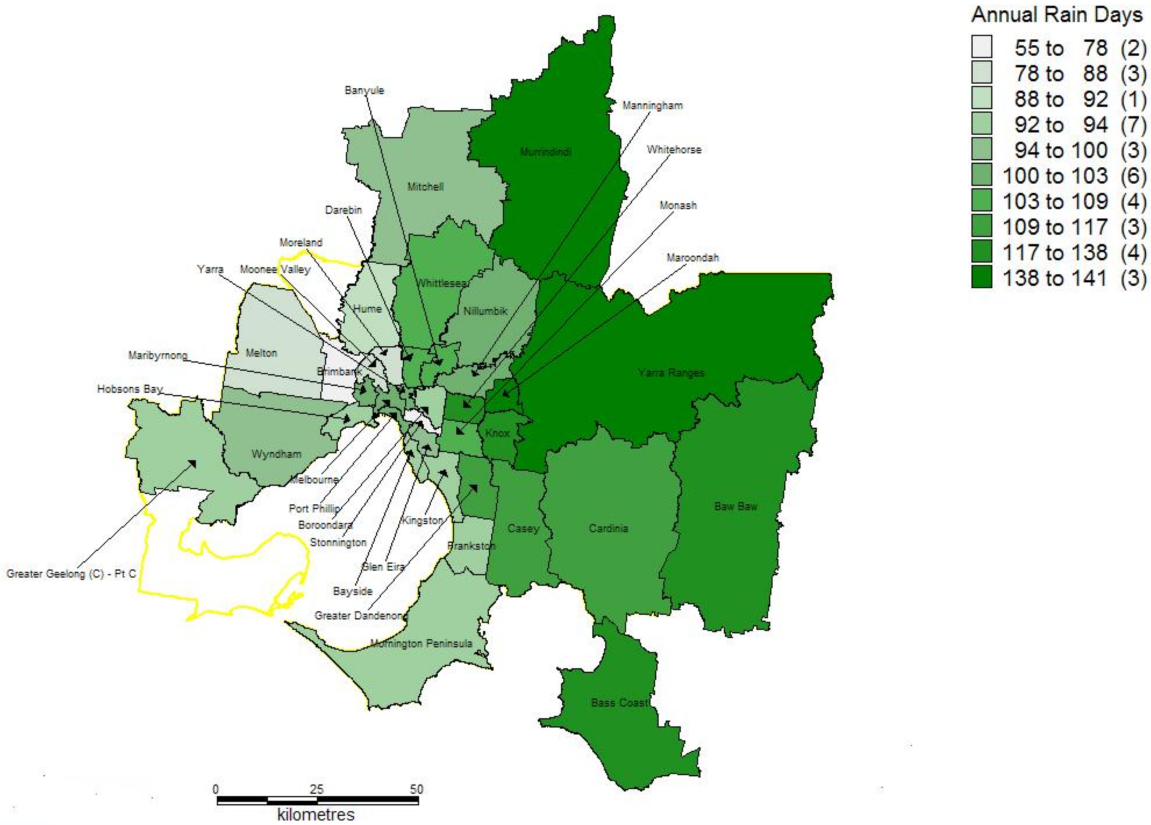

Figure 4.8: Spatial distribution of average annual number of days experiencing rainfall depths greater than 1 mm across the Greater Melbourne region

Figure 4.8 shows considerable variation in average annual number of days subject to rainfall across the Greater Melbourne region with the highest number of rain days (141) occurring at the Murrindindi and the Yarra Ranges areas with the lowest number of rain days (55) occurring in the Stonnington area.

A majority of the region is subject to relatively high number of average annual rain days with only a small proportion of the region experiencing less than 92 average annual rain days. The average frequency of rain days across Greater Melbourne ranges from rainfall occurring every 3 to 5 days.

These frequencies of rain days are expected to generate higher efficiencies of rainwater and stormwater harvesting. The seasonal variation in the frequency of rainfall is presented in Figure 4.9.

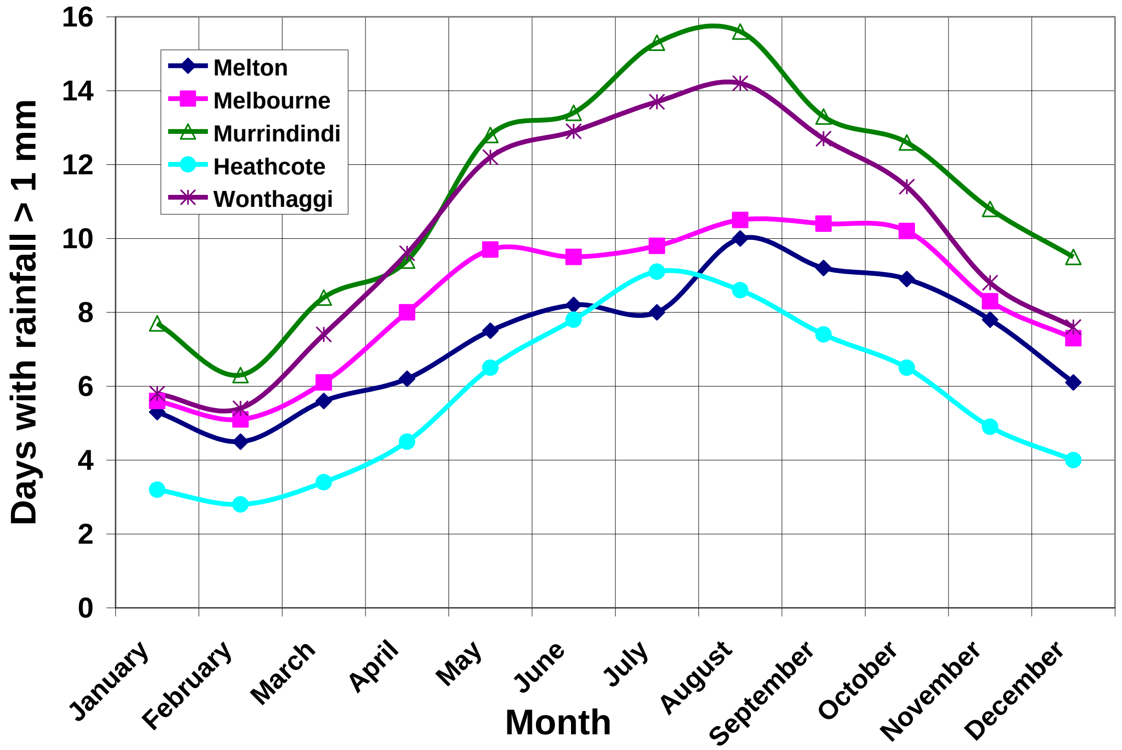

Figure 4.9: Seasonal variation in frequency of rainfall at selected locations

Figure 4.9 shows that the region is subject to higher frequencies of rainfall during the Winter and Spring seasons. Lower frequencies of rainfall are experienced during the Summer season. The difference in frequency of rainfall is more pronounced at the Murrindindi and Wonthaggi locations that are subject to higher rainfall.

Average annual maximum temperature

Daily maximum temperature is also known to influence water use behaviour, in particular outdoor water use, and is, therefore, an important indicator of the potential yields from wastewater reuse, rainwater and stormwater harvesting. Average annual maximum temperatures at each of the zones used in this study are shown in Figure 4.10.

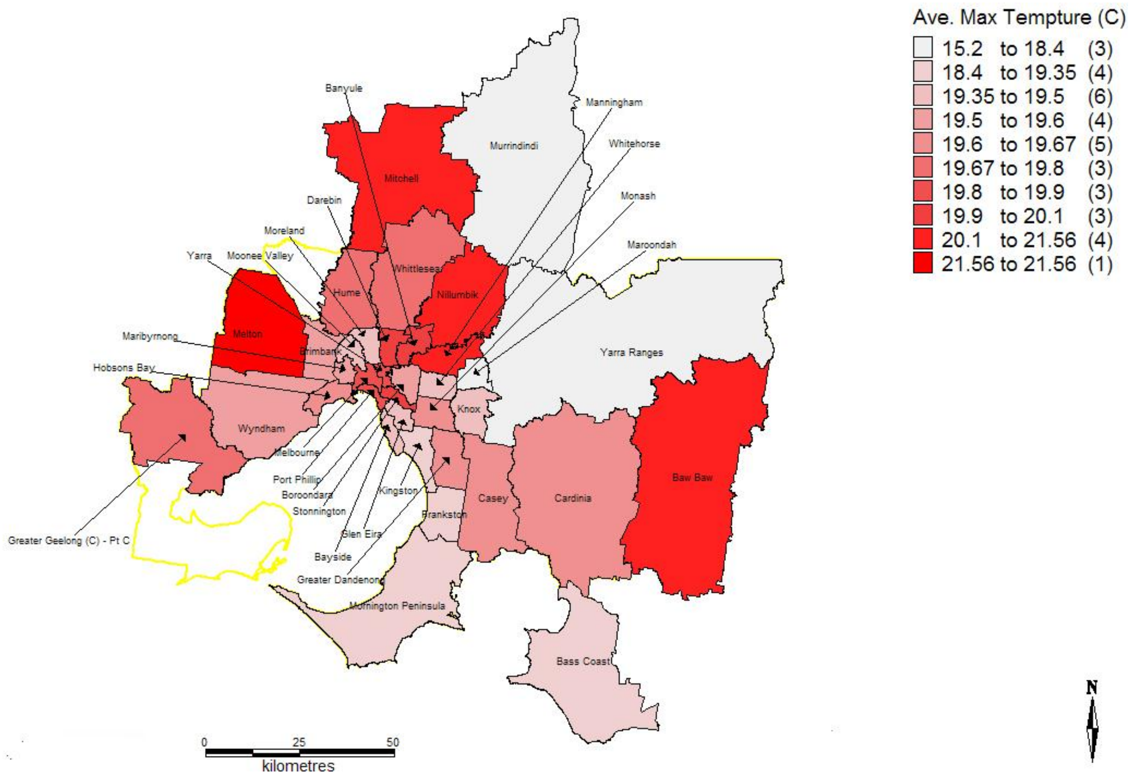

Figure 4.10: Spatial distribution of average annual maximum temperatures across the Greater Melbourne region

Figure 4.10 shows a wide variation in average annual maximum temperatures across the Greater Melbourne region with the highest annual average maximum temperature (21.6°C) occurring at the Melton area and the lowest annual average maximum temperature (15.2°C) occurring in the Maroondah area.

The north western region and a central band across Greater Melbourne which includes the inner regions are subject to higher average annual maximum temperatures which are expected to motivate higher outdoor water use.

Mean monthly maximum temperature

The seasonal variation in average maximum temperatures at selected locations is presented in Figure 4.11.

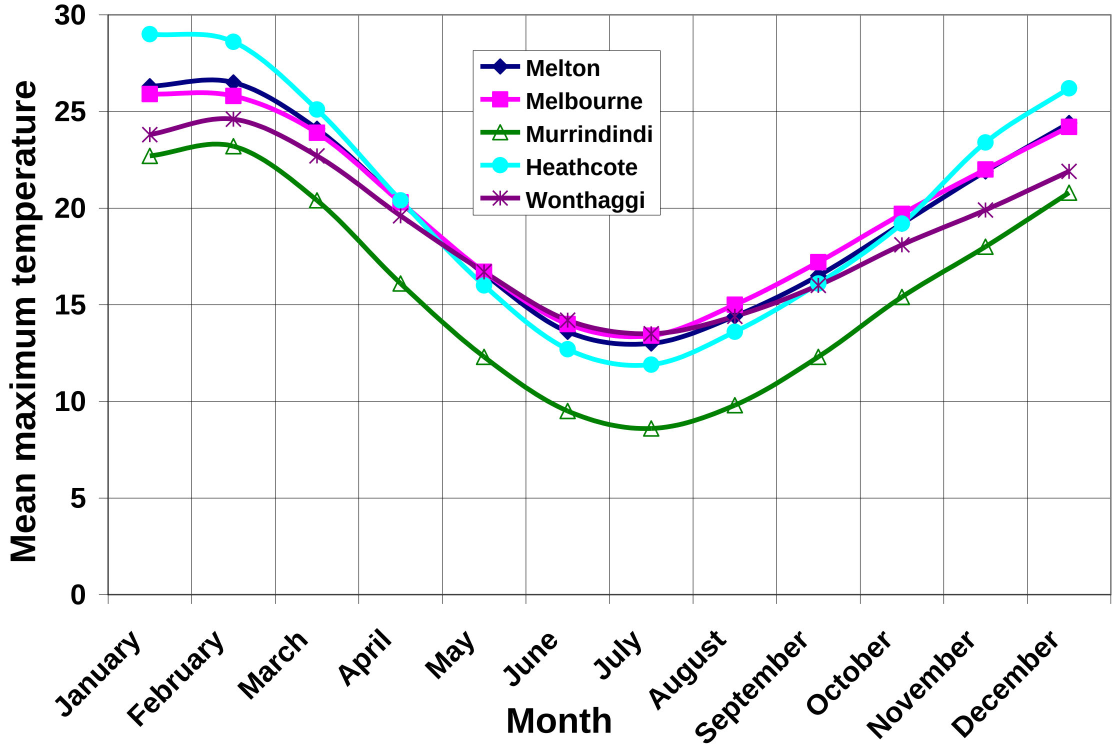

Figure 4.11: The seasonal distribution of average maximum temperatures at selected locations

Figure 4.11 shows that the seasonal distribution of temperature varies for all locations with generally lower average temperatures at Murrindindi. The distribution of average daily maximum temperatures displays greater spatial variation during the Summer season for all locations except Murrindindi.

4.4 Demographics

A robust understanding of demographic behaviours is an important element of analysis of water resources strategies. This study has utilised a range of accepted publications to derive a population profile for Greater Melbourne for the period 2010 to 2050. The profile is based on the number of dwellings present in each LGA over the given time period. Past demographic growth from 1996 to 2006 and current demographic growth for each LGA was derived using ABS 3218.2[26] series of publications.

The growth projections published by Department of Planning and Community Development (DPCD) for "Victoria in the Future 2011" were used in this investigation as shown in Table 4.3.[27] The spatial distribution of individual incomes for the region is presented in Figure 4.12.

26 Australian Bureau of Statistics, 3218.2 - Regional Population Growth, Australia, 2008-09.
27 Department of Planning and Community Development (2011). Victoria in the Future 2011.

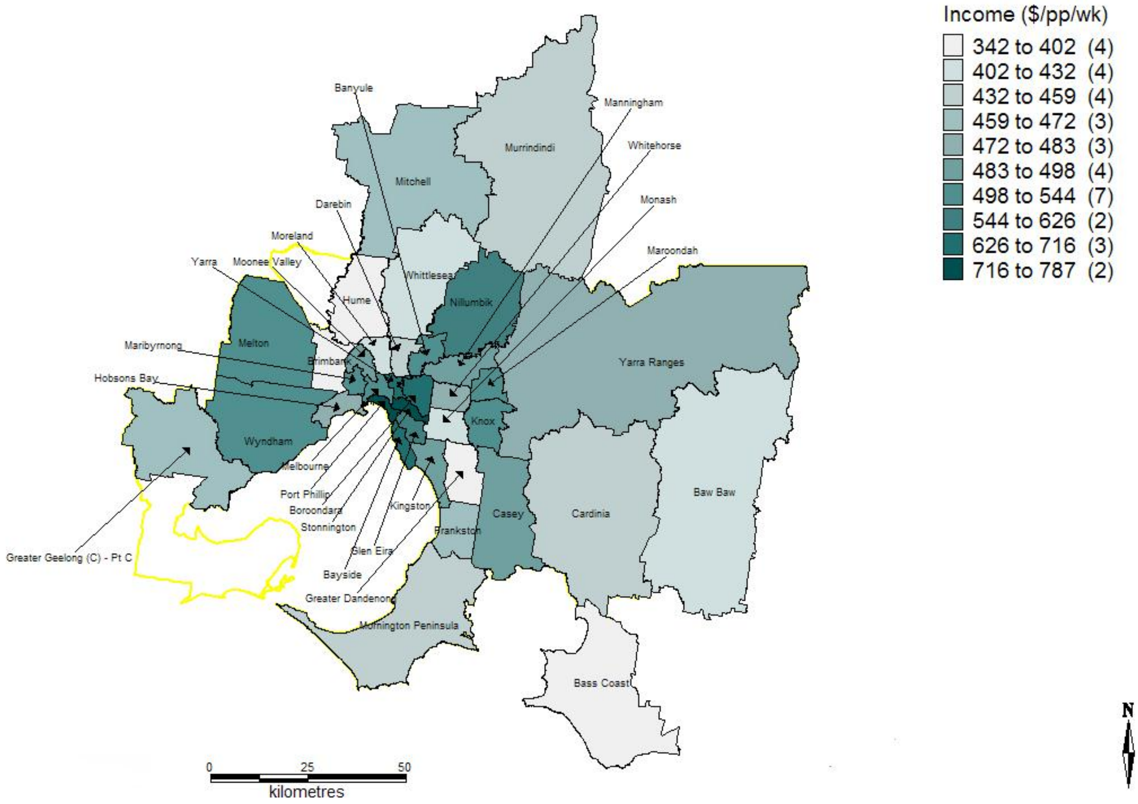

Figure 4.12: Spatial distribution of weighted average individual weekly income across the Greater Melbourne region

Figure 4.12 reveals that the lowest average weekly individual income is at Bass Coast ($348/pp/week) and the highest average income is at Port Phillip ($787/pp/week).

The values of new dwellings and renovated (or redeveloped) dwellings reported in this document were used to derive the renovation rates for use in this study as a fixed proportion for each LGA of the overall total cost of a new dwelling. The renovation or redevelopment rate was derived from ABS 8731.0 series "Building Approvals". It is important to note that the cost of a single average new dwelling has not been used for all of Greater Melbourne – the spatial costs of new dwellings are vastly different in each zone used in this study. The determination of the renovation or redevelopment rate for each zone is shown in Table 4.4.

Table 4.3: Growth in population by zone to 2050

LGA	2010	2011	2016	2021	2026	2031	2036	2041	2046	2051
Banyule	124,249	124,878	127,658	131,447	135,105	138,835	142,454	146,621	151,735	157,201
Bass Coast	22,636	23,118	26,136	29,259	33,025	36,500	40,143	43,742	47,182	50,836
Baw Baw	34,317	35,200	39,317	43,526	47,636	51,657	55,418	59,089	62,517	66,119
Bayside	97,283	98,002	101,476	103,166	104,747	106,541	107,985	109,785	112,552	115,639
Boroondara	169,507	170,974	176,834	180,371	183,769	188,090	192,500	197,424	203,798	210,661
Brimbank	189,386	191,811	204,572	210,129	213,829	217,134	220,309	223,132	227,036	231,474
Cardinia	73,318	77,621	98,982	120,835	136,839	142,383	147,610	152,084	157,596	163,525
Casey	255,659	262,418	295,124	328,504	364,925	404,498	442,738	461,589	477,542	489,311
Darebin	141,139	142,687	149,882	157,514	165,176	172,587	180,078	187,843	197,085	206,799
Frankston	130,462	132,035	138,437	144,889	149,626	152,993	156,183	160,399	165,598	171,193
Glen Eira	137,712	138,513	142,525	146,760	151,666	156,334	161,004	166,321	173,087	180,332
Greater Dandenong	138,558	139,794	147,317	155,528	163,627	173,155	182,120	190,001	199,462	209,453
Greater Geelong	2,514	2,547	2,753	2,985	3,229	3,454	3,653	3,826	3,990	4,161
Hobsons Bay	88,053	88,570	91,107	94,275	97,336	100,132	102,690	105,479	109,085	112,989
Hume	171,996	176,744	197,269	217,926	240,029	263,998	291,042	323,170	344,534	358,279
Kingston	148,830	149,795	155,125	161,390	167,242	173,750	179,883	187,220	196,175	205,661
Knox	156,997	157,459	160,854	165,658	170,437	176,090	181,751	188,255	196,159	204,569
Manningham	119,190	120,160	123,688	127,891	132,502	135,927	139,004	142,452	146,896	151,720
Maribyrnong	72,896	74,364	81,882	90,226	98,108	105,865	113,660	121,481	130,643	140,192
Maroondah	106,932	107,995	112,523	117,078	121,640	126,027	130,151	134,419	139,567	145,045
Melbourne	96,552	100,375	121,781	144,992	167,411	189,004	210,226	231,372	254,941	279,062
Melton	107,150	113,047	140,836	168,491	197,524	225,774	253,921	288,130	314,362	336,776
Mitchell	35,044	35,852	44,805	58,903	77,391	95,261	109,025	120,424	125,620	127,488
Monash	177,726	178,907	184,620	189,897	195,647	200,473	204,917	210,735	218,141	226,089
Moonee Valley	112,804	113,551	117,745	121,800	124,110	126,220	128,297	130,747	134,165	137,944
Moreland	150,838	152,532	160,017	167,243	173,948	180,163	186,356	193,157	201,567	210,526
Mornington Peninsula	150,238	151,554	157,237	164,354	170,946	177,589	183,507	190,618	199,085	208,023
Murrindindi	13,505	14,159	15,585	16,499	17,236	17,909	18,587	19,222	19,838	20,480
Nillumbik	64,184	64,534	65,939	68,124	70,281	72,238	74,137	76,141	78,737	81,556
Port Phillip	97,429	98,210	102,964	108,674	114,367	120,327	126,095	132,319	139,488	146,953
Stonnington	100,351	101,654	106,714	110,978	114,603	118,169	121,661	125,293	129,786	134,597
Whitehorse	156,797	157,685	161,241	165,029	168,801	172,317	175,811	179,835	184,993	190,580
Whittlesea	155,113	163,194	199,381	233,890	263,016	287,568	308,582	324,504	335,798	344,018
Wyndham	156,573	169,030	219,745	261,935	302,471	340,724	370,551	391,965	405,109	416,490
Yarra	79,540	80,862	86,250	92,384	98,484	104,279	109,717	115,287	121,751	128,501
Yarra Ranges	150,198	151,174	154,503	158,089	160,874	163,400	165,870	168,707	172,443	176,580

Table 4.4: Renovation rate by LGA[28]

LGA	Renovation rate relative to the cost of new dwellings (%)		
	100%	50%	10%
Banyule	0.39	1.95	3.87
Bass Coast	0.69	3.45	6.94
Baw Baw	0.39	1.95	3.91
Bayside	0.56	2.8	5.58
Boroondara	0.70	3.5	7.02
Brimbank	0.12	0.6	1.19
Cardinia	0.31	1.55	3.10
Casey	0.16	0.8	1.62
Darebin	0.52	2.6	5.17
Frankston	0.21	1.05	2.13
Glen Eira	0.54	2.7	5.41
Greater Dandenong	0.11	0.55	1.06
Greater Geelong	0.37	1.85	3.7
Hobsons Bay	0.37	1.85	3.72
Hume	0.16	0.8	1.57
Kingston	0.32	1.6	3.19
Knox	0.27	1.35	2.67
Manningham	0.31	1.55	3.09
Maribyrnong	0.47	2.35	4.74
Maroondah	0.32	1.6	3.16
Melbourne	0.72	3.6	7.21
Melton	0.15	0.75	1.49
Mitchell	0.34	1.7	3.41
Monash	0.35	1.75	3.47
Moonee Valley	0.47	2.35	4.68
Moreland	0.42	2.1	4.23
Mornington Peninsula	0.72	3.6	7.16
Murrindindi	0.59	2.95	5.91
Nillumbik	0.41	2.05	4.12
Port Phillip	1.21	6.05	12.08
Stonnington	1.14	5.7	11.44
Whitehorse	0.46	2.3	4.6
Whittlesea	0.13	0.65	1.25
Wyndham	0.16	0.8	1.58
Yarra	1.05	5.25	10.47
Yarra Ranges	0.35	1.75	3.49

[28] ABS, Dec 2010. 8731.0 Building Approvals. Vic, SLA Excel Datacube 2008-09; 2009-10; 2010-11. Australian Bureau of Statistics. Canberra.

Table 4.4 shows the renovation or redevelopment rate in each zone for renovations that incur expenses of greater than 10% of the value of an average dwelling, 50% of the value of an average dwelling and for renovations that are equal or greater than the cost of an average dwelling. The 10% renovation rate indicates the proportion of dwellings subject to partial renovation (such as a kitchen, a bathroom or a new extension) whereas the 100% renovation rate indicates the proportion of dwellings that are substantially redeveloped. The renovation rates for 50% and 10% of dwelling value were used for the BASIX and ULT Options respectively

This investigation also considered Melbourne's urban growth boundary as shown in Figure 4.13.

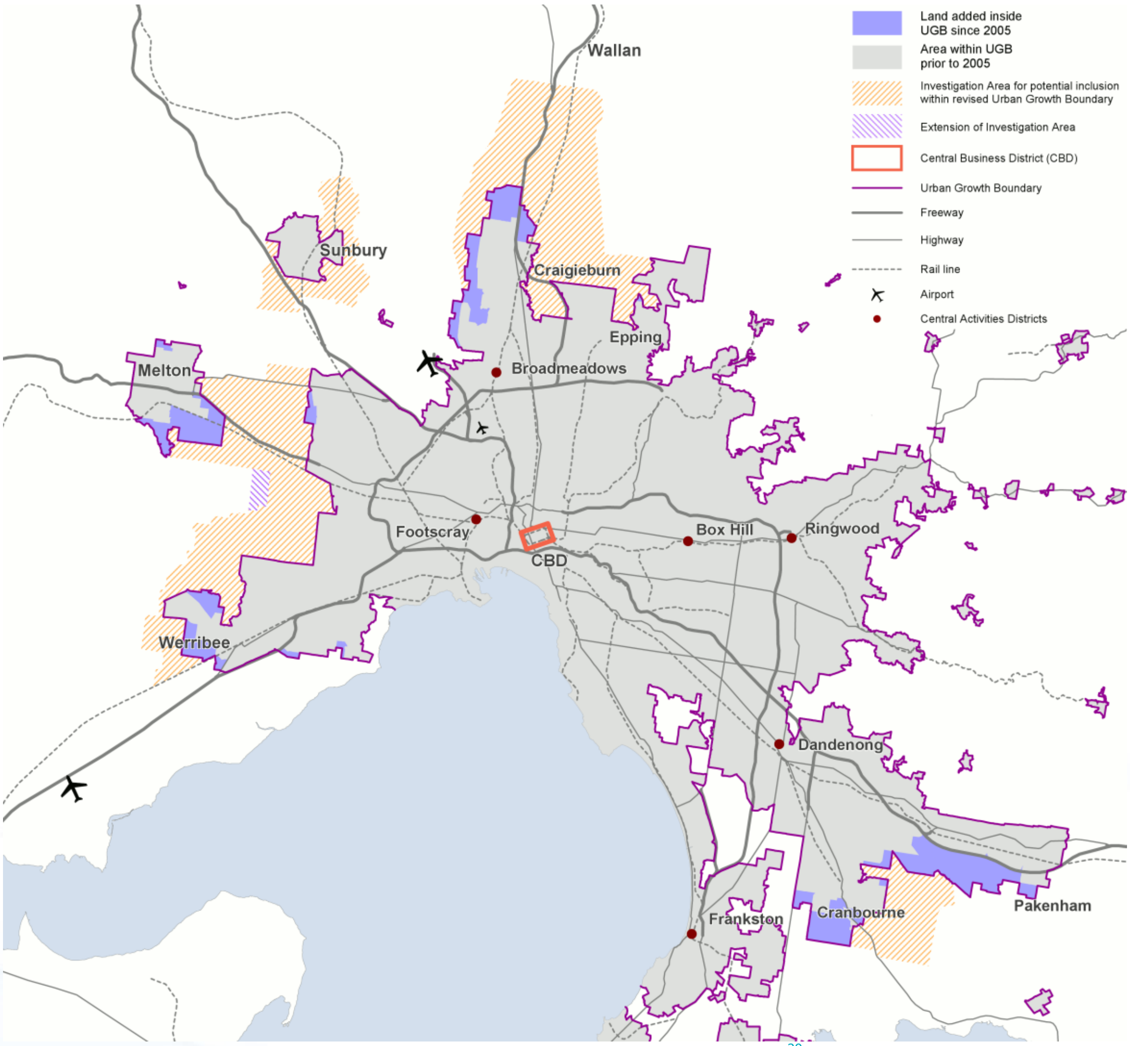

Figure 4.13: Urban growth in Greater Melbourne[29]

[29] DPCD, 2010. Urban Development Program: Annual Report 2009. Victorian Government Department of Planning and Community Development. Melbourne.
DPCD, 2008. Victoria in Future 2008. Detailed Data File: VIF 2008 Projected Households (2006-2056). Victorian Government Department of Planning and Community Development. Melbourne.
ABS, Mar 2010. 3218.0 Regional Population Growth, Australia. Population Estimates by Local Government Area, 2001 to 2009. Australian Bureau of Statistics. Canberra.
ABS, 2007. 2006 Census Community Profile Series. Time Series Profiles (by LGA): Table 15 Dwelling Structure by Number of Persons Usually Resident. Australian Bureau of Statistics. Canberra.
DPCD, 2009. Melbourne 2030: A Planning Update - Melbourne @ 5 Million. Maps: Land Added to UGB since 2005. http://www.dpcd.vic.gov.au/__data/assets/pdf_file/0005/42746/Land_added_to_UGB_since_2005_updated_May_2009.pdf Department of Planning and Community Development. Melbourne.

4.5 Water demands

The performance of alternative water cycle management strategies is primarily dependent on the spatial distribution of water demands and climate processes throughout a region. This section outlines the development of residential and non-residential water demands.

A summary of water demands of detached and semi-detached housing within each LGA for the 2005/06 water year is provided in Figure 4.14. Note that water demands from the period prior to significant regional water restrictions were used in this study to establish accurate baseline water demand behaviours for the region. These water demands were then modified in the systems analysis in response to the adoption of water efficient appliances and behaviours, and by regional water restrictions.

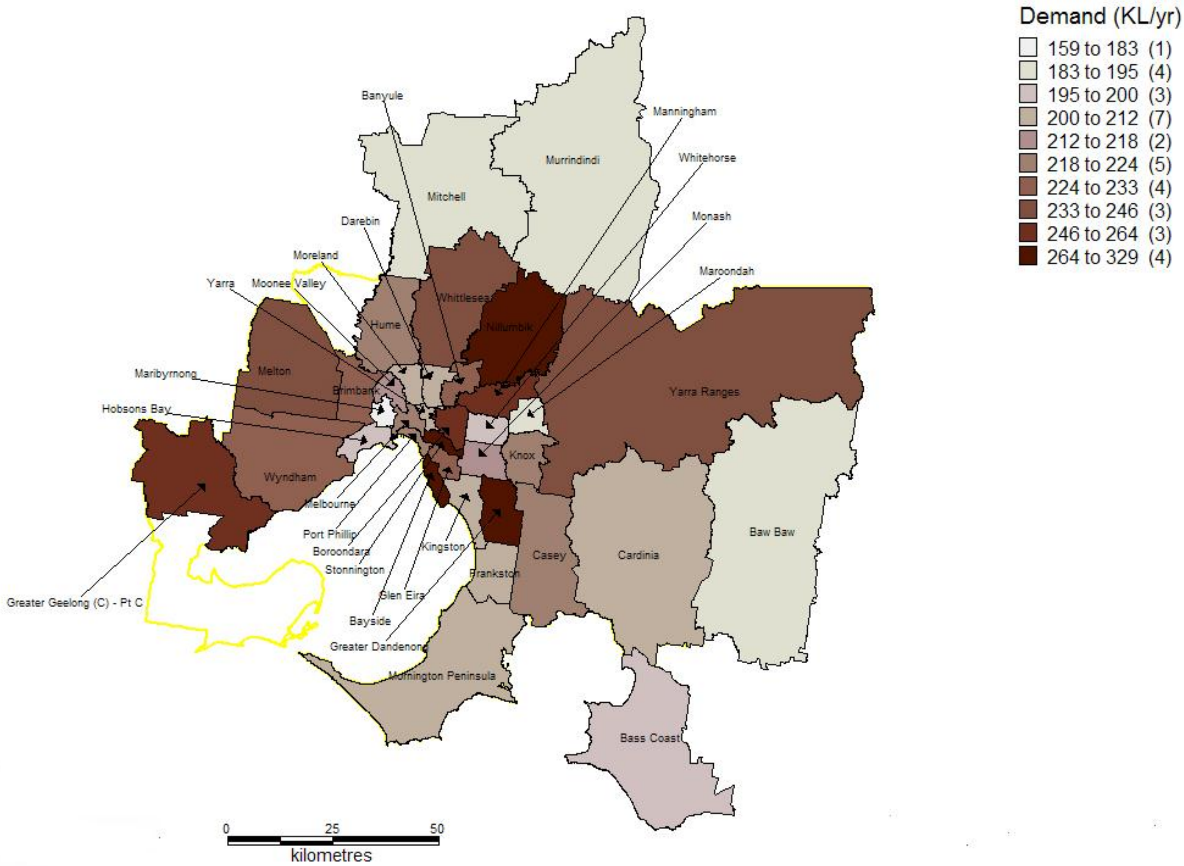

Figure 4.14: Spatial distribution of average household water demand for detached and semi-detached housing from the 2005/2006 water year across the Greater Melbourne region

Figure 4.14 shows a wide variation in average annual household water demands across the Greater Melbourne region and the highest annual average household demand (329 kL) occurring in the Dandenong area with the lowest annual water demand (159 kL) occurring in the Maribyrnong area. The north western region and a central band across Greater Melbourne which includes the inner regions are subject to higher average annual water demands.

This investigation has also included non-residential water demands from each of the zones. The overall proportion water demands from residential, commercial, institutional, industrial and other sectors for Greater Melbourne is shown in Figure 4.15.

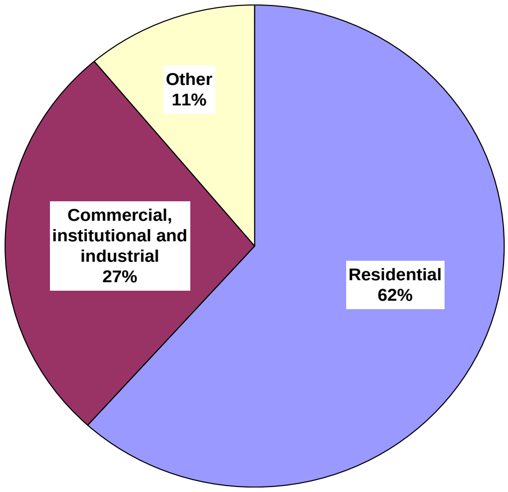

Figure 4.15: Overall distribution of water use for Greater Melbourne (circa 2010)

The non-residential water demands from each zone that were included in this investigation are shown in Figure 4.16.

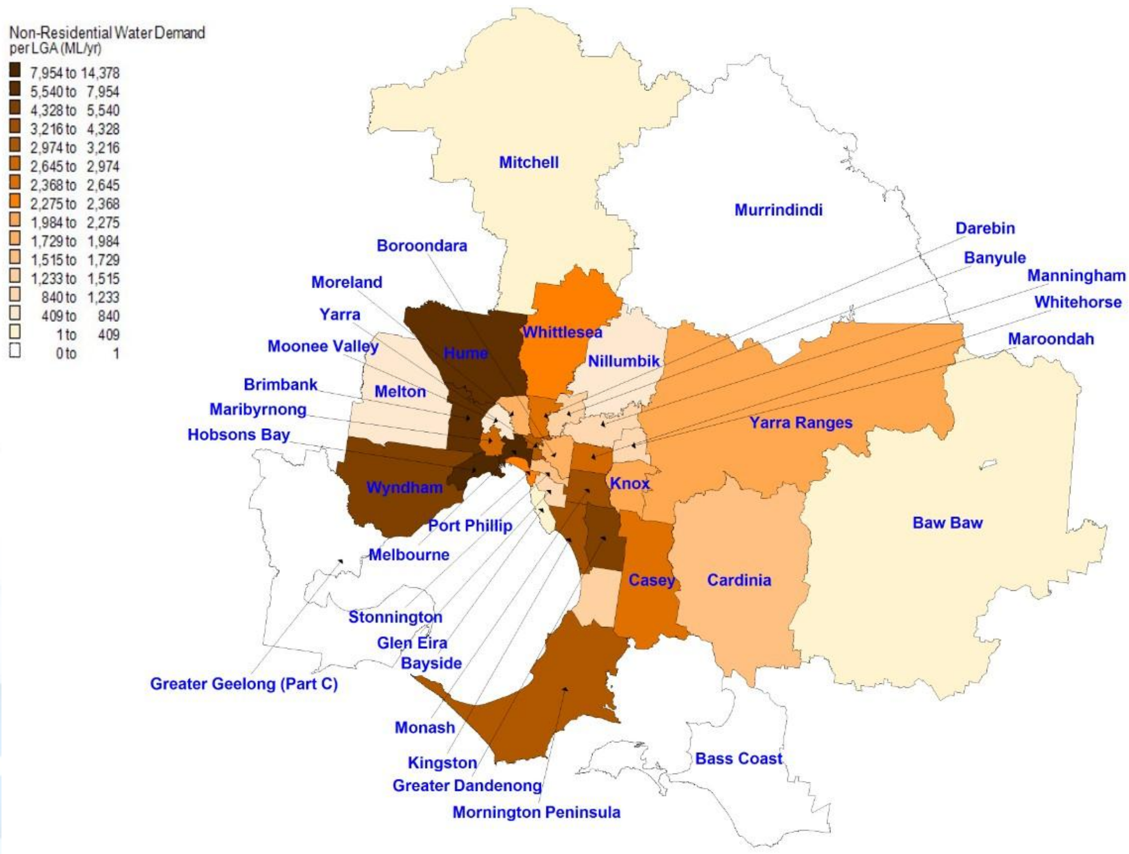

Figure 4.16: Spatial distribution of non-residential water demands in ML/annum (circa 2010)

Figure 4.16 reveals that the magnitude of non-residential water demands varies throughout the region. Non-residential water demands were also simulated using the PURRS model that also accounted for alternative strategies in these sectors.

Residential water demands

The use of average water demands and average household sizes to simulate the performance of alternative water management strategies produces considerable error.[30] Figure 4.14 shows that annual average household water demands are subject to considerable variation across the region. This variation is influenced by a range of factors including the distribution of dwelling types, household sizes, climate and income.

The performance of alternative water cycle management strategies or, indeed, any other water management strategy is primarily dependent on water use behaviour in each household and building. Water use behaviour is also influenced by household size and dwelling type. Information about average household water use for each month, distribution of household sizes and dwelling types were available for each local government area (LGA) and Statistical Local Areas (SLA) from the Australian Bureau of Statistics.

Average water demands at any location are dependent on the distribution of household sizes (Figure 4.17) and dwelling types (Figure 4.18). As shown in Figure 4.17, for example, the distribution of household sizes is different for each type of dwelling and does not take the form of a normal distribution. Note that the distribution of household sizes is skewed toward smaller households for units and semi detached dwellings, and shows a more even distribution for detached housing.

As a consequence of the skewed distributions of household sizes and different types of dwellings, average water demands for an area cannot represent the water demands of an average household. Importantly, this type of average assumption cannot distinguish between the behaviour of different households and the performance of alternative water management strategies in each of the households.

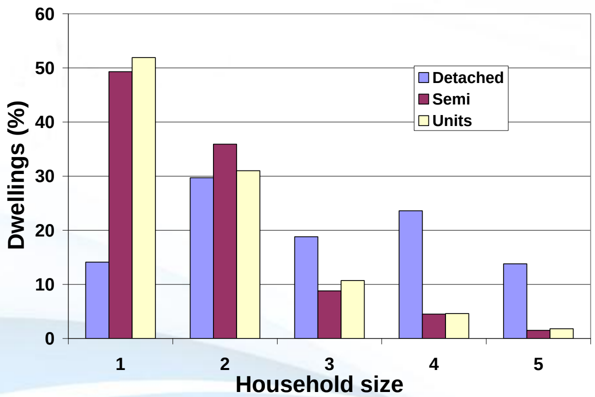

Figure 4.17: Distribution of household sizes at Knox

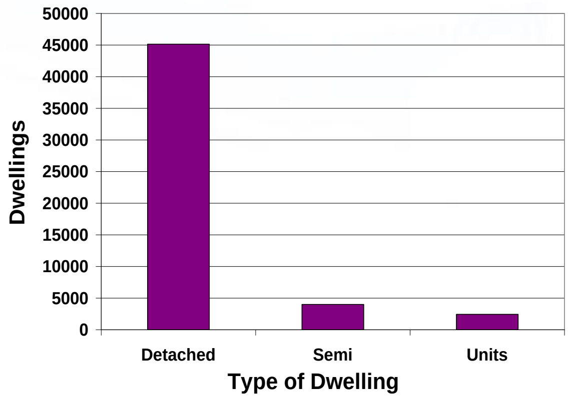

Figure 4.18: Distribution of housing types at Knox

30 Coombes P.J., and M.E. Barry, 2007. The effect of selection of time steps and average assumptions on the continuous simulation of rainwater harvesting strategies. Water Science and Technology. Vol. 55 No. 4. pp. 125 – 133.

As shown in Figure 4.17, for example, the dwelling stock in each area comprises a range of different dwelling types. Each dwelling type will also generate different behaviours that will influence the characteristics of household water use. For example, a detached house may allow the opportunity for significant outdoor water use whilst a unit dwelling is unlikely to provide opportunities for outdoor use.

The distributions of household sizes and dwelling types for an area provided an opportunity to disaggregate average water demand for an area into the likely water demands in each household. This task also required an estimate of the proportion of water demand that is used outdoors.

Selection of the "base" water demand year

The availability of water use data that is disaggregated to the household scale is limited to recently available information. It is preferable that base water demands used in analysis of water supply scenarios be derived for periods that were not subject to regional water restrictions. However, this was not possible for this study. During the 2005/2006 water year Greater Melbourne was subject to level 1 water restrictions and permanent water restrictions that included:

- Use of manual water systems restricted to between 8 pm and 10 am;
- Use of automatic watering systems restricted to between 10 pm and 10 am;
- Use of trigger nozzles on hoses;
- No hosing of paved areas; and
- Applications required for filling new swimming pools.

It was assumed that the requirements of the permanent "water restrictions" were reasonable requirements for improved management of water at the household scale that would remain. As such, household water demands from the 2005/2006 water year were selected in this study as a suitable representation of future water using behaviour for Greater Melbourne.

Note that adoption of additional strategies including connection to wastewater reuse systems and other water efficiency programs were used to modify the base water demands in accordance with a range of time based growth in strategies. These impacts were included by the simulation of a wide range of different water use strategies in different households and subsequently combining the different water use sequences for each zone.

The impacts of regional water restrictions were included in the simulations of water use for each zone after generation of the combined sequences of water use for each zone.

The PURRS (Probabilistic Urban Rainwater and wastewater Reuse Simulator) Model

A schematic of the basic processes in the PURRS (Probabilistic Urban Rainwater and wastewater Reuse Simulator) model is shown in Figure 4.19. The rainfall input to the model can be from pluviograph rainfall data or a synthetic pluviograph rainfall generator. The synthetic pluviograph rainfall generator can be used to create a rainfall pluviograph record from daily rainfall in locations where incomplete or no pluviograph data are available. A more complete description of the PURRS model is provided in the literature[31].

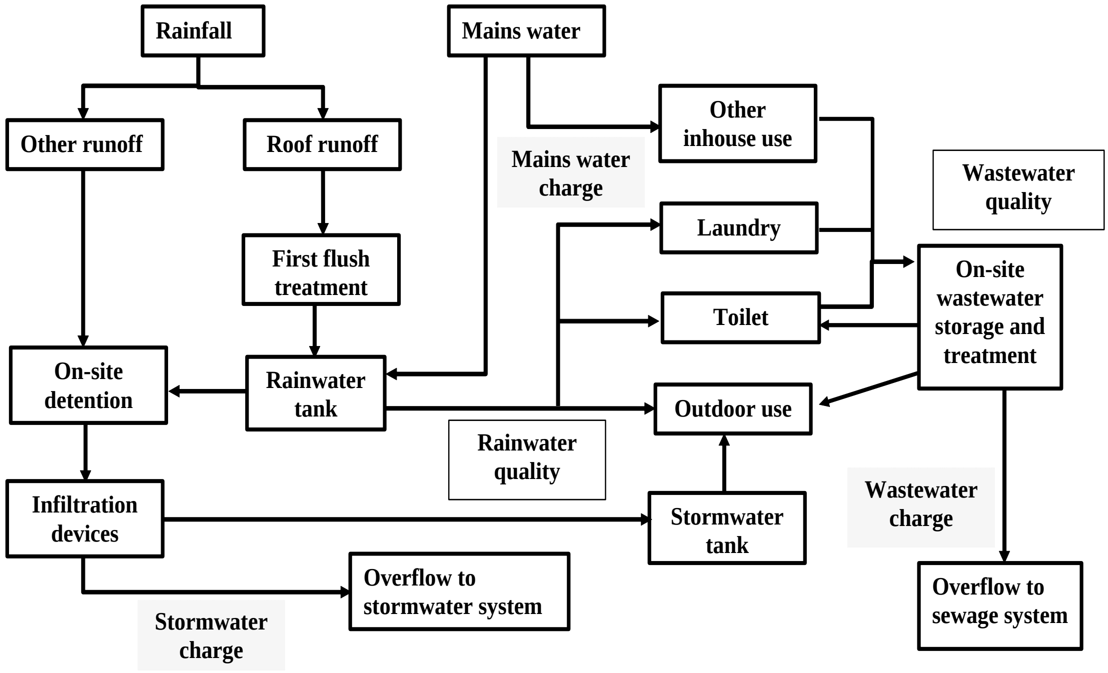

Figure 4.19: Example schematic of the basic processes in the PURRS water balance model

Figure 4.19 shows one of the many combinations of water cycle solutions that can be utilised within the PURRS simulation framework.

The PURRS model was utilised to generate lot and precinct scale responses including behaviour and climate driven water demands, adoption of water efficient appliances, sewage discharges and stormwater runoff that were spatially incorporated in the wider spatial systems framework. This analysis also includes a wide range of spatial processes including water efficient buildings, rainwater harvesting, local wastewater reuse and stormwater harvesting.

The simulation of the performance of each dwelling cluster was assumed to include half of the road frontage to the allotment to account for stormwater runoff from the urban area. Dimensions of the dwelling clusters used in the simulations are presented in Table 4.5.

31 Coombes P.J., 2006. Integrated Water Cycle Modeling Using PURRS (Probabilistic Urban Rainwater and wastewater Reuse Simulator). Urban Water Cycle Solutions.

Table 4.5: Dimensions of residential clusters used in the analysis

Dwelling type	Lot area (m^2)	Roof area (m^2)	Impervious area (%)	Outdoor factor	Number of dwellings
Detached (BAU)	700	250	70	1.0	1
Semi detached (BAU)	500	120	70	0.1	1
Units (BAU)	1,000	600	90	0.05	10
Detached (BASIX and ULT)	700	100	70	1.0	1
Semi detached (BASIX and ULT)	500	100	70	0.1	1
Units (BASIX and ULT)	1,300	600	90	0.05	10

Table 4.5 shows that individual detached and semi detached dwellings, and clusters of ten units were analysed. The roof areas of dwellings that were included in alternative Options were set at a maximum value to account for potential limitations on rainwater harvesting strategies. The stormwater harvesting strategies in the alternative strategies collects stormwater from all impervious surfaces. Note that the outdoor factor accounts for the proportion of outdoor use at a detached dwelling that can be expected for other types of dwellings.

Considering outdoor water use

The variability of outdoor water use for various household types in different climate zones is not usually measured. A unique study of household water use[32] analysed indoor and outdoor water use in 192 houses across 5 climate zones, 14 demographic regions and 12 years in the Hunter region of New South Wales and derived a relationship for estimating monthly average daily outdoor use:

$$OutdoorUse = 7.53M - 11.3AveR - 0.025Inc - 0.816Rdays + 24.44G + 19.08AveT - 251 \quad (4.1)$$

where M is a seasonal index with values from 1 to 6 (January and December = 1; June and July = 6), Inc is the average income of people in the household, AveR is average monthly daily rainfall, G is annual population growth, Rdays is the number of rain days in each month and AveT is the average monthly daily maximum temperature.

This research provided some insight into the behavioural drivers of outdoor water demand. Outdoor water use was found to be independent of household size and garden area but was strongly correlated with climatic variables, measures of dryness, seasonal and socioeconomic variables. Importantly, the research revealed that the magnitude and patterns of outdoor water use is highly variable across a region.

Climate and demographic information from each zone was used in Equation 4.1 to provide an initial estimate of average daily outdoor water use. Importantly, Equation 4.1 also provides information about the likely temporal pattern of outdoor water use.

Outdoor water use is not a constant proportion of household water use throughout a year. As such the use of average proportions of outdoor water use in analysis of alternative water management

32 Coombes P. J., G. Kuczera and J.D. Kalma, 2000. A behavioural model for prediction of exhouse water demand, 3rd International Hydrology and Water Resource Symposium, 793-798, Perth, Australia.

strategies will not provide a reliable understanding of the performance of measures at the household scale and, indeed, across the region. Equation 4.1 has been utilised to estimate the average proportions and the temporal patterns of outdoor water use for input to the water demand algorithms employed in the PURRS water balance model for this study.

It is should be noted that the water demand algorithms used in the PURRS model allow for climate generated daily and diurnal variation of water demands that use information from equation 4.1 as conditioning variables.

The magnitude of the monthly outdoor water uses estimated using Equation 4.1 were then calibrated to measured local values previously provided by the Department of Sustainability and Environment (DSE) and more recent data from water authorities to ensure that the annual average volumes of outdoor water uses were consistent with local behaviour.

It is clear that there is limited knowledge of the magnitude and patterns of outdoor water demand. More comprehensive monitoring programmes are required to allow an enhanced understanding of outdoor water use.

The Outdoor Water Use Model

Domestic outdoor water use such as garden watering, car washing and filling of swimming pools is seen to be a recreational pastime that is dependent on human behaviour. Outdoor water use behaviour is significantly modified by human reaction to daily temperature, days without rainfall and rainfall depth.

The probability of outdoor water use is expected to increase as the length of a period without rainfall increases and the volume of water used is a function of temperature and normal water use patterns (the monthly average daily demand defined by Equation 4.1). People are more likely to use water outside of the house when it is hot and dry, and in accordance with habits.

During a day with rainfall there is a smaller probability of water use and the volume of water used is dependent on the rainfall depth. There is a chance of outdoor water use when people perceive rainfall depth to be insignificant and, conversely, when rainfall depth is perceived to be large there will be no outdoor water use. When that rainfall depth is sufficiently high, people may not use water outside of the house for a number of days. These behavioural considerations have been formalised into a probabilistic framework[33] that drives the daily simulation of outdoor water use. This climatic behavioural simulation approach is used in the PURRS model.

Considering indoor water use

Knowledge of the magnitudes of indoor water uses for different household sizes across a variety of demographic and socioeconomic profiles is also limited. This investigation also utilised relationships

33 Coombes P. J., G. Kuczera and J.D. Kalma, 2000. A behavioural model for prediction of exhouse water demand, 3rd International Hydrology and Water Resource Symposium, 793-798, Perth, Australia.

from a comprehensive long term study of household water uses[34] to estimate monthly daily average indoor water use inDem for a variety of household sizes in different regions:

$$inDem = 27.79 + 145.69P - 0.42M - 10.58AveR + 6.7Rdays - 0.16Inc - 12.28G + 0.49AveT \quad (4.2)$$

where P is the number of occupants in a dwelling.

Indoor water use was found to be strongly dependent on household size and also demonstrated some correlation with climatic variables, measures of dryness, seasonal and socioeconomic variables. The research also revealed that the magnitude and sequence of indoor water use was also variable. Indoor water demand from different household sizes was estimated using Equation 4.2.

The estimated water demands using equation 4.2 reveal that the magnitude of indoor water demands is strongly dependent on household size and displays some seasonal variation. In addition, the relationship between household size and indoor water demands is not linear. These phenomena are consistent with the observations from recent research into household water use. [35,36.]

Equation 4.2 was used to estimate the magnitude of indoor water demands for different household sizes throughout Greater Melbourne for use in the PURRS water balance model. The indoor water demands estimated using Equation 4.2 were then calibrated using locally available measured water demands provided by DSE and water authorities to ensure that simulations of indoor water demands are consistent with local behaviour.

The water use algorithms were then calibrated to observed water use in dwellings throughout the region. Note that the observations of residential water use were derived from rolling metering programs that do not directly measure sequences of water use.

It is important to highlight that there are limited measurements available to determine the magnitudes and patterns of indoor water uses in different sized households. Urban metering, monitoring and measurement practices are dominated by the requirement to derive average water use and need modification to improve understanding of household water use behaviours. Nevertheless, the likely water demands for each household in a given area can be approximated using the available observed data and some informed assumptions based on the equations presented in this report.

Distributions of household size and dwelling types for each LGA and SLA were obtained from the ABS and the average household water demands were provided by DSE and water authorities. This information was used to disaggregate average water demands for an area into the likely water demands in each household.

The indoor water use values derived using Equation 4.2 for different household sizes and outdoor water use were combined with climate data in the water balance model PURRS. The performance of each different household was simulated.

It is important to note that the water demand algorithms in the PURRS model allow for climate generated daily and diurnal variation of water demands that use information from equations 4.1 and

34 Coombes P.J., (2002). Rainwater tanks revisited – new opportunities of integrated water cycle management. PhD Thesis. The University of Newcastle. NSW. Australia.
35 Cui L., M. Thyer., P.J. Coombes and G. Kuczera, 2007. A hidden state Markov model for identifying the long term dynamics of indoor household water uses. Rainwater and Urban Design 2007 Conference. Sydney Australia.
36 Thyer M., M. Hardy., P.J. Coombes and C. Patterson, 2007. The impacts of end use dynamics on urban water system design criteria. Rainwater and Urban Design 2007 Conference. Sydney Australia.

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4.2 as conditioning variables that are modified by daily climate information. The PURRS demand algorithms allow for daily and diurnal variation of water use whilst maintaining expected long term volumes of water use.

Indoor water end uses

Simulation of daily indoor uses in the PURRS model is based on the values estimated using Equation 4.2, diurnal patterns and a distribution of household indoor water uses into kitchen, laundry, toilet, bathroom and hot water uses. In this study the distribution of indoor water uses from the Yarra Valley Water area reported by Roberts[37] was modified for use in PURRS as shown in Figure 4.20.

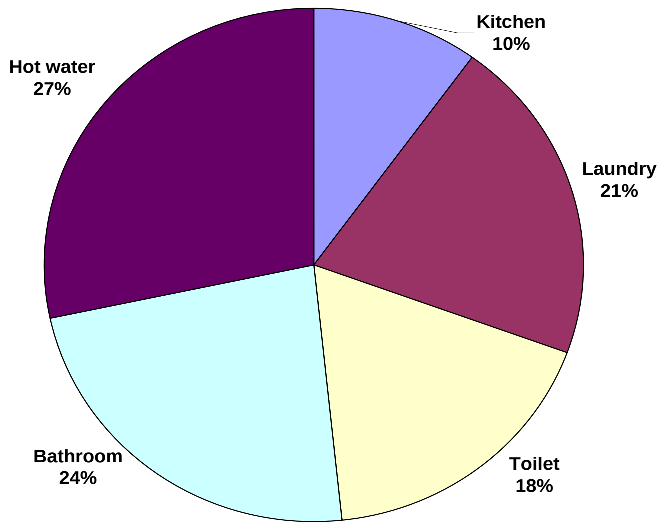

Figure 4.20: Distribution of household indoor water uses

The water use algorithms were also used to generate sewage discharges from each household and non-residential building throughout the region. The proportion of indoor use via hot water services was determined to provide an understanding of strategies that utilise the water quality improvement characteristics of domestic hot water services and to fully understand the potential to reduce the energy use for heating water by use of water efficient appliances. The water use algorithms were also used to generate sewage discharges from each household and non-residential building throughout Greater Melbourne.

Non-residential water demands

This investigation also included non-residential water demands from each of the zones. The proportions of water demands from non-residential sectors for Greater Melbourne are shown in Figure 4.16.

[37] Roberts P., 2006. End use research in Melbourne suburbs. Water. Australian Water Association. 51-55.

Non-residential water demands are a significant and variable proportion of the total urban water demand throughout Greater Melbourne. These water demands were simulated using the PURRS model that also accounted for alternative strategies for the non-residential sector.

Water use information was collated with summaries of business categories (such as the Census of Land Use and Employment) and information about numbers of connections from water authorities to estimate the land use and numbers of non-residential connections in each zone. Non-residential water demands were assumed to increase at the same rate as growth in total residential dwellings in each zone.

4.6 The transition framework

A transition framework was used to generate daily water cycle responses for each zone as shown in Figure 4.21. Sequences of daily water balance results from the PURRS model were compiled using seasonal information and historical climate data including daily rain depths, cumulative days without rainfall and average daily maximum ambient air temperature to create resource files of water demand, wastewater generation and stormwater runoff. The method of non-parametric aggregation[38] was then utilised to generate daily water use, wastewater discharges and stormwater runoff in each zone using the historical resource files and climate replicates generated for the simulation of the regional system.

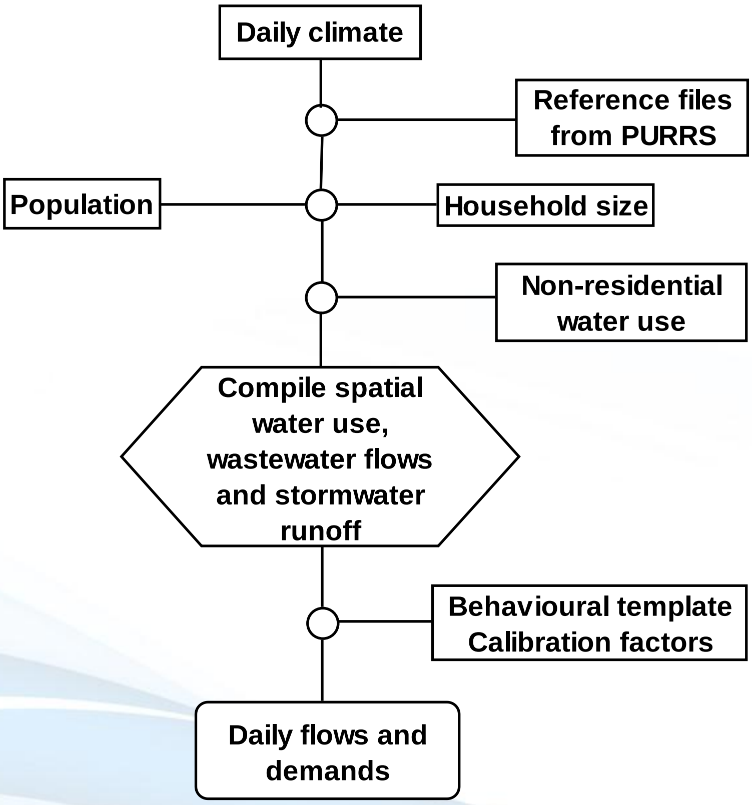

Figure 4.21: The transition framework

38 Coombes P.J., G. Kuczera, J.D. Kalma and J.R. Argue. An evaluation of the benefits of source control measures at the regional scale. Urban Water. 4(4). London, UK. 2002.

Figure 4.21 demonstrates that at each time step climate variables from the regional model are used to find matching climate variables and coincident daily water use, sewage generation and stormwater runoff results for each dwelling from the reference files.

These results are combined with population, non-residential water use and demographic data at each time step to estimate total indoor and outdoor use, sewage flows and stormwater runoff for each zone.

The sequences of data from the PURRS simulations were combined in the transition framework using the framework presented in Figure 4.22. Daily sequences of water cycle information; such as water demands, wastewater discharges and stormwater runoff; were combined for different household sizes, different dwelling types and a combination of different water cycle management Options for each strategy in the Transition Framework.

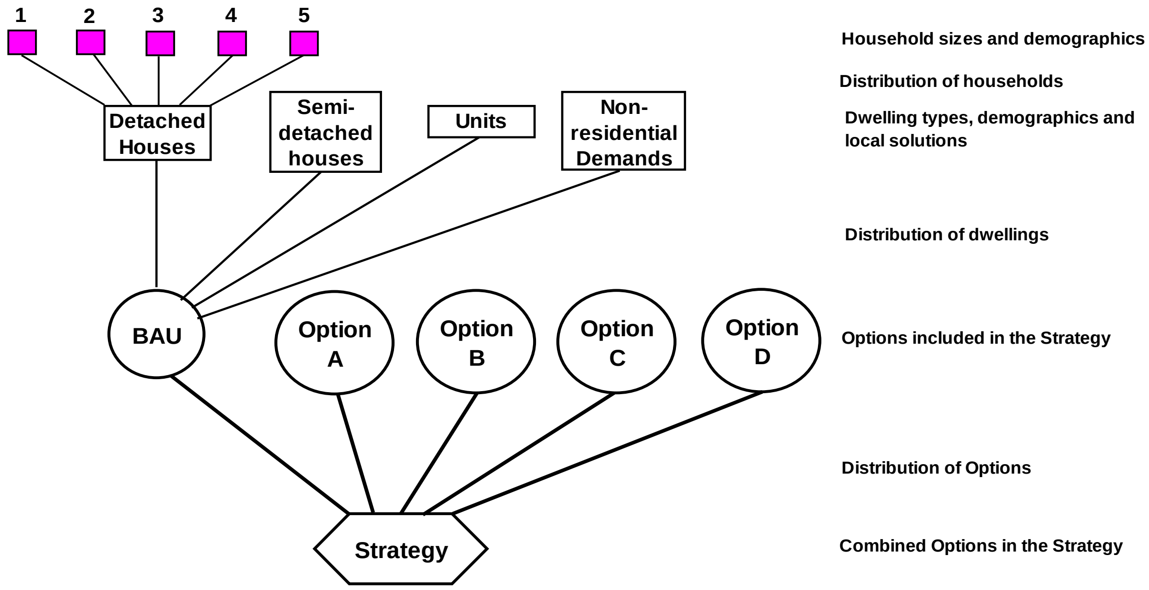

Figure 4.22: Structure for combining different household sizes, dwelling types and water cycle management Options in the Transition Framework

The climate variables in the regional systems model were derived using the synthetic climate series generated using historical climate sequences. Importantly the climate replicates are temporally and spatially consistent with the rainfall and stream flows in the water supply catchments.

4.7 Stochastic generation of climate and streamflow data

Single sequences of historical data are almost always inadequate for the assessment of the performance of systems. Even when average annual demand and the configuration of a system remains static over time, historic streamflow records are frequently too short to permit accurate assessment of performance of water systems. This is particularly true for systems with a low probability of experiencing shortfalls in water supply.

This understanding motived the use of a multiple sequences of data (replicates) that were equality likely to occur in the simulation of the performance of the Greater Melbourne system. It is also important that the use of multiple replicates of inputs that generate multiple replicates of system behaviour is required to understand the probability of certain events (such as water shortages).

Reliable assessment of the performance of water systems requires the use of stochastic streamflow, rainfall and demand information that is generated from historical data. This process makes better use of the historical data by fitting a probability model to the data and then randomly sampling from the model.

The flowchart in Figure 4.23 presents the procedure to generate stochastic data[39] that has been modified by the author to provide integrated data for simulation of systems. A simple multi-site probability model was fitted to annual climate and streamflow data. This allowed estimates of the probability model parameters as well as their distributions that describe the uncertainty about the parameters.

The probability model generates the desired length of annual data that is then disaggregated into seasonal data using the method of fragments. This procedure is repeated until the required number of climate and streamflow replicates have been generated. Each replicate represents an equally likely sequence of future climate and streamflow sequences.

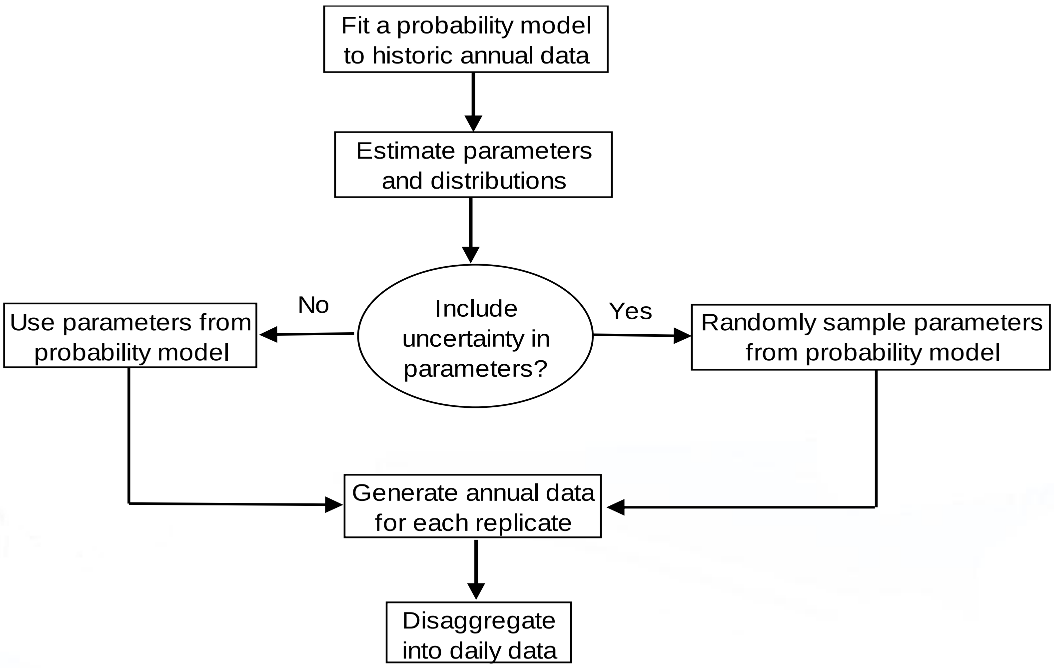

Figure 4.23: Flowchart of data generation procedure

The process can also be described as a lag-one multi-site model [40] can be applied to climate, streamflow and demand data provided the annual means are stationary.

These annual flows are transformed using a Box-Cox statistical process [41] to obtain the data used in the sampling process. The transformation ensures that the data is approximately normally distributed.

[39] Kuczera G., 1987. On maximum likelihood estimators for multi-site lag one streamflow model: complete and incomplete data cases. Water Resources Research. Vol. 23 No. 4. pp. 641-645.
40 Matalas N.C., 1967. Mathematical assessment of systematic hydrology. Water Resources Research. Vol. 3, No. 4. pp. 937-945.

The multi-site lag-one process utilises a probability model. This model incorporates variances that were assumed to be normally and independently distributed with mean of 0 and a covariance matrix which describes the spatial correlation between data sites.

The transformation parameter was independently estimated for each site by computing the skew of the data for different values of transformation parameters and by selecting a value that has a skew closest to zero. The matrices of parameters were estimated using the method of maximum likelihood.[42]

Generation of annual data for each year involves three steps. First the vector of variances is randomly sampled from a distribution with mean 0 and the covariance matrix. Then the transformed annual data was computed. Finally a reverse transformation was employed to generate annual data for each site. The method of fragments[43] is a simple scheme that was used to disaggregate annual data into seasonal data following generation of annual data.

Sequences of annual data for each site were generated using the lag-one process and key sites were selected. Two key sites were used in this investigation including a sequence of daily rainfall and daily maximum temperatures. This allowed generation of 100 replicates of rainfall, streamflow, evaporation and streamflow for the Greater Melbourne region.

4.8 Climate change

A key driver for predictions of climate change is increases in temperature. It is important to capture the response of variables such as rainfall, evaporation and streamflow to the increase in temperature.

Replicates of climate and streamflow data were generated using the process described in Section 4.7 with the additional inclusion of incremental increases in temperature. The process captured historical relationships of daily maximum temperatures with climate and streamflow data. Disaggregation into daily values was achieved using the temperature as a key site.

This study utilised climate change scenarios derived by CSIRO from recent IPCC summaries of global climate models. Low and high emissions scenarios were adopted to account for the continuing growth in global emissions.

Expected seasonal changes in temperature and rainfall will have a moderate impact on analysis of water balances including rainwater and stormwater harvesting, stormwater quality and outdoor water demands.

Our analysis included multiple replicates of potential climate behaviour that were based on the longest possible climate records and incorporated expected climate change by using temperature as a key statistical driver. This allowed a rate of increase in annual temperatures of 0.025 °C/year and 0.05 °C/year from the expected high emissions scenario to be included as a fundamental driver of emerging changes in rainfall, evaporation, streamflow and related processes.

41 Box G.E.P. and C.R. Cox., 1964. The analysis of transformations. Journal of the Royal Statistical Society. Series B. Vol. 26, No. 2. pp. 211-252.
42 Kuczera G., 1987. On maximum likelihood estimators for multi-site lag one streamflow model: complete and incomplete data cases. Water Resources Research. Vol. 23 No. 4. pp. 641-645.
43 Svanidze G.G., 1960. Mathematical modeling of hydrological series. Water Resources Publications. Fort Collins, Colorada.

A summary of the latest results from the IPCC models provided by the Bureau of Meteorology (BOM) for 2050 is presented in Figure 4.24.

Climate Futures for region centred on 37.5°S, 141.5°E

2050 A1Fi

		Surface Temperature - Annual (° C)			
		Slightly Warmer < 0.50	Warmer 0.50 to 1.50	Hotter 1.50 to 3.00	Much Hotter > 3.00
Rainfall - Annual (% change)	Much Drier < -15.00		Likelihood: 1 of 24 models (4%)	Likelihood: 3 of 24 models (12%)	
	Drier -15.00 to -5.00		Likelihood: 3 of 24 models (12%)	Likelihood: 8 of 24 models (33%)	Likelihood: 1 of 24 models (4%)
	Little Change -5.00 to 5.00		Likelihood: 1 of 24 models (4%)	Likelihood: 7 of 24 models (29%)	
	Wetter 5.00 to 15.00				
	Much Wetter > 15.00				

		Surface Temperature - Annual (° C)			
		Slightly Warmer < 0.50	Warmer 0.50 to 1.50	Hotter 1.50 to 3.00	Much Hotter > 3.00
Rainfall - Annual (% change)	Much Drier < -15.00			Likelihood: 1 of 24 models (4%)	Likelihood: 1 of 24 models (4%)
	Drier -15.00 to -5.00		Likelihood: 1 of 24 models (4%)	Likelihood: 9 of 24 models (37%)	Likelihood: 1 of 24 models (4%)
	Little Change -5.00 to 5.00		Likelihood: 1 of 24 models (4%)	Likelihood: 8 of 24 models (33%)	Likelihood: 1 of 24 models (4%)
	Wetter 5.00 to 15.00			Likelihood: 1 of 24 models (4%)	
	Much Wetter > 15.00				

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Proportion (%) of models for selected variables

- No models
- < 10% of models
- 10% - 33% of models
- 33% - 66% of models
- 66% - 90% of models
- > 90% of models

Figure 4.24: A summary of climate models from the IPCC analysis of the high emissions assumptions

Figure 4.24 shows that the majority of global climate models predict increases in average temperatures ranging from 1.5°C to 3°C for the region. These predictions also suggest an equal likelihood for little change in rainfall or dryer rainfall conditions.

Previous estimates of the impacts of climate change by the Department of Sustainability and Environment (DSE) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) are presented in Table 4.6.[44]

[44] DSE (2008). Climate change in the Port Philip and Western Port region. Department of Sustainability and Environment.

Table 4.6: Summary of the impacts of climate change for Greater Melbourne

Criteria	2030	2070	
		Low	High
Change in average temperature (°C)	0.6 to 1.1	0.9 to 1.9	1.8 to 3.7
Change in annual rainfall (%)	-8 to 0	-13 to 0	-24 to 0
Change in potential evaporation (%)	+1 to +5	+1 to +9	+2 to +17
Change in annual stream flow (%)	-5 to -30	-5 to -50	-5 to -50

Table 4.6 shows that previous estimates of climate change for Greater Melbourne predicted large changes in average temperatures and potential evaporation with moderate changes in rainfall. This information was utilised for this investigation.

4.9 Regional systems

The WATHNET network linear program for water supply headworks simulation was utilised to analyse the combined water, sewage, wastewater reuse and waterway networks. A wide range of spatial information generated by the lot scale analysis was combined in the scale transition framework described above for use in the systems analysis.

The movement of water, sewage, recycled water and stormwater throughout Greater Melbourne was simulated over a 40 year period using 100 replicates of climate sequences. This allowed analysis of peak flows in trunk infrastructure, assessment for regional sewage discharges, stormwater runoff and water demands.

Water systems

The schematics of the trunk water distribution, demand nodes and water supply networks (including the Yarra River) used in this study are shown in Figure 4.25.

Information from the author's previous studies and data from DSE, water retailers (City West Water, South East Water and Yarra Valley Water) and the bulk supplier (Melbourne Water) was utilised to construct the major water and sewage flow paths employed in the systems analysis as shown in Figure 4.25. In addition, extensive forensic examination of public documents was untaken to clarify a range of issues and confirm the accuracy of the information used in this analysis.

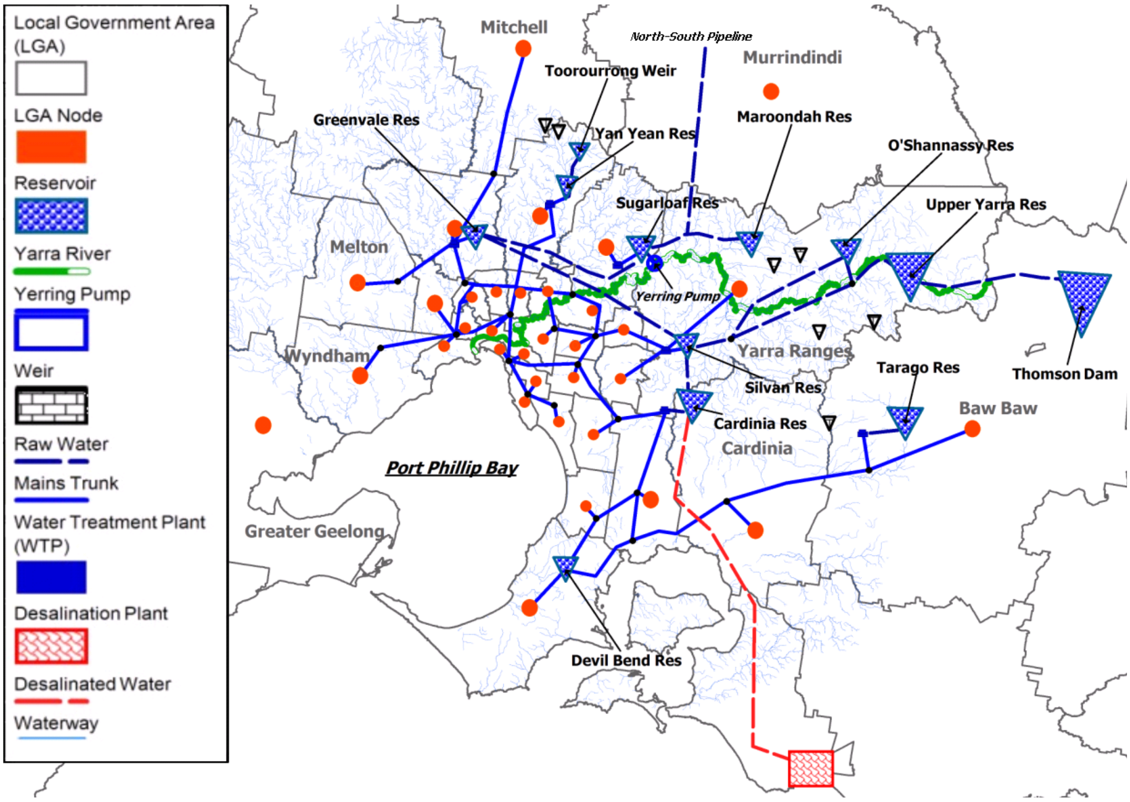

Figure 4.25: Schematic of water regional and spatial water networks for Greater Melbourne used in this study

The water supply headworks system is characterised by the Yarra River scheme that includes the Thomson Dam, Upper Yarra Reservoir, O'Shannassy Reservoir, a number of diversion weirs, the Yerring pumps from the Yarra River and transfers to Cardinia Reservoir.

The headworks system also includes the Maroondah – Sugarloaf scheme that includes Maroondah Reservoir, Sugarloaf Reservoir and a connection to the Goulburn River via the North South pipeline. The Yan Yean scheme includes Toorourrong Weir and Yan Yean Reservoir. The water supply system also includes the Tarago Reservoir and the Wonthaggi desalination plant.

Water Supply Headworks harvesting and diversion

The water supply headworks system includes a range of harvesting strategies from river systems and diversions from weirs on streams into dams and reservoirs. Each of the harvesting and diversion strategies is subject to various constraints that were included in the systems analysis. The Tarago and Bunyip River systems are described in Table 4.7.

Table 4.7: Summary of Tarago and Bunyip River System

Reservoir or Weir	Source Streams	Catchment Area (ha)	Diverted to	Diversion Capacity (ML/day)	Capacity (ML)
Bunyip River Weir	Bunyip River	4,100	Bunyip Main Race or Beaconsfield Reservoir	40	40
Crystal Creek Weir	Crystal Creek	-	Tarago Main Race	10	N/A
Tarago River Weir	Tarago River	7,700	Tarago Main Race	80	46
Tarago Reservoir	Tarago River	11,400	Tarago to Westernport Pipeline or Tarago Main Race	65 80	28,925

The Tarago and Bunyip River system is also subject to the following releases

- Passing flow released from Tarago Reservoir : 5 ML/day
- Gippsland Water extracts 1.2 ML/day from Tarago Reservoir for supply to Neerim South.

A summary of the Thomson and Upper Yarra system is provided in Table 4.8.

Table 4.8: Summary of Thomson and Upper Yarra system

Reservoir or Weir	Source Streams	Catchment Area	Diverted To	Diversion Capacity (ML/day)	Capacity (ML)
Thomson Reservoir	Thomson River	48,700	Thomson-Upper Yarra Tunnel or Thomson Hydro	1,410 (480)*	1,068,000
Upper Yarra Reservoir	Yarra River	33,670	Upper Yarra Aqueduct or Yarra Valley Conduit	See below	200,579

The Thomson and Upper Yarra system is subject to the releases described below.

- Thomson Hydro Power Station – Capacity 480 ML/day
- Upper Yarra Aqueduct – Capacity 820 ML/day to Starvation Basin
- Yarra Silvan Conduit from Starvation Basin - Capacity 630 ML/day
- Yarra Valley Conduit – Capacity 900 ML/day

A summary of the Upper Yarra Tributaries System is shown in Table 4.9.

Table 4.9: Summary of Upper Yarra Tributaries system

Diversion Weir	Source Streams	Catchment Area	Diverted to	Diversion Capacity (ML/day)
Armstrong Creek	Armstrong Creek East Armstrong Creek West	6,100	Upper Yarra Aqueduct	210
McMahons Creek	Micks Creek	3,960	Upper Yarra Aqueduct	220
Starvation Creek	Big Flume Creek	2,062	Yarra Silvan Conduit	90

A summary of the O'Shannassy Reservoir and Tributaries System is provided in Table 4.10.

Table 4.10: Summary of O'Shannassy Reservoir and Tributaries System

Reservoir or Weir	Source Streams	Catchment Area	Diverted to	Diversion Capacity (ML/day)	Capacity (ML)
O'Shannassy Reservoir	O'Shannassy River	12,720	O'Shannassy Aqueduct or Yarra-Silvan Conduit	215 278	3,123
Cement Creek Weir	Cement Creek	1,350	O'Shannassy Aqueduct	30	N/A
Coranderrk Creek Weir	Coranderrk Creek	1,860	O'Shannassy Aqueduct	110	N/A

A summary of the Maroondah-Sugarloaf system is presented in Table 4.11.

Table 4.11: Summary of Maroondah-Sugarloaf system

Reservoir Weir	Source Streams	Catchment Area	Diverted to	Diversion Capacity (ML/day)	Capacity (ML)
Maroondah Reservoir	Watts River and Graceburn Aqueduct	14,680	Maroondah Aqueduct	233	22,145
Sugarloaf Reservoir	Yarra River, Maroondah Aqueduct	900	Winneke-Preston Main	1,000 (4 x 250 ML/d pumps)	96,253
Graceburn Creek Weir	Graceburn Creek	2,504	Yarra Siphon or Maroondah Reservoir	35	ns
Donelly's Creek Weir	Donelly's Creek	1,427	Maroondah Aqueduct	27 (includes Sawpit)	ns

The Maroondah – Sugarloaf system is subject to the following releases:

- Winneke Water Treatment Plant – capacity 450 ML/day that can be upgraded to 750 ML/day

- Covered Clearwater Reservoir – Capacity 200 ML
- Pipeline from Clearwater Reservoir to Supply System – capacity 1,000 ML/day

A summary of the Toorourrong – Yan Yean System is provided in Table 4.12.

Table 4.12 Summary of Toorourrong – Yan Yean System

Reservoir or Weir	Source Streams	Catchment Area (Ha)	Diverted to	Diversion Capacity (ML/day)	Capacity (ML)
Silver Creek Weirs	Hellhole, Mud, Stony and Silver Creeks	2,020	Silver-Wallaby Aqueduct	60	N/A
Wallaby Creek Weir	Wallaby Ck	2,152	Wallaby Aqueduct	180	N/A
Toorourrong Reservoir	Plenty River and Wallaby Aqueduct	9,530	Yan Yean	410	273 181
Yan Yean Reservoir	Clear Water Channel from Toorourrong	2,250	Treatment Plant to water supply	394	30,226

The Yan Yean Water Treatment Plant has a peak capacity of 155 ML/day and an average capacity 120 ML/day.

Releases for environmental Flows and other commitments

The environmental releases and other commitments included in the systems model are presented in Table 4.13.

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Table 4.13: Requirements for downstream releases included in this investigation

System	Location	Flow Requirement
Tarago and Bunyip	Drouin West gauging station	The Lesser of: • 12 ML/day or • natural flow at the Drouin West gauging station
Thompson - Upper Yarra	Thomson River below the dam	10,000 ML/annum for environmental entitlement; 12,000 ML/annum for irrigation entitlements
	Upper Yarra River below the dam (at Doctors Creek gauging station)	10 ML/day
Yarra Tributaries	Armstrong Ck West Branch – below the weir	• The lesser of 5 ML/day and the natural flows. • Maintain the practice of ceasing diversions on the rising limb of high flow.
	Armstrong Ck East Branch below the weir	The lesser of 1 ML/day and the natural flow
	McMahons Creek below the weir	• The lesser of 2 ML/day and the natural flows • Maintain the practice of ceasing diversions on the rising limb of high flows
	Starvation Creek below the weir	• The lesser of 2 ML/day and the natural flows • Maintain the practice of ceasing diversions on the rising limb of high flows
O'Shannassy System	O'Shannassy River below the reservoir	The lesser of 8 ML/day and the natural flow. Water can be provided as an average of the lesser of 8 ML/day or natural flow over any 28 day period with a minimum flow on any day of the lesser of 4 ML/day or natural flows.
	Coranderrk Creek below the weir	The lesser of 3 ML/day and natural flow
Maroondah – Sugarloaf	Graceburn Creek below the weir	• The lesser of 3 ML/day or natural flows if inflows to weir < 15 ML/day, or • 6 ML/day if inflows to weir ≥ 15 ML/day
	Watts River below Maroondah Reservoir	1 ML/day
	Donelly's Creek below the weir	• The lesser of 2 ML/day and natural flows if inflows to weir < 7 ML/day, or • 5 ML/day if inflows to weir ≥ 7 ML/day
Wallaby – Silver Creek	Silver Creek below Hellhole, Muddy and Stony creeks	• 0 ML/day if total inflows < 0.5 ML/day • 0.5 ML/day if inflow from 0.5 to 1.0 ML/day • 50% of inflow if inflows from 1.0 to 4.0 ML/day • 1.0 ML/day if inflow > 4.0 ML/day
	Wallaby Creek below the weir	• 0 ML/day if total inflow < 0.5 ML/day • 0.5 ML/day if inflow from 0.5 to 1.0 ML/day • 50% of inflow if inflows from 1.0 to 2.0 ML/day • 1.0 ML/day if inflow > 2.0 ML/day
Toorourrong – Yan Yean	Plenty River below Toorourrong Reservoir	The lesser of 1 ML/day and the natural flow released from the Clear Water Channel
Middle Yarra	Yarra River at Millgrove gauging station	• 80 ML/day between December and May, or • 350 ML/day between June and November
	Yarra River at Yering Pumps gauging station	• 200 ML/day between December and May, or • 350 ML/day between June and November
Cardinia Creek	Cardinia Creek below Cardinia Reservoir	5 ML/day

Catchments upstream of major reservoirs provide inflow to the water supply headworks system for Greater Melbourne. Rainfall and streamflow data was obtained for these catchments and utilised in stochastic data generation and hydrology processes to develop inputs to the systems analysis.

Upstream catchments were identified using topographic data. The longest and most complete daily rainfall records were obtained from the Bureau of Meteorology (BOM) nearby to each of the major reservoirs. The rainfall records for catchments flowing into Melbourne's reservoirs (including Goulburn River as a source for the Sugarloaf Pipeline) are shown in Table 4.14.

Table 4.14: Rainfall data for the water supply catchments supplying Greater Melbourne

Catchment	BOM Stations	Station number	Period
Yan Yean Reservoir	Toorourrong Res	86117	1893 - 2010
	Yan Yean	86131	
Tarago Reservoir	Jindivick	85042	1900 - 2010
	Neerim South	85202	
O'Shannassy Reservoir	O'Shannassy Res	86090	1916 - 2010
Maroondah Reservoir	Maroondah weir	86070	1893 - 2010
Upper Yarra Reservoir	Reefton	86271	1970 - 2010
	Warburton	86090	
Silvan Reservoir	Silvan	86106	1918 - 2010
	Montrose	86076	
Goulburn River	Yea	88067	1890 - 2010
	Strath Creek	88158	
Thomson Dam	Walhalla	85091	1890 - 2010
	Aberfeldy	85278	
	Erica	85238	

Sequences of streamflow entering reservoirs were also required to simulate the performance of the Greater Melbourne system. Streamflow data were obtained from Melbourne Water Corporation (MWC) and the Victorian Water Resource Data Warehouse (VWRDW).[45] The streamflow locations incorporated into the simulation are presented in Table 4.15.

45 Victorian Water Resource Data Warehouse (2011), http://www.vicwaterdata.net/vicwaterdata/home.aspx

Table 4.15: Streamflow sites used in the simulation of the Greater Melbourne system

Site	Details and station number (duration)	Source
Thomson Inflow	225110, 225114, 225020 (1/5/66 - 31/12/2010)	MWC
	water balance (1/1/1982 – 31/1/2010)	MWC
Maroondah Inflow (Watts River)	229264 (1/1/1929 - 31/12/2010)	MWC
Tarago Inflow (Tarago River)	228224 (1/1/1990 – 31/12/2010)	MWC
O'Shannassy Inflow (O'Shannassy River)	229658 (1/1/1915 - 31/12/2010)	MWC
Tarago Inflow (Tarago River)	228224 (1/1/1990 – 31/12/2010)	MWC
Upper Yarra Inflow	229104, 229106, 229109 (1/1/1990 – 31/12/2010)	MWC
Cardinia Ck inflow	228228 (1/1/1990 – 31/12/2010)	MWC
Goulburn River	405202 (1/1/1990 – 31/12/2010)	VWRDW
Armstrong Creek	229104 (1/1/1990 – 31/12/2010)	MWC
McMahons Creek	229106 (1/1/1990 – 31/12/2010)	MWC
Starvation Creek	229109 (1/1/1990 – 31/12/2010)	MWC
Graceburn Creek	229133 (1/1/1990 – 31/12/2010)	MWC
Coranderrk Creek	(1/1/1990 – 31/12/2010)	MWC
Donellys Creek	229277 (1/1/1990 – 31/12/2010)	MWC
Silver Creek	405100 (1/1/1990 – 31/12/2010)	MWC

Wastewater systems

The major wastewater networks, treatment plants and discharge locations to waterways were included in the systems analysis as shown in Figure 4.26.

The wastewater network was established in the systems analysis to facilitate interaction between the wastewater system, waterways and reuse systems. For example, it was assumed that up to 15% of stormwater runoff from urban areas (about 7% of rainfall) currently enters the wastewater systems as a function of rainfall intensity. It is our view that the majority of stormwater enters the wastewater system via cumulation of stormwater flows in sewage trenches that allow infiltration to sewers at the weak links in the sewage system – manholes and house connections.

Inclusion of wastewater flows in the systems analysis allows an understanding of the impacts on wastewater management by interaction with stormwater management processes (such as WSUD) that retain stormwater near the sources of runoff and local reuse of wastewater.

The compilation of these systems was also assisted by the reports "2009 Melbourne Metropolitan Sewage Strategy" [46], the "Eastern Treatment Plant and Western Treatment Plant Biosolids Beneficial Use Strategy" [47].

[46] MWC (2009). 2009 Melbourne Metropolitan Sewage Strategy.
[47] MWC (2006). Eastern Treatment Plant and Western Treatment Plant Biosolids Beneficial Use Strategy

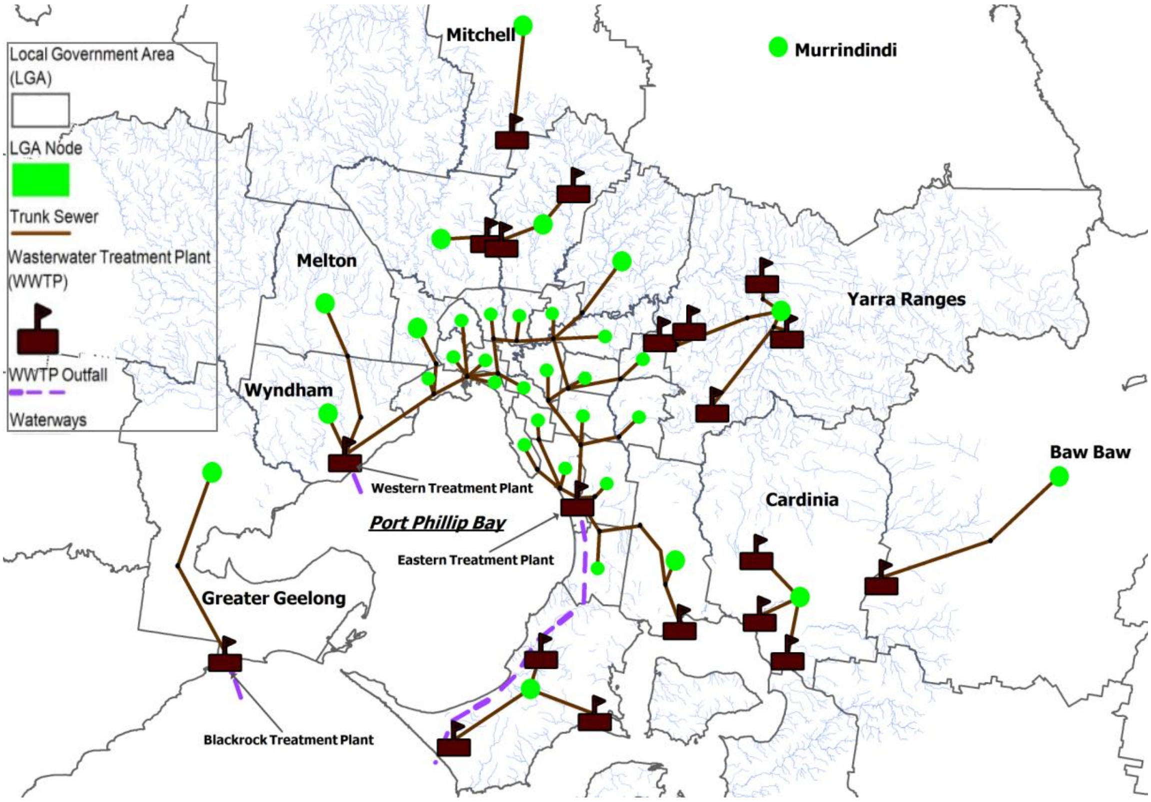

Figure 4.26: Schematic of the trunk wastewater systems and treatment plants included in the study

Figure 4.26 shows that the major wastewater systems servicing Greater Melbourne include the networks discharging to the Eastern and Western regional treatment plants located near Port Philip Bay, smaller treatment plants located across the region in mostly inland areas, and areas that are not serviced by wastewater treatment plants.

Effluent from these wastewater treatment plants discharge to Port Phillip Bay, Bass Strait and inland waterways. In some cases, the volumes of effluent discharged to waterways is mitigated by reuse of treated wastewater for a range of purposes. For example, effluent from the Western and Eastern treatment plants is used for agricultural irrigation and effluent from the Aurora treatment plant is reused for domestic uses in nearby areas.

Waterways and stormwater systems

The significant catchments and waterways within Greater Melbourne have been included in systems analysis to generate understanding of the impacts on waterway health and flooding created by the different Options for Greater Melbourne. These systems were compiled from a wide range of sources and informed by the reports such as "Better Bays and Waterways" [48] and "Melbourne's Rivers and Creeks" [49]. A schematic of the major waterways and stormwater catchments used in this analysis is presented in Figure 4.27.

[48] MWC and EPA (2009). Better Bays and Waterways – A water quality improvement plan for Port Phillip Bay and Western Port
[49] MWC (2004). Melbourne's Rivers and Creeks

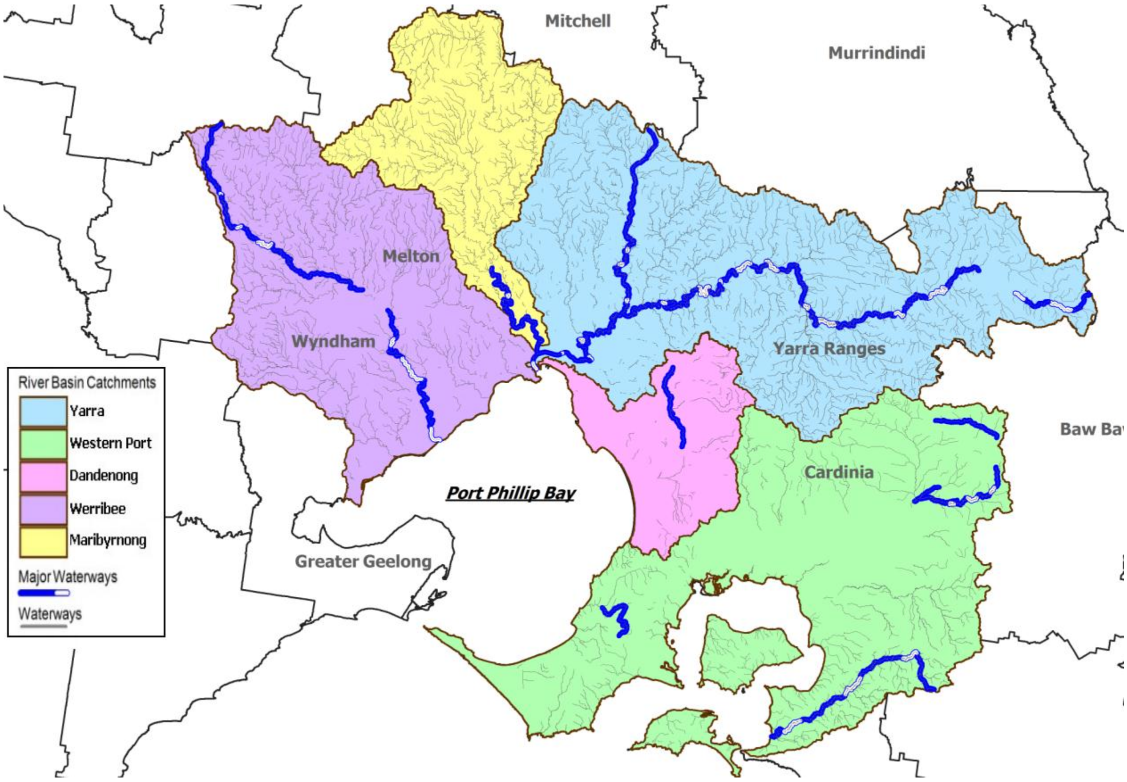

Figure 4.27: Schematic representation of the waterways and stormwater systems

Figure 4.27 presents the major stormwater catchments and waterways incorporated in this investigation. These waterways were included in the systems analysis to understand the feedback effects provided by the Options including rainwater and stormwater harvesting, and reducing effluent discharges to waterways. These benefits are likely to include changes in stormwater quality and probability of flooding.

Note that this analysis has only included stormwater runoff from urban allotments (residential and non-residential) to waterways to allow direct understanding of the changes created by different Options. This analysis includes all streamflows in the upper reaches of rivers that are included in the water supply headworks system.

An extract of the spatial network used in the systems analysis is provided in Figure 4.28.

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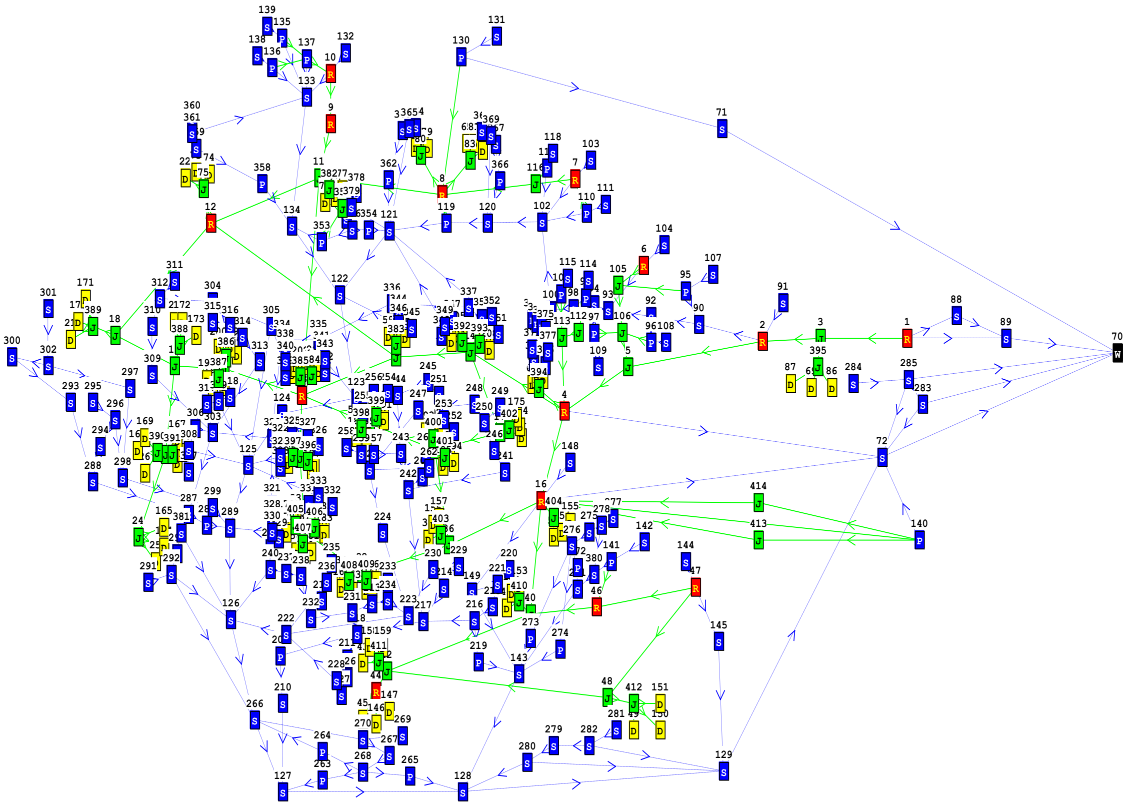

Figure 4.28: Network used in the systems analysis of the water cycle in Greater Melbourne

Figure 4.28 shows the spatial network used in the systems analysis that includes reservoirs, demand nodes, wastewater treatment plants, waterways, sewer and water transfer systems. Note that outputs from the Transition Framework that combines sequences of demands and flows for a range of dwellings, non-residential areas and water cycle Options are inputs to each node in the network.

Extracts from a single climate replicate for outputs from the systems analysis for sequences of total water storages and water restrictions are shown in Figure 4.29; sequences of water transfers from Silvan Reservoir to Cardinia Reservoir are shown in Figure 4.30; discharges to the Eastern Wastewater Treatment Plant are presented in Figure 4.31; and stormwater runoff from the Melbourne LGA are shown in Figure 4.32.

These examples of data extracted from the systems analysis provide an indication of the wide range of information that can be extracted from the systems analysis.

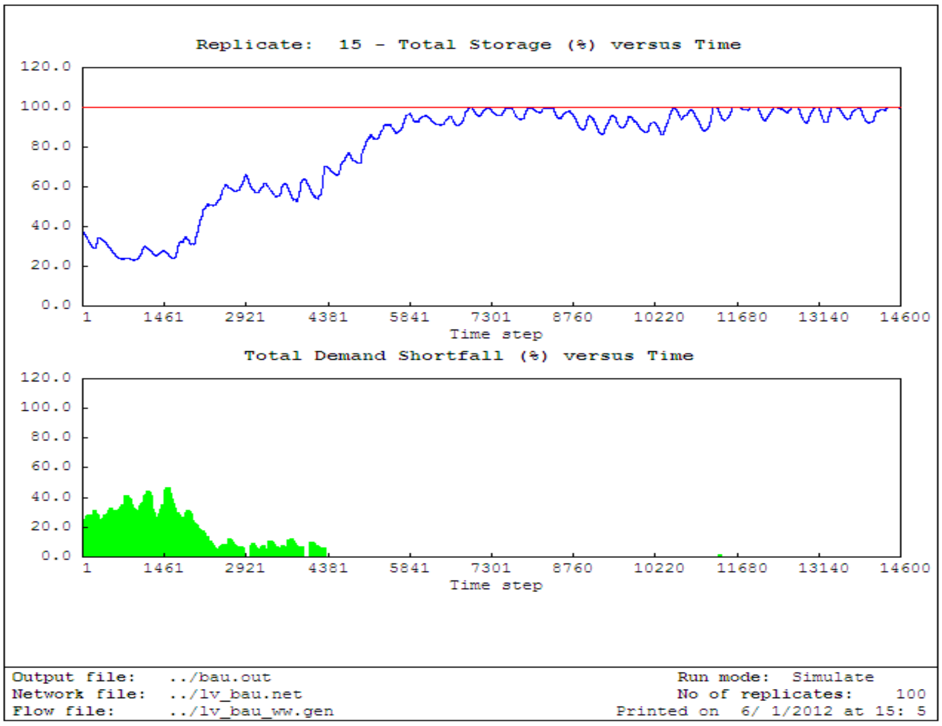

Figure 4.29: Extract from the systems analysis showing the sequences of total water storages and water restrictions from a single replicate

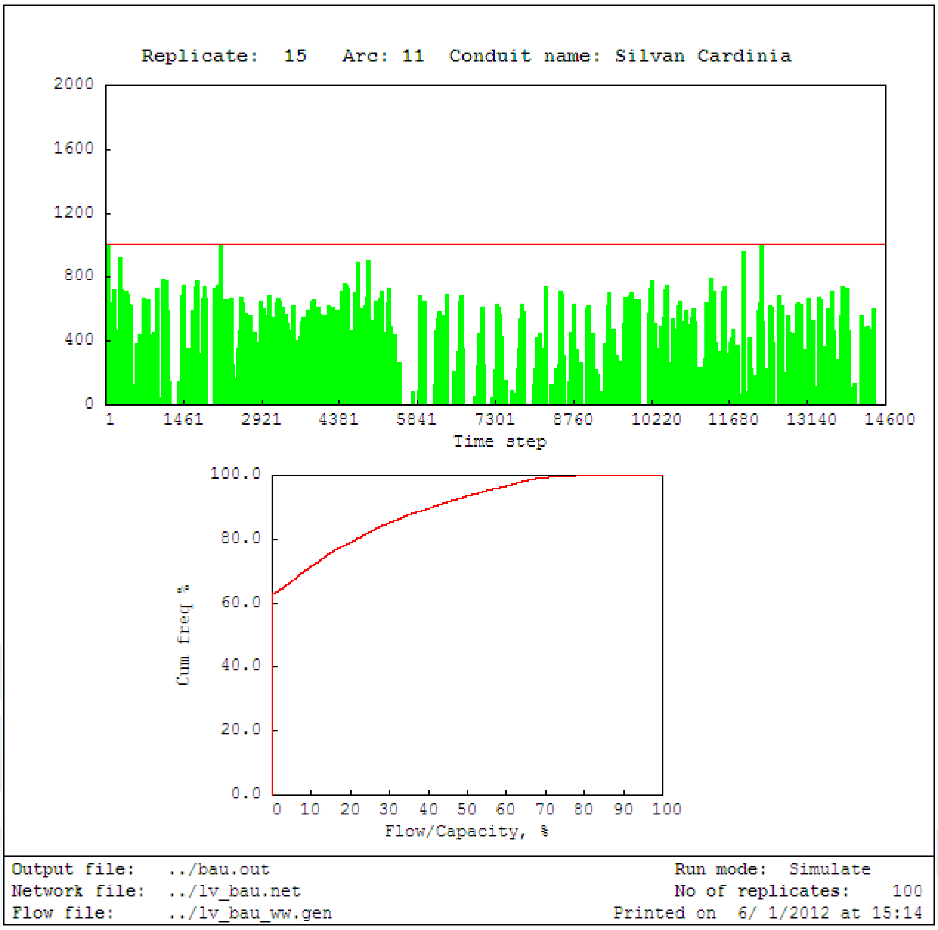

Figure 4.30: Water supply to Cardinia Reservoir from Silvan Reservoir from one of the climate replicates

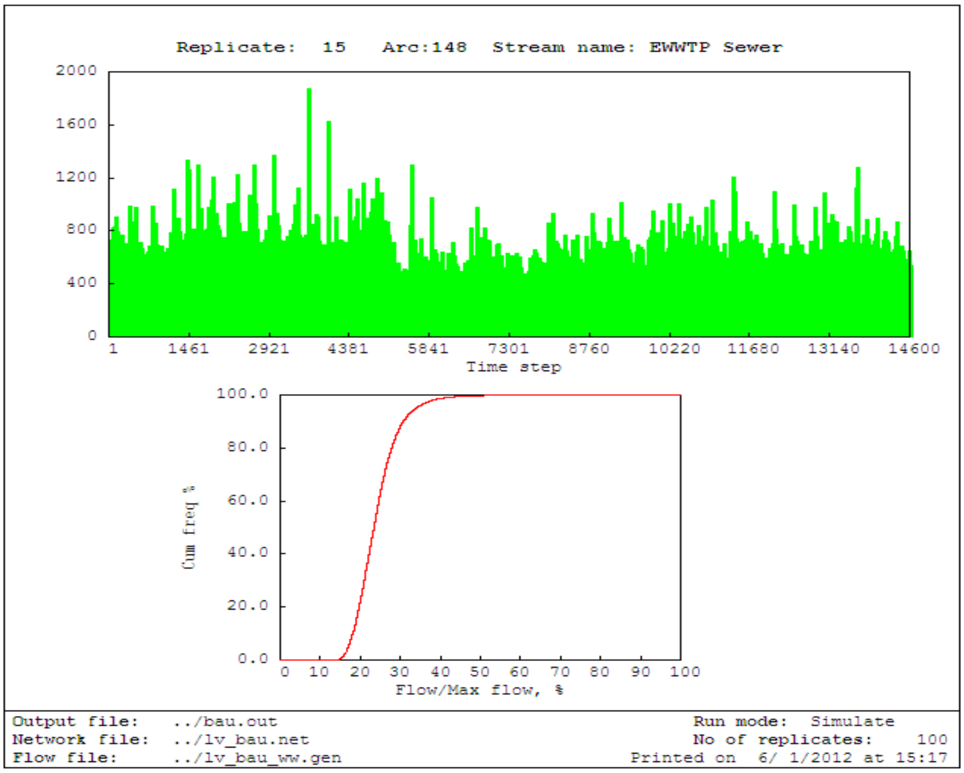

Figure 4.31: Wastewater discharges to the Eastern Wastewater Treatment Plant for the single climate replicate

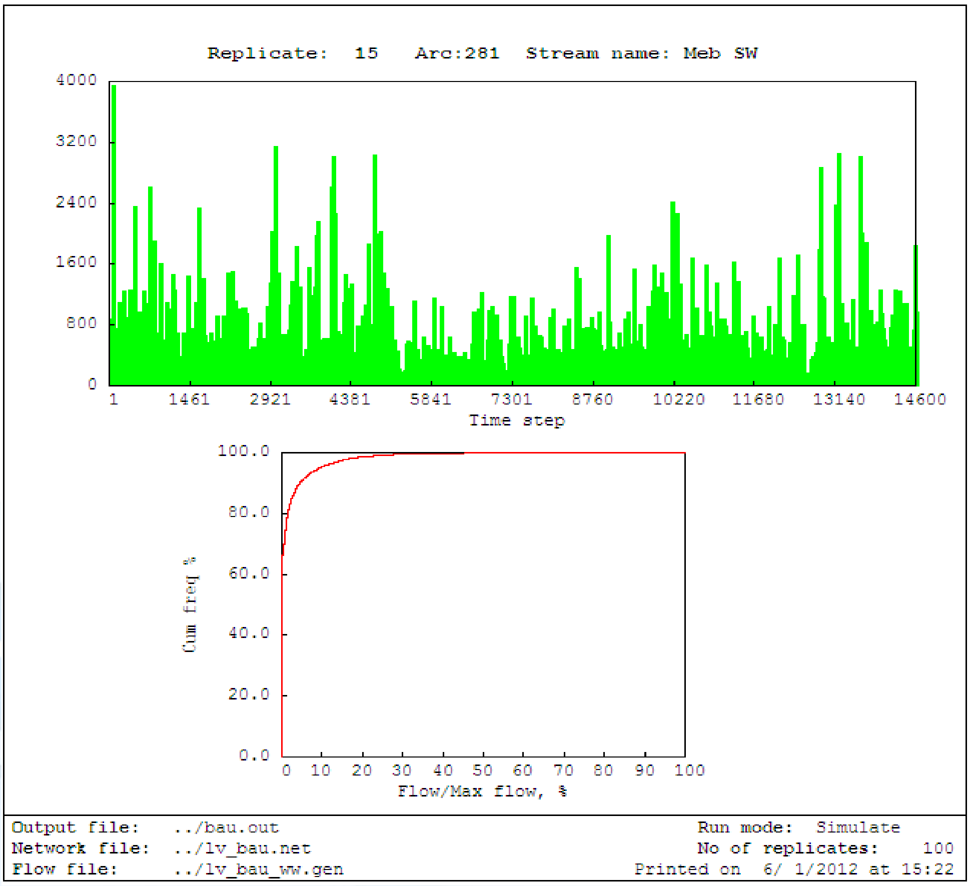

Figure 4.32: Stormwater runoff to waterways from Melbourne LGA from a single climate replicate

4.10 Stormwater considerations

Victorian government policy such as The State Environment Protection Policy – Water of Victoria and Victorian Urban Stormwater Best Practice Environmental Management Guidelines provide objectives that are consistent with a systems perspective on protecting downstream environments from the impacts of urban development.

The natural water cycle is profoundly changed by urban development and the hydraulic systems constructed to provide stormwater services to towns and cities. Typically, the area of impervious surfaces is increased whilst natural watercourses are replaced with pipes and channels designed to be hydraulically efficient to expedite the removal of stormwater to downstream environments.

To date, assessment of rainwater and stormwater harvesting in the Greater Melbourne region has been mostly limited to generic assessments of potential yield using assumptions based on spatial and temporal average water demands and climate inputs. This method of assessment cannot recognise the potential of rainwater and stormwater harvesting to provide a wide range of stormwater benefits.

This oversight is due to the coarseness of the analysis and a failure to analyse rainwater and stormwater harvesting systems as part of urban stormwater systems. An overview of the impacts of local rainwater harvesting on the urban stormwater system is shown in Figure 4.33.

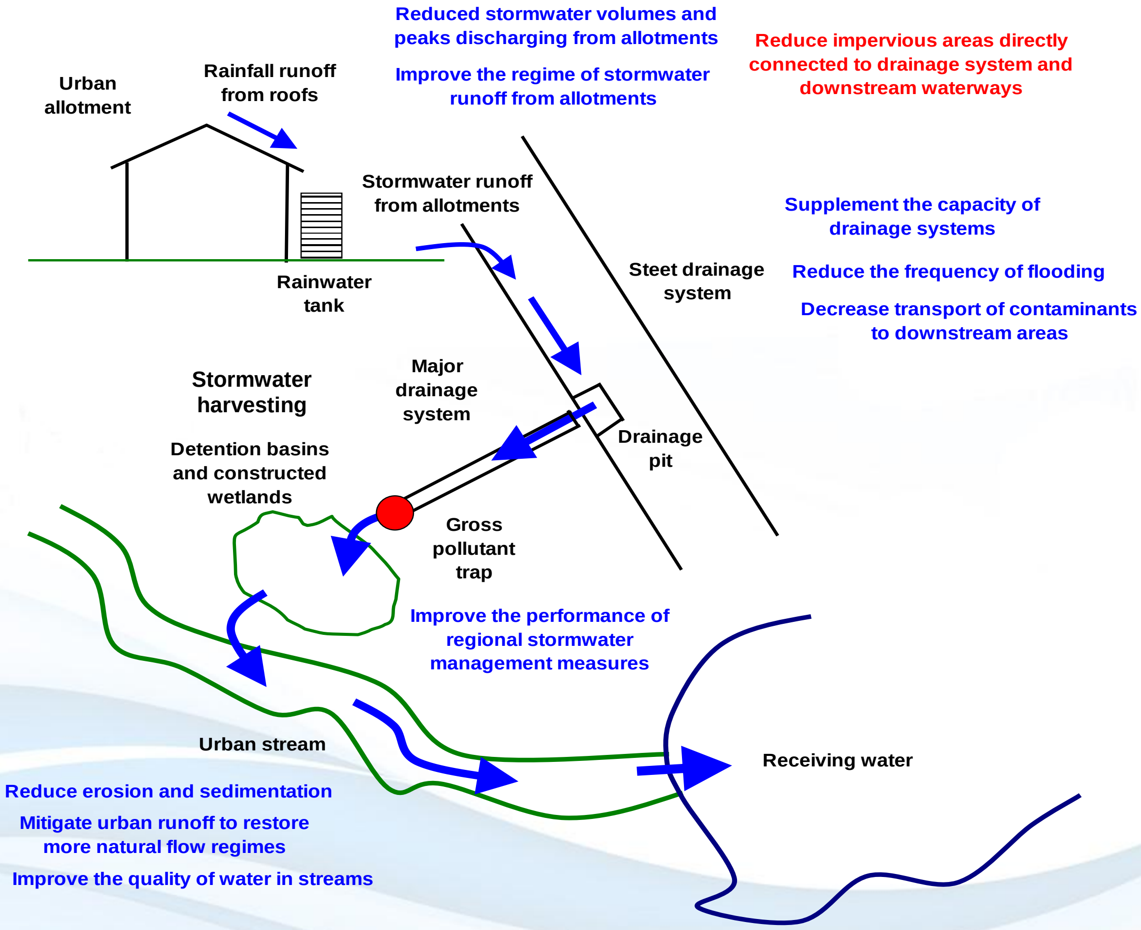

Figure 4.33: An overview of the impacts of rainwater tanks on the urban stormwater system

Figure 4.33 shows that use of rainwater harvesting to collect rainfall runoff from roofs reduces the volumes of stormwater runoff and peak stormwater discharges from urban allotments. This will reduce the effective impervious area of each allotment and increase the capacity of urban stormwater management systems to manage flooding.

The use of rainwater and stormwater harvesting will also reduce the frequency of stormwater runoff thereby improving stormwater runoff regimes that will combat the effects of urbanisation on waterway ecosystem health. A combination of reduced stormwater runoff volumes and reduced frequency of stormwater runoff from areas with rainwater and stormwater harvesting also decreases the transport of contaminants to waterways.

Rainwater harvesting from roofs can replace or supplement local government requirement for onsite detention.[50,51] However, this opportunity is often lost by use of codified design approaches that rely on discrete and average assumptions about storm bursts and initial conditions.[52] The use of systems analyses that incorporate first principles hydrology in real projects has revealed considerable benefits from multi-scale management of stormwater runoff, including mitigation of flood risks, stormwater runoff volumes and urban stormwater pollution.[53,54,55] This analysis has also revealed substantial land savings ranging from 13% for rainwater tanks to 47% for rainwater and stormwater harvesting with street scale WSUD measures.

These land savings are generated by interventions throughout an urban area that manage smaller stormwater flows in comparison to the capacity of systems required to manage larger accumulated stormwater flows at the end of the system. In addition, end of line management of stormwater acts to mitigate flooding and water quality impacts rather than avoiding these problems.

Infill development is a significant issue that generates additional stormwater runoff that is difficult to manage but can be mitigated using decentralised objectives[56] such as effective impervious area or site discharge index[57]. The Doncaster Hill project demonstrates that use of measures at the allotment, street and precinct scale can mitigate stormwater runoff and the associated impacts of urban infill development.[58]

This study has utilised the results from the systems analysis of Greater Melbourne used to understand the reduction in stormwater volumes discharging from areas with rainwater and stormwater harvesting. Reductions in volumes and frequency of stormwater runoff also indicate

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50 Coombes P.J., 2009. The use of rainwater tanks as a supplement or replacement for onsite stormwater detention (OSD) in the Knox area of Victoria. H2009. 32nd Hydrology and Water Resources Symposium. Engineers Australia.
51 Coombes Peter John, Kuczera George Alfred, Frost Andrew James, Geoff O'Loughlin, Stephen Lees, 2003. The Impact Of Rainwater Tanks In The Upper Parramatta River Catchment', Australian Journal Of Water Resources, Vol. 7 121-129
52 Coombes P.J., and M.E. Barry, 2008. Determination of available storage in rainwater tanks prior to storm events. Water Down Under 2008. Engineers Australia.
53 Coombes P.J., D. Boubli and J. Argue, 2003. Integrated water cycle management at the Heritage Mews development in western Sydney. 28th Hydrology and Water Resources Symposium. Engineers Australia.
54 Coombes P.J., 2009. Integrated water cycle management at Armstrong Creek – towards targets for sustainable development. WSUD09. Engineers Australia.
55 Bonacci Water, 2010. Integrated stormwater management at the Werribee Employment Precinct. Report for the Department of Planning and Community Development.
56 Bonacci Water, 2011. Mitigating the stormwater impacts of increasing urban density. Report for Melbourne Water.
57 Donovan I. and P.J. Coombes, 1998, 2000 and 2001. WSUD discussion paper, practices notes and water smart planning provisions (including the Site Discharge Index). The Hunter Region Organisation of Councils.
58 Coombes P.J., A. Cullen and K. Bethke, 2011. Towards sustainable cities – integrated water cycle management (IWCM) at the existing Principal Activity Centre at Doncaster Hill. 33rd Hydrology and Water Resources Symposium. Engineers Australia.

improvements in stormwater runoff regimes and decreases in the transport of contaminants to waterways.

In addition, peak stormwater discharges from allotments are used to indicate the contribution of rainwater and stormwater harvesting in supplementing urban stormwater management systems, mitigating flooding and reducing erosion in waterways. The impacts of stormwater harvesting and infiltration strategies provide similar process benefits to those described above.

The assessment of the stormwater runoff characteristics throughout Greater Melbourne in each of the Options was undertaken using the PURRS model to continuously simulate the performance of each Option. Peak daily stormwater discharges were extracted from the analysis at all locations for each Option throughout Melbourne and ranked according to average recurrence intervals (ARI). This analysis has revealed a rich understanding of the variable responses of the peak discharges throughout Greater Melbourne.

The response for all of Greater Melbourne was derived as a single curve of the average recurrence interval (ARI) of peak daily discharges to allow an understanding of the reductions in stormwater runoff and the value of changes in the probability of average annual damage (AAD) from flood events.

Values from the report by Halcrow for DSE[59] were used to estimate the benefits of the different Options on prevention of flood risks and associated damages. The report estimated reductions in Average Annual Damage (AAD) associated with stormwater management according to a certain set of assumptions and a flood damage curve. The frequency of peak daily stormwater runoff volumes derived from this investigation was calibrated to results for stormwater runoff from the Halcrow study to estimate reductions in the probability of Average Annual Damage from each Option.

Future requirements for trunk stormwater infrastructure were also evaluated by estimating the land area of infill and new developments for LGAs using information provided by DPCD and ABS. The current costs ($/ha) to provide stormwater infrastructure in Redevelopment Services Schemes (RSS) and Development Services Schemes (DSS) for each LGA were provided by the Waterways Group at MWC. This information was combined with reductions in stormwater runoff volumes to estimate the capital costs of trunk stormwater infrastructure for each Option.

The value of land in redevelopment or new development areas was derived from median house prices provided by The Real Estate Institute for each LGA. It was assumed that the land value at each location was 50% of the median house price at a density of 14 dwellings/ha to estimate the value of land in each LGA. A discount rate of 9% and CPI of 2.5% was used to estimate the net present value of land savings for each Option.

Analysis of stormwater quality

The PURRS model was also used to continuously simulate the stormwater quality responses from each Option. The concentrations of different pollutants expected for different types of urban

59 Halcrow Pacific Pty Ltd., 2009. Flood risk reduction – assessment of costs and benefits. Submitted to DSE and reported as "not published by DSE".

development published in Chapter 3 of Australian Runoff Quality[60] were incorporated in the analysis thereby allowing understanding of the changes in pollutant loads generated by the different Options.

4.11 Constituents in wastewater

A range of wastewater quality indicators were also used to analyse the performance of the Options including Biological Oxygen Demand (BOD), Total Suspended Solids (TSS), Total Dissolved Solids (TDS) and Total Nitrogen (TN). The median concentrations of each indicator were derived using sampling results from 20 wastewater treatment plants across the region as shown in Table 4.16.

Table 4.16: Base concentrations of key water quality indicators

Indicator	Concentration (tonnes/GL)
BOD	247
TSS	294
TDS	429
TN	44

The values for the key indicators shown in Table 4.16 were used to analyse the changes in constituent loads discharging to existing wastewater plants. Note that these values were used to determine the tariffs charged for use of the western and eastern wastewater treatment plants in accordance with ESC rulings.

It was agreed during the stakeholder and review process that the analysis would not consider the impacts of wastewater surcharges on waterways to avoid conjecture about the quality of wastewater that would ultimately enter waterways. Nevertheless, it is our contention that overflows of untreated sewage to waterways during rain events does occur throughout Melbourne and this issue should be considered.

4.12 Security of regional water supplies

The security of the regional water supplies for Greater Melbourne was defined for this analysis as the probability in any year or season of regional water restrictions that are based on the triggers presented in Table 4.17.

A greater than 10% chance of water restrictions in any year or season was considered to be an unacceptable level of water restrictions that should motivate a requirement for regional augmentation of the system. It is important to understand that regional water restrictions are not a demand management measure. Water restrictions are required to greatly reduce the cost of infrastructure for the provision of water security in countries with highly variable climates such as

60 Engineers Australia (2006). Australian Runoff Quality – a guide to water sensitive urban design

Australia. The water restriction policy imposed on outdoor uses that is consistent with past investigations[61] and is presented in Table 4.17.

Similarly, the water restriction policy imposed on non-residential uses and indoor residential uses is provided in Table 4.18. Note that the expected response to water restrictions by reductions in indoor residential water use has been observed from past studies. Although regional water restrictions are historically imposed on outdoor water uses these measures have also evoked a reduction of indoor uses.

Table 4.17: Regional water restrictions imposed on outdoor use

Total Water storage (%)	Reduction in water use (%)
60	
	33
55	
	57
50	
	75
40	
	100
0	

Table 4.18: Regional water restrictions imposed on outdoor use

Total Water storage (%)	Reduction in water use (%)
50	
	5
40	
	10
30	
	15
20	
	20
0	

The water restriction strategies outlined in Tables 4.17 and 4.18 were adopted for this investigation as a reasonable indicator for the requirement to augment regional water supply systems. Clearly an investigation of the optimum water restriction policy for Greater Melbourne is warranted.

[61] Coombes P., 2005. Integrated water cycle management: analysis of resource security. Water. March Edition. AWA. Sydney.

Nevertheless, acceptance of higher probabilities for water restrictions will delay augmentation of the systems and abolition of water restrictions will result in earlier augmentation of the regional water supply.

4.13 Greenhouse gas emissions

The potential impacts of climate change will have significant impacts on human and natural systems. There is a need to adapt our cities to be resilient in response to climate change and to reduce emissions of greenhouse gases to mitigate further changes in climate regimes.

This study has adopted climate change scenarios derived by CSIRO[62] from recent IPCC[63] summaries of global climate models. Our analysis includes multiple replicates of potential climate behaviour that are based on the longest possible climate records and incorporate expected climate change by using temperature as a key statistical driver. This allows a rate of increase in annual temperatures from the expected high emissions scenarios to be included as a fundamental driver of emerging changes in rainfall, evaporation, streamflow and related processes.

This study has evaluated energy uses of key water cycle infrastructure to assess the impacts of each Option on greenhouse gas emissions. The translation factor of 1.21 kg CO_2 for each kWh of energy use for Victoria published by the Department of Climate Change was utilised in this analysis.[64]

The pumping energy of various elements of trunk infrastructure in the various Options was also determined for the transport of water across Melbourne. This analysis included the spatial energy characteristics of sourcing, transporting and disposing of water, sewage and stormwater throughout Greater Melbourne.

Information about the energy use of various elements of the Options were obtained from a wide range of sources for use in this investigation including: Benchmarking report published by the National Water Commission, data provided by the water authorities, research publications and the annual reports of each water authority as shown in Table 4.19.

62 CSIRO (2007). Climate change in Australia.
63 IPCC Fourth Assessment Report: Climate Change 2007 (AR4), Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007.
64 Department of Climate Change (2011). National Greenhouse Account Factors

Table 4.19: Energy use of various elements of the Options

Item	Energy use (kWh)/ML)
Desalination including tranfers	4,900
North South pipeline	600
MWC water distribution and treatment	307
MWC sewage distribution and treatment	1,038
CWW water distribution and treatment	2.7
CWW sewage distribution and treatment	67
SEW water distribution and treatment	91
SEW sewage distribution and treatment	661
YVW water distribution and treatment	33
YVW Sewage distribution and treatment	191
Membrane Bioreactors	900
Rainwater and stormwater harvesting distribution	1,068
Treatment of stormwater	800
Distribution of treated wastewater	800
Water efficient appliances	-9.9

The values for energy use from Table 4.19 were used in the systems analysis to provide understanding of the greenhouse gas emissions associated with the different Options for water cycle management in Greater Melbourne.

Importantly, the economic and energy efficiency of MBR systems are subject to ongoing improvements.[65] The energy use of the precinct scale MBR plants was estimated to be 900 kWh/ML and the energy required to distribute the treated wastewater was 800 kWh/ML.[66,67] Note that the energy use of MBR plants in Europe and Singapore range from 550 kWh/ML to 900 kWh/ML.

Importantly, the economic and energy efficiency of MBR systems are subject to ongoing improvements.[68] It is often claimed that MBR systems use more energy due to a requirement for air scouring of membranes. However, the energy efficiency of MBR plants is actually a function of overall plant design, operation and downtime.[69]

The common practice of designing and establishing MBR plants in the same schematic as traditional wastewater treatment plants (such as IDAL) is a key driver for inefficiencies – MBR plants must be

65 General Electric (2011). GE's next generation MBR wastewater treatment system slashes energy use, boosts productivity.
66 Coombes P.J., A. Cullen and K. Bethke (2011). Toward sustainable cities – Integrated water cycle management (IWCM) at an existing principal activity centre at Doncaster Hill. 33rd Hydrology and Water Resources Symposium. Engineers Australia.
67 Wallis-Lage C.L., and S.D. Levesque (2009). Cost Effective and Energy Effiecent MBR systems. SIS09.
68 General Electric (2011). GE's next generation MBR wastewater treatment system slashes energy use, boosts productivity.
69 Livingston D., and K. Zhang (2011). Energy efficiency of MBR. Water and Wastes Digest.

designed, established and optimised solely as MBR plants to achieve high levels of economic and energy efficiency.

The desalinated water supply is estimated to have an energy use of 4,900 kWh/ML. This study has not assumed that the energy demands from desalination are neutralised by green power. Lower carbon energy sources should be utilised to reduce our existing carbon footprint rather than to neutralise new water sources that have a high energy demand. In addition, the provision of green energy is not usually included in the costs for provision of water projects.

Installation of water efficient clothes washers is expected to reduce energy use by 3.5 kWh/ML of water saved.[70] Energy savings from water efficient showers and dishwashers was estimated to be 6.4 kWh/ML. This study has assumed greenhouse gas emissions will attract a carbon price of $25/tonne.

4.14 Spatial processes

The systems analysis of the Greater Melbourne region included a range of spatial locations (local government areas) that were situated within each of jurisdictions of the retail water authorities. Whilst historical financial and energy use was available for each authority, this information was not provided for each zone used in this study. Fortunately MWC provided this spatial information for stormwater costs. However, MWC and retail water authorities did not provide this information for each local government area (LGA).

It was therefore necessary to use a meaningful ratio to distribute the historical costs and energy use from each water authority to the LGAs within the jurisdiction of the authority. These spatially adjusted costs and greenhouse gas emissions were then used as inputs to the systems analysis.

The energy use and costs of transferring water and sewage throughout Greater Melbourne was transformed into local impacts by a spatial ratio (SpatFact) that was derived using the following equation:

$$SpatFact_l = \left(\frac{[Dist_l + \Delta H_l]Dem_l}{\sum [Dist_l + \Delta H_l]Dem_l} \right) \tag{4.3}$$

where Dist is the transfer distance within the trunk infrastructure from bulk water supply to each LGA or the transfer distance from each LGA to a wastewater treatment plant, ΔH is the total of increases in elevation encountered throughout the transfer, and Dem is the water demand or sewage discharge at each LGA. Note the SpatFact is a simple ratio.

Equation 4.3 was required to disaggregate regional data from the water authorities into the energy use and costs to transfer water and sewage to each LGA. The demands, distance and cumulative increases in elevation throughout each transfer were evaluated by combining a digital terrain model with the water and wastewater distribution networks as shown (for example) in Figure 4.34 for water transfers to Mornington from Cardinia and Tarago reservoirs.

70 PMSIEC (2007). Water for Our Cities: building resilience in a climate of uncertainty. Section by Coombes on household energy use. Report by the Prime Minister's Science, Innovation and Engineering Council working group.

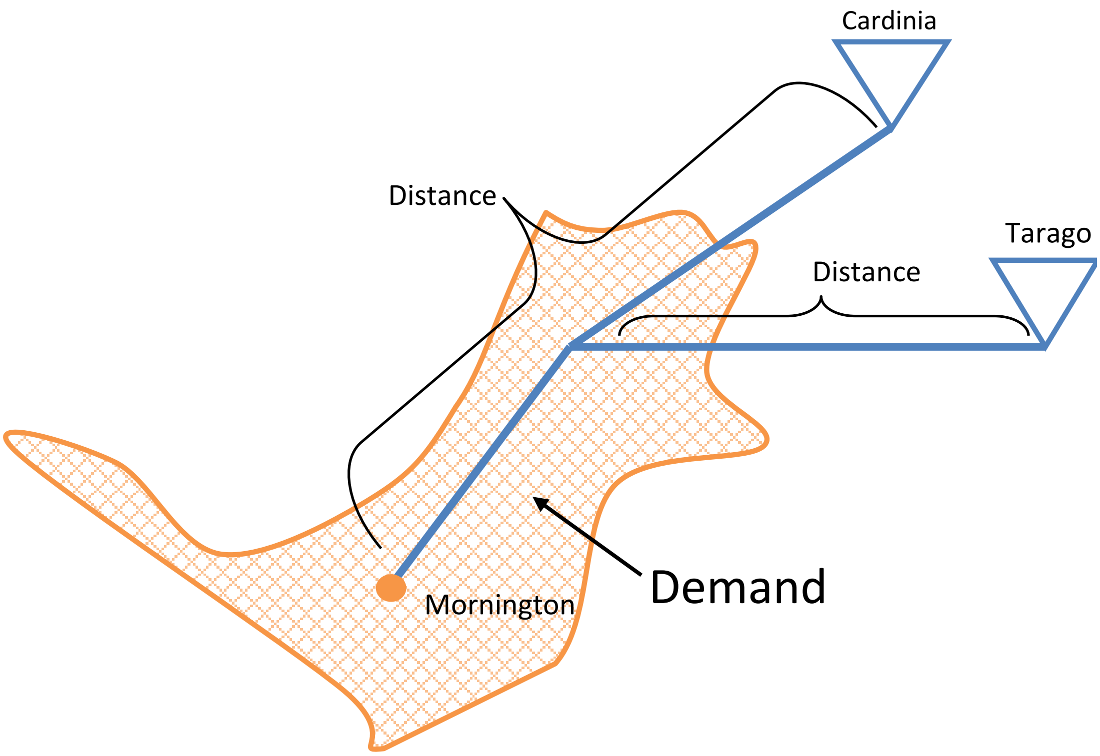

Figure 4.34: Schematic representation of distance and demand function

Figure 4.34 demonstrates that the spatial ratio includes the distances from all relevant bulk water reservoirs to the centroid of the Mornington demand zone and water demand within the zone. Cumulative increases in elevation along the major transfer routes were also included in this process. The derivation of spatial ratios to determine the spatial distribution of costs and emissions for provision of services to each LGA is demonstrated in Figure 4.35.

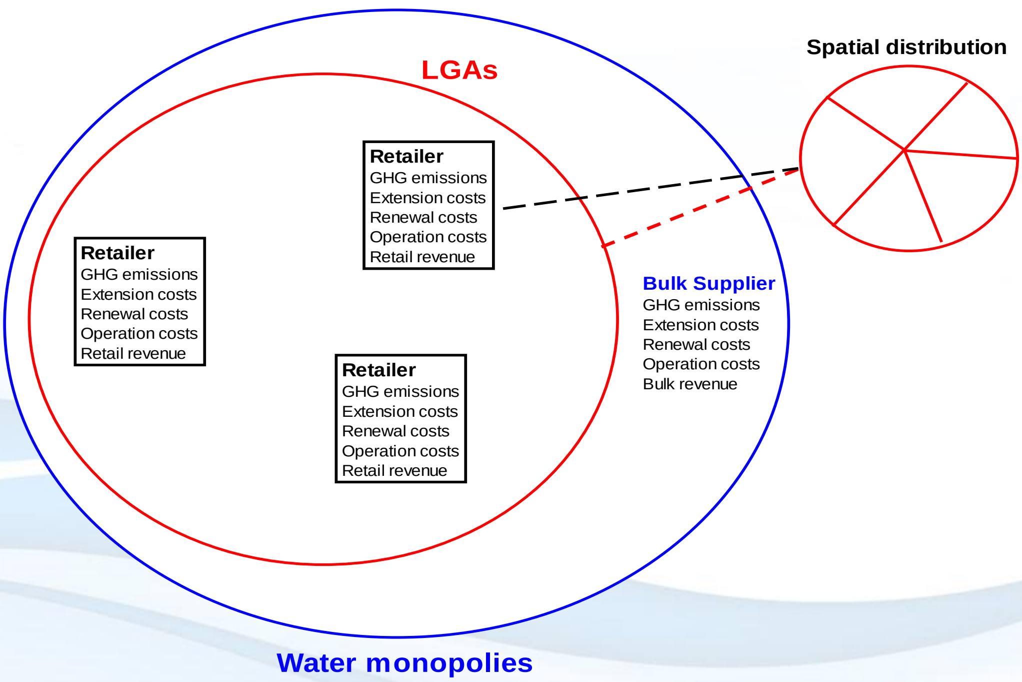

Figure 4.35: Diagram of the distribution of costs and greenhouse gas emissions of providing services to each LGA

The distance and changes in elevation throughout each transfer was evaluated by combining a digital terrain model with the water and wastewater distribution networks as shown (for example) in Figures 4.36 and 4.37 for water transfers to Port Philip and Murrindindi respectively. Wastewater transfers across terrain from Casey and Manningham are presented in Figures 4.38 and 4.39 respectively.

Figure 4.36: A cross-section of the transfer of water from Cardinia to Port Philip LGA

Figure 4.37: A cross-section of the transfer of water from Maroondah to Murrindindi LGA

Figure 4.38: A cross-section of the transfer of wastewater from Casey LGA to eastern treatment plant

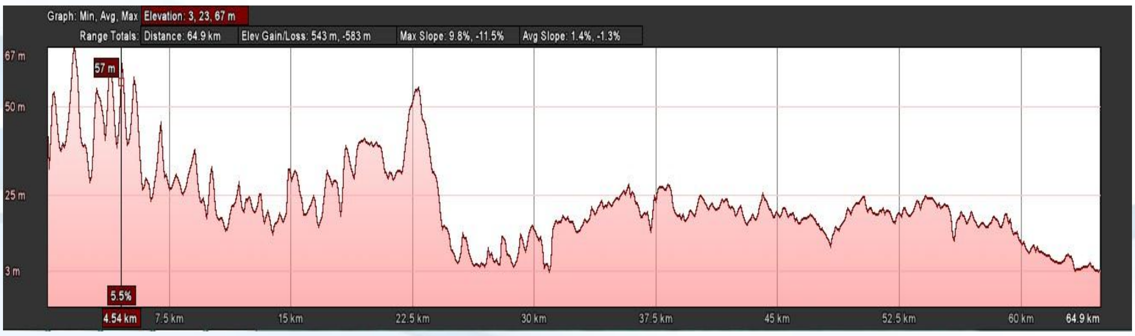

Figure 4.39: A cross-section of the transfer of wastewater from Manningham LGA to eastern treatment plant

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Figure 4.36 shows (for example) that the transfer of water to the Port Philip LGA in the trunk water network includes a total distance of 49.9 km and a cumulative increase in elevation of 447 m. Note that water is transferred over higher ground elevations along the route to Port Philip. In contrast Figure 4.37 reveals that the transfer of water to Murrindindi involves a distance of 53.3 km and a cumulative increase in height of 1,423 m.

Figure 4.38 reveals that the transfer of wastewater from the Casey LGA includes a total distance of 29.8 km and a total increase in elevation of 158 m. Wastewater is transferred over higher ground elevations along the route to the eastern wastewater treatment plant. Figure 4.39 shows that wastewater from Manningham is transferred across a distance of 64.9 km with a cumulative increase in height of 543 m.

The sums of transfer distances and increases in elevation (using metres as the unit of calculation) for water supply and disposal of wastewater throughout Greater Melbourne are shown in Figures 4.40 and 4.41 respectively.

Figure 4.40 reveals that the longest transfer distances for water supply are to inland and western areas that are distant from bulk water supplies. The longest transfer distance of 105,000 m is currently to the Bass Coast LGA.

Figure 4.41 shows that the longest transfer distances for wastewater is from the current growth areas and inland areas. The longest transfer of wastewater of 64,900 m is currently from Manningham.

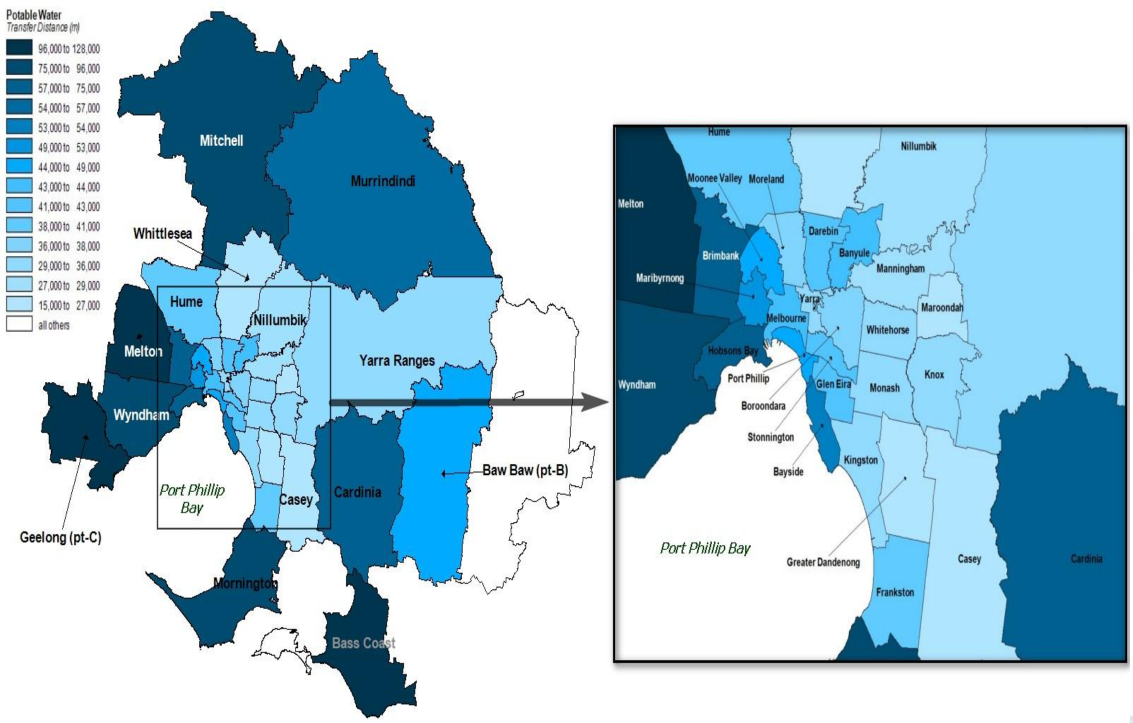

Figure 4.40: Transfer distance of water supply across Greater Melbourne

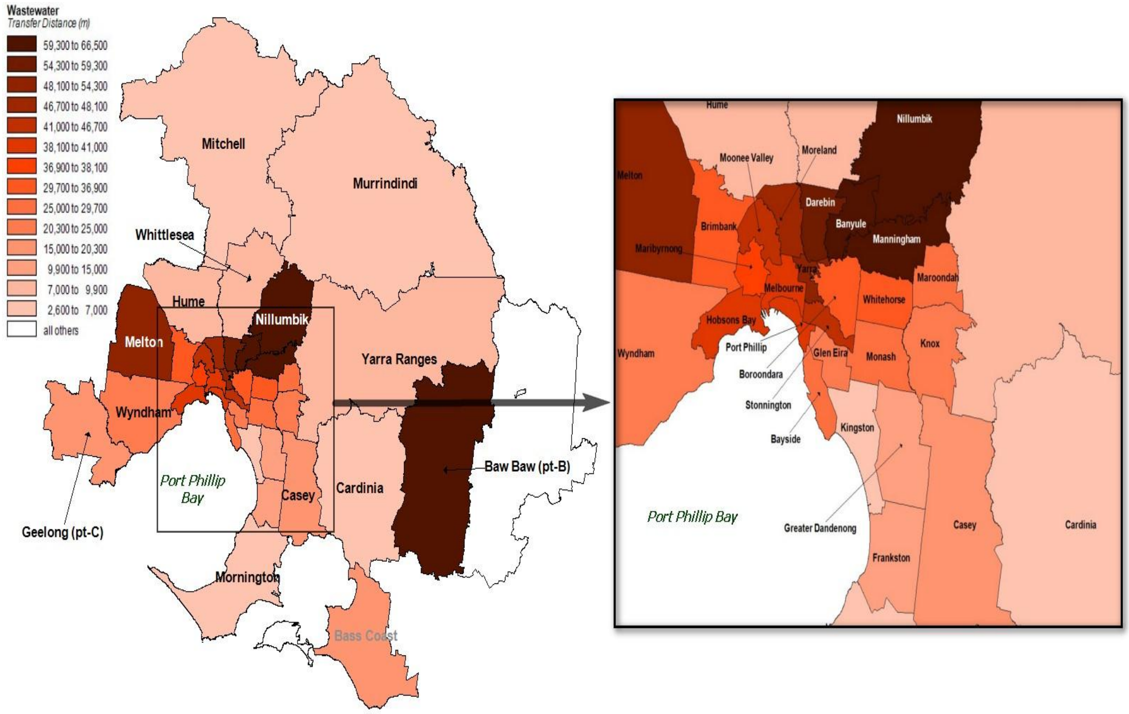

Figure 4.41: Transfer distance of wastewater mangement across Greater Melbourne

4.15 Economic considerations

When considering the economics of the system it is important to account for the economic transfers within the system. Broadly, they can be described as economic costs and benefits. There are a number of levels of expenses and revenues, or benefits within a system.

From an economic perspective, there are costs involved in the bulk and retail provision of water and wastewater services. There are also costs associated with the impact on the environment of activities such as disposal of wastewater in waterways and oceans, or the impact of constructing a new dam or desalination plant.

On the other side of the ledger are a series of economic benefits from the provision of water services. These include the provision of utility and amenity to individuals and society though the provision of water and wastewater services. Benefits are also derived by returning water to certain environments and ecosystems as shown in Figure 4.42. It is important to holistically consider all of the economic impacts within the systems analysis.

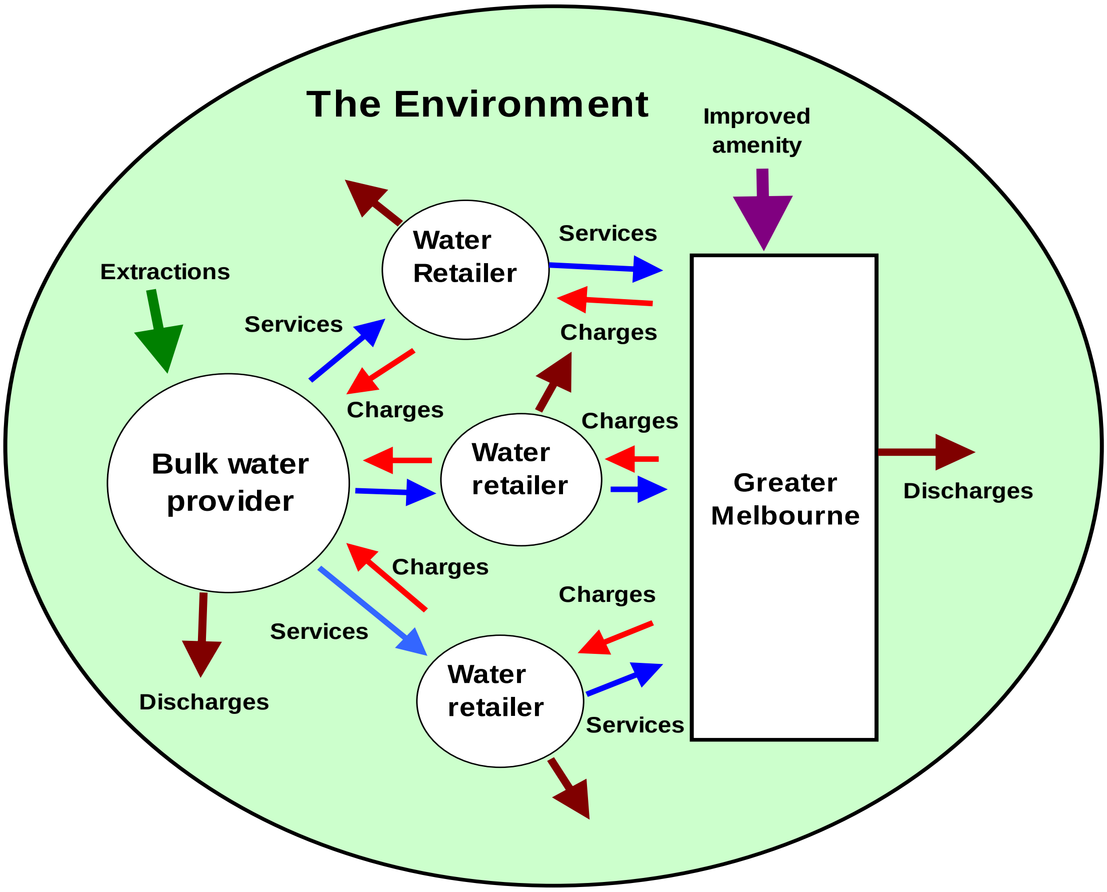

Figure 4.42: Schematic of the key economic transactions within the system considered in the analysis

From a financial perspective, there are a series financial transactions associated with the provision of water and wastewater services between the entities involved in the process including Governments, the bulk water authority, retail water authorities and the community as outlined in Figure 4.43.

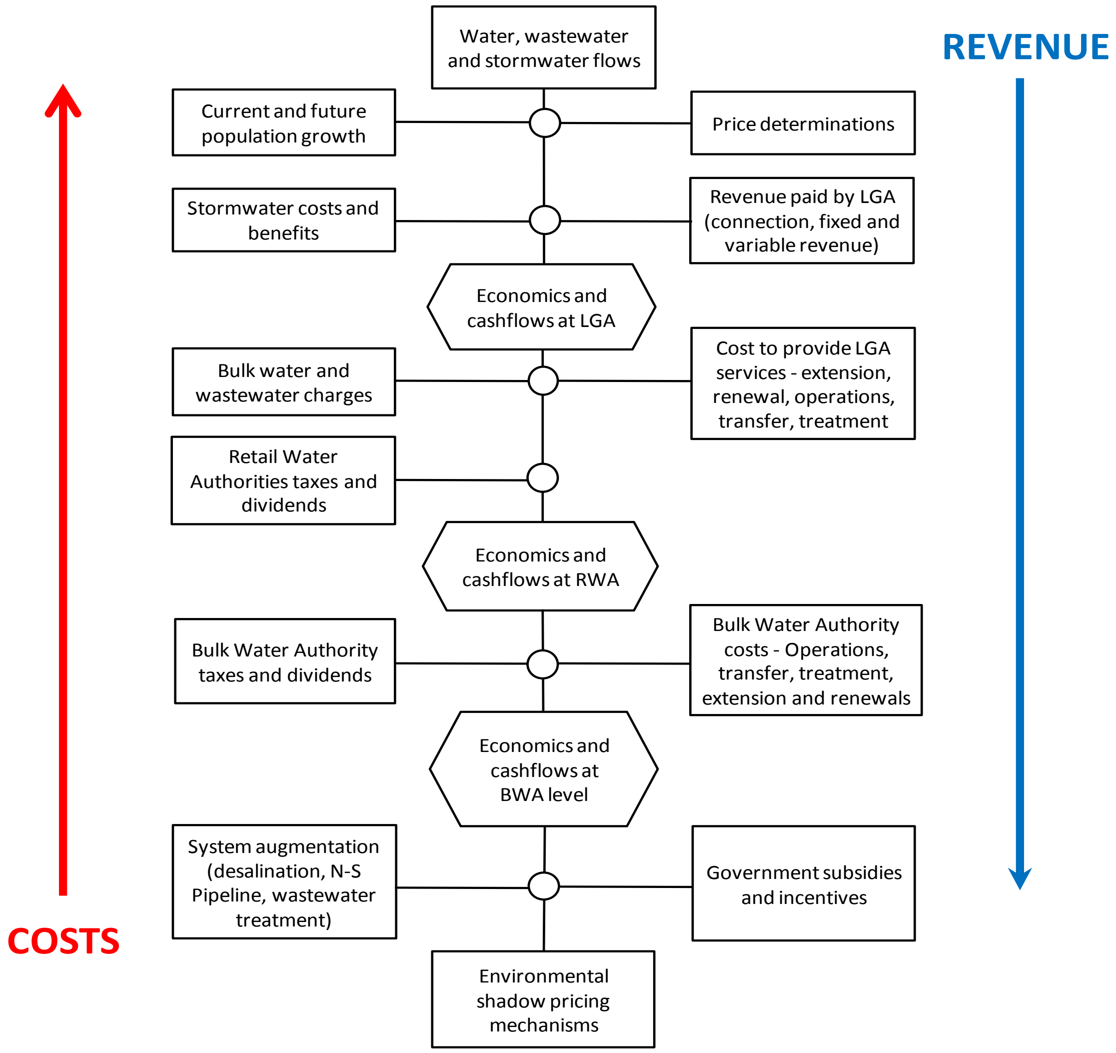

Figure 4.43: Schematic of the economic analysis

Figure 4.43 shows that our economic analysis has evaluated the detailed transactions involved in the transfer of services from the bulk water authority (BWA) to retail water authority (RWA) to Greater Melbourne with consequent charges (revenue earned) for these services. In addition, the economic analysis considers the impacts of stormwater runoff and sewage discharges to water quality in waterways, and on urban flooding.

It is important to consider both the economic and financial aspects of the provision of services when undertaking a systems analysis of water resources. The economic analysis includes the revenue earned by water authorities from developer, fixed and variable charges to connected properties in each zone for water and wastewater services.

The economic impact of the delivery of these services has been defined as extension, renewal, operation costs of the water and wastewater systems. The foundation elements of these expenses and revenues are imbedded in the dynamic analysis of the spatial economics for water and wastewater services as shown in Figures 4.44 and 4.45 respectively.

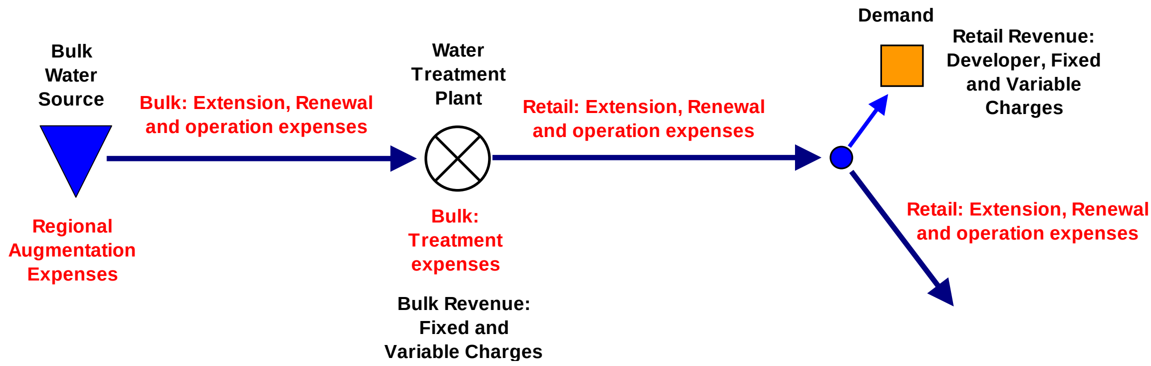

Figure 4.44: Foundation elements for water systems in the dynamic economic analysis

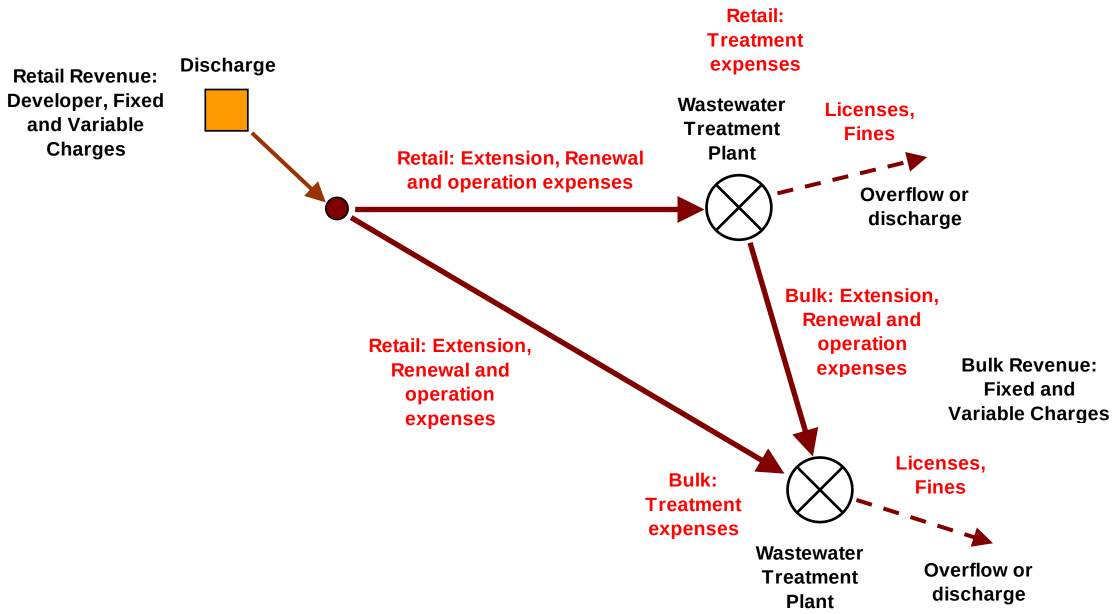

Figure 4.45: Foundation elements for wastewater systems in the dynamic economic analysis

Figures 4.43 and 4.44 demonstrate that extension, renewal and operation costs are included in the spatial systems analysis for each of the basic transfer elements in the network. Transfer of water from one location to another requires the use of infrastructure and a range of associated resources that are included using this methodology.

Note that the costs associated with transfer of additional flows in the sewage networks generated by infiltration of stormwater are also included in this method. Moreover, the financial impacts of alternative water strategies that may have some reliance on the existing centralised network are also counted in this method – failure to supply sufficient water from (say) a stormwater harvesting system at a given spatial location will require additional water supply from the centralised system which may generate a requirement to augment the central systems and incur extension costs.

Extensions, renewals, transfer and treatment costs have been derived for each area from local information wherever possible as follows:

- **Extension** – The costs to augment infrastructure to meet each additional unit of demand

- **Renewal** – The annual costs of renewing or replacing existing infrastructure for each unit of demand
- **Operation** – The costs to move and treat water and sewage throughout the system

The economic analysis also includes bulk water charges levied by Melbourne Water, dividends payed to the Victorian Government (determined to be 13% of gross revenue), Company taxation (defined as 30% of profit), augmentation of wastewater treatment capacity and management of biosolids.

In addition, provision of these services includes the costs of augmentation of local and regional water supplies. Throughout the analysis financial values are their real value.

Key data sources and assumptions underpinning the economic analysis

A number of data sources have been used in the development of this economic analysis as follows:

- "Melbourne metropolitan water price review 2009-10 to 2012-13" and supporting documentation published by the Victorian Essential Services Commission
- "2009-10 National Performance Report - Urban water utilities" published by the Water Services Associration of Australia
- "Melbourne Water Annual Report 2010-11" published by Melbourne Water Corporation
- "City West Water Annual Report 2010" published by City West Water
- "South East Water Annual Report 2010-11" published by South East Water
- "Yarra Valley Water Annual Report 2010/11" published by Yarra Valley Water
- Confidential data provided by Melbourne Water Corporation, City West Water, Yarra Valley Water, South East Water and Barwon Water

Information from the 2009-10 financial year has been used wherever possible in the development of the economic analysis. Alternatively, information from the 2008-09 year has been used and calibrated to enable comparative analysis. Key assumptions are listed in Table 4.20.

Table 4.20: Assumptions underpinning economic analysis

Category	Rate
CPI	2.5%
Base year	2009-10

Security of regional water supplies

The security of regional water supplies can be delivered from natural sources including dams (for example from the Thompson Dam) and waterways (such as the Yarra River), or from manufactured water sources including Desalination (currently the Victorian Desalination Plant at Wonthaggi) and recycled water. Another regional source of water is the North South pipeline.

A greater than 10% chance of water restrictions in any year or season was considered to be an unacceptable level of water restrictions that should trigger a requirement for regional augmentation of water supplies. The security of water supplies to Greater Melbourne can be augmented by additional desalination plants.

Alternatively, the requirement for regional augmentation can be avoided by the provision of water security within Greater Melbourne by use of water efficient buildings, rainwater and stormwater harvesting and reuse of wastewater.

Regional Augmentation - Desalination

As part of the Our Water Our Future strategy the previous Victorian Government committed to delivering a desalination plant to augment metropolitan water supplies. It was subsequently determined that the reverse osmosis desalination plant will have a capacity of 150 GL/annum that can expand to a capacity of 200 GL/annum as required. The desalination plant was expected to start producing water by December 2011.

There is potentially another 50 GL/annum of desalination capacity available at the Wonthaggi location for future augmentation of regional water supply. It was estimated that an increase in desalination capacity of 50 GL at Wonthaggi would cost about $750 million. The fixed and variable costs of the current desalination plant were estimated to be $500 million/annum and $450/ML in 2011 values. It was assumed in the analysis, whenever possible, that the desalination plant is utilised when total volume of water in Melbourne's water storage is less than 65%.

Following a 50 GL expansion of the Victorian Desalination Plant the next logical approach to augmenting the systems water supply is to construct another desalination plant in the west of Melbourne.

This augmentation would be more expensive as the base infrastructure will need to be designed and constructed. Using Victoria's first desalination plant and other regions including South East Queensland, Sydney, Adelaide and Perth as an example of the cost of future augmentations was derived as shown in Table 4.21.

Table 4.21: Costs of future augmentations of the water system using desalination

Size of Desalination	Estimated Cost
50 GL/annum	$2 billion
100 GL/annum	$4 billion
150 GL/annum	$5 billion

Regional Augmentation – Sugarloaf Pipeline

The North South Pipeline is a 75 GL/annum transfer water pipeline from the Goulburn River to the Sugarloaf water supply scheme. The North South Pipeline is part of the previous Government's "Our Water, Our Future" water strategy announced in 2007. The pipeline officially commenced operating in February 2010, however is not currently operating due to return to higher rainfall regimes and the current Governments policy to only use this source of water in an emergency.

It was assumed for this investigation in accordance with government policy that the North South Pipeline would be utilised when the total volume in Melbourne's water storages is less than 30%.

The pipeline route is from the Goulburn River near Yea and heads south to the Sugarloaf Reservoir north-east of Melbourne. The pipeline links the Goulburn River, a tributary of the Murray Darling river system, with the water system for Greater Melbourne. The pipeline was promoted as being able to transfer up to 75 GL of water annually to Melbourne's water supply.

Similar to the desalination plant, there is extensive information available on this project. It is however important to understand the impact of the Sugarloaf pipeline from a systems analysis perspective. The fixed and operating costs of the pipeline of $170 million/annum to 2019 and $122.67/ML respectively were included in the analysis.

Costs of providing bulk water services

The extension, renewal and operation expenses for water and wastewater services incurred by Melbourne Water used in this study derived from published data are presented in Table 4.22.

Table 4.22: Costs of providing bulk water and wastewater services

Water costs ($/ML)			Wastewater costs ($/ML)		
Extension	Renewal	Operation	Extension	Renewal	Operation
3,097	220	290	4,784	358	260

Costs of providing retail water services

The water retailers, City West Water (CWW), South East Water (SEW) and Yarra Valley Water (YVW) provide water and wastewater services to their respective geographical customer bases. MWC distributes water via their trunk main system and each water retailer has an agreement to extract water from the regional network.

The water is then distributed through the retailer's water distribution network to the community within their area of operations. Likewise wastewater is transferred by the retailer's from customers either to their own wastewater treatment plants, or into the bulk regional wastewater network. The costs provided in Table 4.23 have been determined using information from annual reports, ESC documentation and benchmarking report prepared by NWC and WSAA.

Table 4.23: Costs for delivery of water and wastewater services by water retailers

Water retailer	Water costs ($/ML)			Wastewater costs ($/ML)	
	Extension	Renewal	Extension	Renewal	Extension	Renewal
CWW	3,321	231	694	13,284	44	259
SEW	6,102	126	585	26,383	126	255
YVW	4,082	292	409	21,358	641	194

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Retail Water Prices

A comparative base is required to understand the future price path of bulk and retail water services. In 2009, the Essential Services Commission (ESC) provided a determination for the future price path for retail water prices for each of the Retail Water Authorities. These future prices for the period from 2009-10 to 2012-13 used in this study are provided in Table 4.24.

Table 4.24: Determination of fixed and variable water, wastewater and recycled water price for 2008-09 to 2012-13

Financial year	CWW		SEW		YVW	
	Fixed ($/annum)	Variable ($/kL)	Fixed ($/annum)	Variable ($/kL)	Fixed ($/annum)	Variable ($/kL)
	Retail water charges - ESC (2009 $)					
2008-09	126.52	1.02	56.96	1.01	75.54	1.02
2009-10	136.64	1.23	64.94	1.21	87.25	1.22
2010-11	146.21	1.46	71.43	1.44	99.46	1.46
2011-12	156.44	1.64	75.72	1.61	110.4	1.63
2012-13	167.39	1.77	78.75	1.74	119.24	1.76
Retail wastewater charges - ESC (2009 $)						
2008-09	134.59	1.34	192.67	1.26	184.54	1.32
2009-10	154.78	1.42	231.2	1.39	221.45	1.48
2010-11	176.45	1.5	275.13	1.5	263.52	1.63
2011-12	199.39	1.6	308.15	1.57	295.15	1.79
2012-13	223.31	1.69	332.8	1.63	318.76	1.94
Retail recycled water charges - ESC (2009 $)						
2008-09	20	1.02	20	1.01	20	1.02
2009-10	20	1.23	20	1.21	20	1.22
2010-11	20	1.46	20	1.44	20	1.46
2011-12	20	NA	20	NA	20	NA
2012-13	20	NA	20	NA	20	NA

The ESC has also determined the rate of change of prices from the base year (2009-10) across the future determination periods. There are two elements to the increase in prices over the determination period – consumer price index (CPI) and real cost increases. The fixed and variable changes for each authority have been determined from their cost profiles of providing water services.

This determination of the price path has been used to establish the base for a price path from 2010 to 2050. It was assumed that prices will only increase at the CPI rate of 2.5%.

Bulk Water Prices

Bulk Water prices to be paid by the water retailers to the bulk supplier have been determined by the ESC for the 2009-2013 period. Unique prices and price paths for water and wastewater services have been determined for each retail water authority. Bulk water services are charged to each retailer as a fixed tariff and a variable usage fee as shown in Table 4.25.

Table 4.25: Determination of bulk water prices for City West Water, South East Water and Yarra Valley Water

Financial year	Headworks		Transfer	
	Fixed ($/annum)	Variable ($/ML)	Fixed ($/annum)	Variable ($/ML)
	City West Water			
2009-10	20,823,860	471	5,679,540	136
2010-11	23,989,087	543	6,542,830	157
2011-12	30,602,878	693	8,346,688	200
2012-13	39,040,091	884	10,647,870	255
	South East Water			
2009-10	28,314,418	471	10,564,811	116
2010-11	32,618,210	543	12,170,663	133
2011-12	41,611,050	693	15,526,114	170
2012-13	53,083,217	884	19,806,664	217
	Yarra Valley Water			
2009-10	31,578,951	471	15,063,892	92
2010-11	36,378,951	543	17,353,604	106
2011-12	46,408,628	693	22,137,993	136
2012-13	59,203,487	884	28,241,437	173

The bulk wastewater prices for each retailer are provided in Table 4.26. Note that wastewater price determination is separated into wastewater entering the eastern and western wastewater treatment plants. Bulk wastewater services attract charges based on a volumetric service fee, a volumetric usage fee, as well as a fee for the constituents of the wastewater including Biological Oxygen Demand (BOD), Total Suspended Solids (TSS), Total Dissolved Solids (TDS) and Nitrogen (N).

Table 4.26: Bulk wastewater prices (fixed and variable charges) for City West, Yarra Valley and South East Water

Financial year	Service ($/annum)	Usage ($/ML)	BOD ($/tonne)	SS ($/tonne)	N ($/tonne)	TDS ($/tonne)
	CWW Eastern					
2009-10	3,629,171	471	350	194	724	18
2010-11	4,180,805	543	404	223	835	22
2011-12	5,333,452	693	515	285	1,065	26
2012-13	6,805,485	884	657	363	1,358	31
	CWW Western					
2009-10	3,629,171	136	10	2	171	18
2010-11	4,180,805	157	12	2	197	22
2011-12	5,333,452	200	15	3	251	26
2012-13	6,805,485	255	19	4	321	31
	SEW Eastern					
2009-10	5,509,922	471	350	194	724	18
2010-11	6,347,431	543	404	223	835	22
2011-12	8,097,417	693	515	285	1,065	26
2012-13	10,332,304	884	657	363	1,358	31
	SEW Western					
2009-10	5,509,922	116	10	2	171	18
2010-11	6,347,431	133	12	2	197	22
2011-12	8,097,417	170	15	3	251	26
2012-13	10,332,304	217	19	4	321	31
	YVW Eastern					
2009-10	6,050,093	471	350	194	724	18
2010-11	6,969,707	543	404	223	835	22
2011-12	8,891,255	693	515	285	1,065	26
2012-13	11,345,242	884	657	363	1,358	31
	SEW Western					
2009-10	6,050,093	92	10	2	171	18
2010-11	6,969,707	106	12	2	197	22
2011-12	8,891,255	136	15	3	251	26
2012-13	11,345,242	173	19	4	321	31

Developer and Headworks charges

An important component in the growth of a city is the development of new areas and the redevelopment of existing areas. Whenever a new development is constructed the developer must pay the relevant water retailer authority "head works" charges to contribute to capacity of the overall system. The headworks and connection charges levied by each of the retail authorities are presented in Table 4.27.

Table 4.27: Determination of headworks and connection charges for water and wastewater services by ESC

New customer contribution ($) for lot size ($m^2$)			Connection charge ($)
< 450	450 – 1,350	> 1,350	
564	1,127	2,254	413

Economics of the options

Option 0: Business as Usual (BAU)

This is the base case for water cycle management which assumes that mains water and centralised management of wastewater will be the sole source of services to Greater Melbourne. The BAU Option assumes that additional potable water will be available in the Greater Melbourne water supply system by construction of the Wonthaggi desalination plant and the Food Bowl Modernisation project. It is assumed that all buildings in this Option include the equivalent of two star appliances as shown in Table 4.28.

Table 4.28: Characteristics of water efficient appliances in the BAU Option

Appliance	Water use
Toilets	6/3 Litre flush
Taps	7.5 litres/minute
Showers	9 litres/minute
Clothes washers	130 litres/wash

Options 1 and 2: BASIX and BASIX1

It was assumed for these Options that all new and redeveloped buildings and dwellings include the equivalent of six star appliances as shown in Table 4.29

Table 4.29: Characteristics of Water Efficient Appliances in the WEA Option

Appliance	Water use	Reduction (%)
Toilets	4.5/3 Litre flush	20
Taps	4 litres/minute	47
Showers	7 litres/minute	22
Clothes washers	80 litres/wash	38
Outdoor (BASIX only)	Low irrigation gardens	50

Note that the BASIX1 Option does not include water efficient gardens. Water efficient clothes washers are currently adopted in about 8% of Melbourne's households and are expected to reduce laundry water use by 38% at an additional cost of $100 for each washer. The small proportion of water efficient clothes washers impacting on current water demand trends indicates that adoption in a demand management strategy should produce maximum water savings.

Water efficient shower roses have a 52% adoption in Melbourne and are expected to reduce bathroom water use by 22% from current water use patterns at an additional cost of $60 for each system. Current water use patterns will include the water savings from water efficient 6/3 L flush toilets that are installed in over 85% of Melbourne households. Installation of 4.5/3 flush toilets is expected to reduce water use for toilet flushing by 20% at an additional cost of $70 for each system. It was assumed that water efficient appliances are replaced every 15 years.

This option also includes the collection of rainwater from roofs of all buildings to supply toilet flushing, laundry and garden watering. Each rainwater supply system will include a small first flush device (20 L) and a mains water bypass system for backup during periods when water levels in tanks are low.

The average cost to install rainwater tanks to supply household laundry, toilet and outdoor uses was sourced from recent research into the rainwater industry.[71,72] The capacity of rainwater tanks was 5 kL for each detached or semi-detached dwelling, 20 kL for each cluster of 10 units and 50 kL for each 1,000 m^2 of non-residential roof area as costs of $3,000, $6,500 and $14,600 respectively. The design life of pumps was assumed to be 15 years with replacement costs of $450 for detached housing. The replacement costs of pumps supplying units and non-residential development was $650.

Note that installation of rainwater harvesting systems largely avoids the requirement for On Site stormwater Detention (OSD) and, at worst, supplements the requirement for OSD.

Investigations into the impacts of climate change on the performance of water resources in Australia has revealed that the future yields from Thomson Dam supplying Melbourne are subject to increasing uncertainty and decline. In contrast the certainty and magnitudes of rainwater yields from tanks in Melbourne were subject to marginal change because the roof surfaces in urban areas are impervious and are, therefore, not subject to the considerable losses that reduce runoff from water supply catchments.[73]

Options 3 and 4: ULT and ULT1

These Options build on the previous Options and incorporates the use of building or Precinct scale wastewater treatment plants that supply non-potable water uses. This strategy will utilise modular membrane bioreactors at a range of scales from building to Precinct scale. These systems are currently available as complete treatment packages. It is expected that these systems will cost about

71 Coombes P.J., 2007. Energy and economic impacts of rainwater tanks on the operation of regional water systems. Australian Journal of Water Resources. 11(2). 177-191.
72 Marsden Jacobs, 2007. The costs effectiveness of rainwater tanks in urban Australia. Report for the National Water Commission.
73 Coombes P.J., and M.E. Barry. 2008. Climate change, efficiency of water supply catchments and integrated water cycle management in Australia. Australian Journal of Water Resources. Engineers Australia.

$5m/ML of daily treatment capacity with treatment costs of $1,085/ML. These systems were assumed to be replaced every 30 years and have annual maintenance costs at 4% of capital costs.

It was assumed that the cost of a "third pipe" distribution system was $3,000, $2,000 and $1,000 for each detached, semi detached and unit dwelling respectively. In addition, it was assumed that the cost of a third pipe system was $3,000 for each unit of non-residential demand equivalent to the demand of a detached dwelling.[74] It was assumed that reticulated systems are replaced every 100 years and have annual maintenance costs at 0.5% of capital costs

Membrane bioreactor (MBR) wastewater treatment plants with ultra-filtration (UF) are used to supply toilet, outdoor and other non-potable water uses. These Options also include the water efficiency strategy outlined in Options 1 and 2.

Option 3 (ULT) includes stormwater harvested from urban catchments in regional storages at a magnitude of 5 kL/dwelling or 50 kL for each 1,000 m^2 of impervious surfaces in non-residential areas. Stormwater harvesting will supply potable water uses at a cost of $3,000 for each dwelling or each equivalent volume of non-residential water demand. These systems were assumed to be replaced every 30 years and have annual maintenance costs at 4% of capital costs.

Option 4 (ULT1) does not include stormwater harvesting and alternatively uses rainwater harvesting from roofs to supply laundry and hot water demands. The costs of rainwater harvesting for this Option were assumed to be similar to Options 1 and 2.

Analysis of these types of projects that contain integrated infrastructure solutions reveal considerable additional infrastructure savings and benefits at the local scale that can be established at the design phase of the project.[75]

The significant opportunities embedded within integrated water cycle management strategies are only revealed by detailed and integrated systems analysis of the entire water cycle. These opportunities are often, unfortunately, overlooked by the use of traditional assumptions and more simplistic analysis processes.

The time value of money and housing affordability

Water cycle infrastructure required for development or redevelopment of settlements is currently delivered as large scale civil engineering projects with lengthy timelines. The indirect financial costs (such as the time value of money and financing costs) from delays in provision of centralised infrastructure or approval of alternative schemes can dominate the land development industry.[76] A five year delay in delivery of infrastructure increases the cost of housing by at least 18% and a twenty year delay increases the cost of housing by 40%. The three main factors that impact on these financial burdens are:

- The time taken to design, approve, procure and construct large centralised infrastructure. The time and financial costs of large infrastructure in the water sector are commonly under-

[74] Bonacci Water, 2009. Specification of wastewater treatment and reuse infrastructure for the town of Gidgegannup. Report for Port Bouvard Ltd
75 WBM, 2005. Strategic stormwater study for the Pimpama Coomera Water Futures Strategy. Report for Gold Coast City Council with assistance from Dr. Peter Coombes.
76 Cullen Capital and Bonacci Water., 2008. Financial benefits of implementing sustainable integrated water cycle management. Sustainable Integrated Water Cycle Management Forum. Sunshine Coast.

estimated at the plannning and development stages (eg; The Wonthaggi Desalination Plant). This creates substantial additional indirect impacts on holding costs

- The limited linear, temporal and spatial nature of centralised infrastructure forces narrow development corridors, sequential development and long time delays (depending on decisions about infrastructure pathways and the distance of development land from the preferred centralised infrastructure strategy). This process forces development into areas that may otherwise be non-optimal for land development whilst creating extreme differentials in holding costs. For example at Armstrong Creek near Geelong the developer at the end of the sequential and linear delivery of the trunk sewer expects that the holding costs to more than double the ultimate cost of housing – this process has probably rendered the land unviable. In contrast, this developer proposed a precinct scale water and wastewater solution which would halve development costs and allow prompt land supply – but needed government approval.
- The limited linear, temporal and spatial nature of centralized provision of infrastructure generates extreme cases of gaming in the market place – a developer can purchase land in the linear pathway for provision of infrastructure and using a range of mechanisms can dominate the market by delaying extension of infrastructure. This process creates skewed competition in the market for land which creates artifical shortages of developable land and consequent increased prices

This has been used to estimate the net present value of land development for the period 2010 to 2050 and the impact of a delay of one year on all developments throughout the period to understand the impact of holding cost on the urban development industry and potential home owners.

5 Hindcasting, calibration and validation

The systems model for Greater Melbourne was created in 2006 and continuously developed during the period prior to Stage I of the MAC process using data provided by a wide range of agencies. A limited amount of additional data was provided during Stage I of the MAC process that was employed to enhance the model.

This Chapter provides an overview of the processes used to calibrate, validate and enhance the biophysical systems model that was utilised by the Ministerial Advisory Council (MAC). This process includes interactions with the MAC across Stages I and II of the Living Victoria process, the review panel and a large number of stakeholders. Importantly, this process allowed the inclusion of data and information that was not available to Bonacci Water during Stage I of the MAC. The stakeholder process allowed enhancement and validation of the systems model beyond the achievements of Stage I of the MAC.

The previous reports by Bonacci Water namely, "Study 1 – transitioning to a resilient, liveable and sustainable Greater Melbourne (system wide study)" and "Rainwater tank evaluation study for Greater Melbourne" should be read in conjunction with this Chapter.[77,78] These reports provide an essential overview of the historical development of the biophysical systems model, and a range of existing key inputs and processes in the systems model.

The processes leading to calibration and validation of the biophysical systems model included interactions with stakeholders who revealed a range of operating rules and data that was unavailable to Bonacci Water during Stage I of the MAC. This process also involved an overview of the calibration used for the model in Stage 1 of the MAC and use of the model to "hind cast" the performance of the water supply system for Greater Melbourne for the period 1990 to 2010. The performance of the model was compared to observed data from the past. This is a critical step in demonstrating the efficacy and accuracy of the model predictions over a range of Options and Scenarios investigated in this study. Each component of the hindcasting and validation process is described below.

5.1 Interaction with stakeholders

The hindcasting and validation process included a series of workshops and meetings with stakeholders that identified additional information and data that was ultimately employed to enhance the systems model of the Greater Melbourne region. The organisations which Bonacci Water engaged with and sourced information from during the process included:

[77] Coombes P.J. and Bonacci Water (2011). Study 1 – transitioning to a resilient, liveable and sustainable Greater Melbourne (system wide study). Report to the Ministerial Advisory Council for the Living Melbourne Living Victoria water policy.
[78] Bonacci Water and Urban Water Cycle Solutuions (2008). Rainwater tank evaluation study for Greater Melbourne. Report for the Department of Sustainability and Environment.

Victorian Government Agencies

- Department of Sustainability and the Environment (DSE)
- Office of Water (OoW) at DSE
- Department of Planning and Community Development (DPCD)

Independent authorities

- The Essential Services Commission (ESC)
- The Victorian Competition and Efficiency Commission (VCEC)
- The Growth Area Authority (GAA)

Water authorities

- Melbourne Water Corporation (MWC)
- City West Water (CWW)
- Yarra Valley Water (YVW)
- South East Water (SEW)
- Barwon Water (BW)
- Western Water (WW)
- Gippsland Water (GW)
- South Gippsland Water (SGW)

Australian Government Agencies and Authorities

- The National Water Commission (NWC)
- The Australian Bureau of Statistics (ABS)
- Bureau of Meteorology (BoM)
- The International Panel for Climate Change (IPCC)

Industry organisation

- Water Services Association of Australia (WSAA)

The above organisations provided information and discussion that was utilised in this investigation.

Estimated licensed water use (diversions) from rivers in the water supply headworks system were provided by Melbourne Water Corporation (MWC) for inclusion in the systems analysis and are shown in Table 5.1.[79] In addition, the trigger levels for bans on licensed extractions from rivers in the Yarra Basin were also supplied by MWC.[80] This information was combined to amend the systems

[79] Argent R. M., (2006). A decision support system for water quality improvement in Port Philip and Western Port. CEAH Report 01/06. Provided by Melbourne Corporation.
[80] Melbourne Water Corporation (2007). Drought response plan – licensed water users (updated April 2007). Provided by Melbourne Water Corporation.

model from Stage I of the MAC to include licensed extractions from the Yarra and Bunyip River systems, and to incorporate stream flow based constraints on water use.

Table 5.1: Annual water diversions from rivers

Location	Diversion (ML/yr)	Diversion (%)
Lower Yarra River	9,000	1.9
Yarra River (Warrandyte)	3,500	0.8
Yarra River (Yering)	8,360	2.3
Yarra River (Healesville)	3,960	2.6
Upper Yarra River	4,200	6.4
Bunyip River	6,280	5

The estimated licensed diversions from the Yarra and Bunyip Rivers shown in Table 5.1 were incorporated in the systems analysis as proportions of streamflow at each location in the river systems. The rules that limit extractions from rivers during periods of low flows as described in the Drought Response Plan for licensed water users were included in the systems model.

It is important to highlight that the ultimate use of water licenses in the river basins was unknown and, as a consequence, the potential magnitude of licensed extractions from the river systems was unknown. Nevertheless, conservative maximum diversions were assumed for the systems analysis that mitigates uncertainty about the ultimate extractions from the river systems.

The stream flow records provided by MWC at the completion of Stage 1 of the MAC were combined with sequences of observations at key points in the water supply headworks system and the system management rules. This process allowed Bonacci Water to discover a requirement to also include residual streamflows from the Yarra River as "Yarra Balance" flows as shown in Figure 5.1.

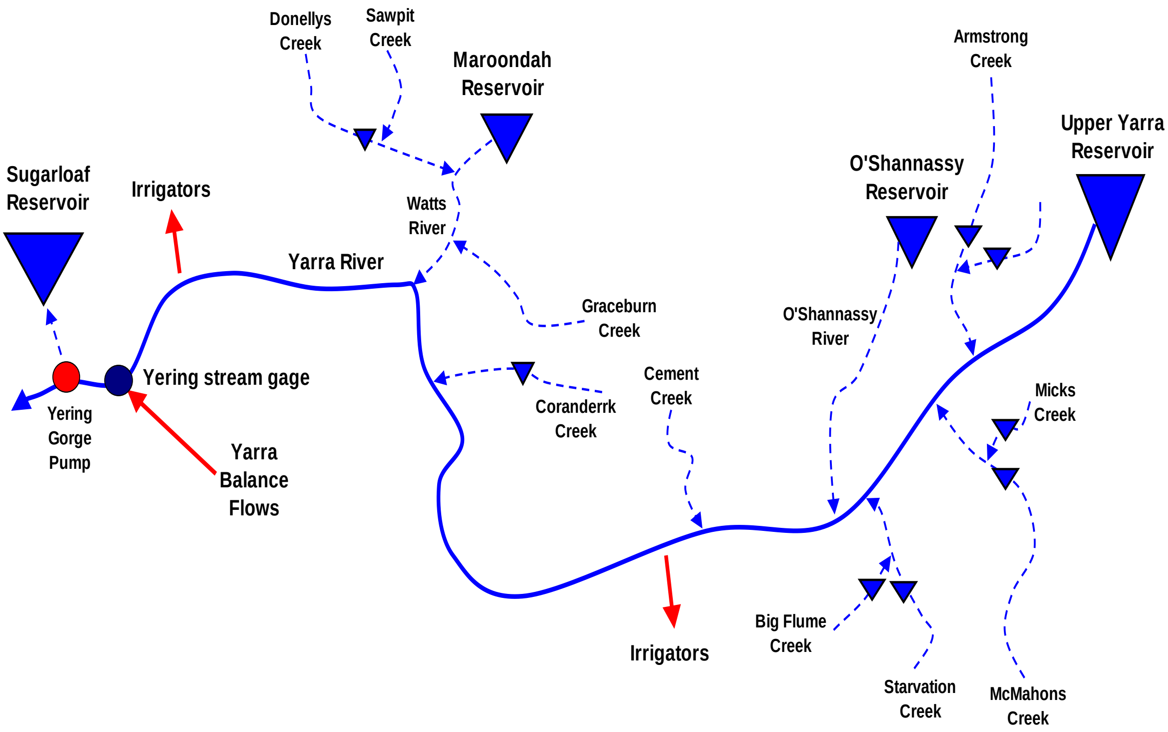

Figure 5.1: Aspects of the Yarra River Basin used to determine the Yarra Balance flows

Figure 5.1 demonstrates that the residual gauged streamflows from tributaries into the Yarra River were combined with water extractions by irrigators to derive the actual residual streamflows in the Yarra River at the Yering Stream Gauge. The difference between the residual and observed streamflows at the Yering Stream Gauge represents the balance of inflows from Yarra River catchments that should be and were included in the analysis. These streamflows were defined as the Yarra Balance Flows for use in the systems model.

The water networks in the systems analysis were originally established using the Water Supply System Description provided by MWC during Stage I of the MAC.[81] This information was supplemented by the System Management Rules that were provided by MWC during the stakeholder process.[82] This information was augmented during Stage II by discussions with MWC about the operational methods preferred for the water supply headworks system. In particular, the preferred strategy to maximise storage volumes in Silvan Reservoir and to use the reservoir as a balancing storage was included in the rules utilised by the systems model.

Further investigations by Bonacci Water and associated discussions with MWC also revealed that the water supply headworks systems is subject to bulk entitlements acruing to Southern Rural Water (SRW) for supply to the Macalister Irrigation District.[83] These entitlements including 6% of inflows to the Thomson Dam and a 45 GL share of the storage were included in the systems model. In addition, the average water transfers to SRW for the Bacchus Marsh Irrigation District (BMID) of 949 ML/year and the Werribee Irrigation District (WID) of 762 ML/year were included in the systems analysis.

[81] Melbourne Water (1998). Water supply system description.
[82] Melbourne Water Corporation (2010). 2009/2010 system management rules.
[83] Water Act (1989). Bulk entitlement (Thomson/Macalister – Southern Rural Water) conversion order 2001.

It was also important to include all current and future external water demands on Greater Melbourne in the systems analysis. Bonacci Water held discussions with MWC and all of the external water retail companies to obtain sequences of past water demands and projections of future dependancy on the Greater Melbourne system as shown in Table 5.2.

Table 5.2: Water demands on Greater Melbourne from external regions

Location	Demand (ML/yr)	
	2010	2050
Western Water	11,250	34,097
Barwon Water	0	15,230
Westernport Water, Gippsland Water, South Gippsland Water	235	6,957

Table 5.2 highlights the future water demands by the external regions that were included in the systems analysis. In addition, discussions with MWC revealed the rules governing the magnitude of water releases from Thomson Dam for generation of hydro electricity as shown in Table 5.3.

Table 5.3: Rules governing the release of water from Thomson Dam for generation of hydro electricity

Dam storage (%)	Release (ML/day)
0	0
73	225
80	370
89	480
100	480

The rules governing water releases from Thomson Dam for generation of hydro-electricity shown in Table 5.3 were included in the systems analysis.

The retail water authorities (RWA), City West Water, South East Water and Yarra Valley Water, provided residential and other water demands for all of the local government areas (LGA) within the Greater Melbourne region for 2009 and 2010. Annual water demands at each LGA for 2010 are presented in Table 5.4.

Table 5.4: Annual water demands for each local government area within the Greater Melbourne region for 2010

Location	Water demand (ML/yr)		Location	Water demand (ML/yr)	
	Residential	Other		Residential	Other
Banyule	6,644	7,925	Maribyrnong	3,719	2,645
Bass Coast	1,565	2,324	Maroondah	5,320	1,184
Baw Baw	168	217	Melbourne	6,316	14,378
Bayside	6,257	7,016	Melton	2,798	468
Boroondara	10,220	12,151	Mitchell	395	42
Brimbank	17,311	23,415	Monash	9,637	3,216
Cardinia	3,052	4,567	Moonee Valley	3,727	673
Casey	13,147	15,708	Moreland	8,247	1,729
Darebin	7,606	9,974	Mornington Peninsula	9,488	3,056
Frankston	7,301	8,534	Murrindindi	1,022	475
Gleneira	8,099	9,143	Nillumbik	3,149	409
Greater Dandenong	7,323	11,652	Port Phillip	5,886	2,310
Greater Geelong	657	730	Stonnington	4,177	1,596
Hobsons Bay	4,971	12,925	Whitehorse	8,287	2,945
Hume	7,185	12,725	Whittlesea	8,117	2,275
Kingston	8,128	11,382	Wyndham	4,318	4,833
Knox	8,198	10,269	Yarra	1,446	2,974
Manningham	6,976	840	Yarra Ranges	6,150	1,985

Table 5.4 highlights the variations in the magnitude and distribution of water demands throughout Greater Melbourne. It is also noteworthy that other water demands (such as commercial, industrial or institutional demands) are greater than residential demands in some LGAs. This information was used in the systems model in the hindcasting process for validation of the model and as initial demands at the commencement of systems analysis of Options.

Bonacci Water utilised a range of publications during State I of the MAC process to overcome a range of differing views about demographic projections to derive a population profile for Greater Melbourne for the period 2010 to 2050. There was considerable reluctance to provide demographic information during Stage I of the MAC that was overcome during Stage II.

The Department of Planning and Community Development (DPCD) provided demographic projections during Stage II of the MAC process.[84] These detailed projections replaced the projections used in the systems analysis during Stage I of the MAC that were previously based on Census data from 2006[85]

[84] DPCD (2011). Revised unpublished population projection that account for the considerable population growth that accured during 2006 to 2010. Department of Planning and Community Development.
[85] ABS (2006). 2006 Census of population and housing.

and previous advice from DPCD.[86] The previous (Stage I) and current (Stage II) estimates of population projections for metropolitan Melbourne are shown in Figure 5.2.

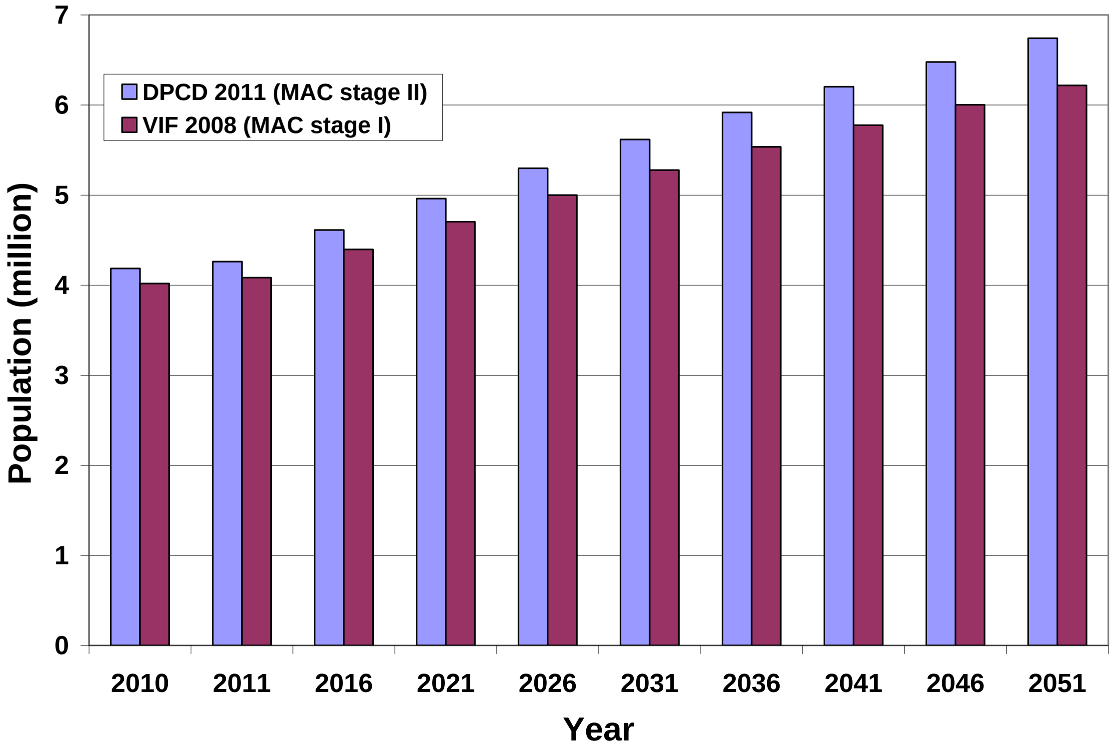

Figure 5.2: Population projections for Metropolitan Melbourne

Figure 5.2 reveals considerable difference between the population projections provided in Stages I and II of the MAC process. Importantly, the previous estimates of population profiles provided an overall growth rate of 1.37% for Greater Melbourne and the current projections assume a growth rate of 1.53%. This substantial increase in projected growth has very significant impacts on the simulation of water cycle processes for Greater Melbourne and highlights a major uncertainty that impacts on analysis of water resources. Hence it was important to account for these types of uncertainties by analysing Scenarios of potential system behaviours – such as 0% and 2% growth rates (See Chapter 3).

The DPCD and the Growth Area Authority (GAA) also ultimately provided current information about the urban growth area boundaries surrounding metropolitan areas of Greater Melbourne. There was a reluctance to provide this information for inclusion in the systems analysis.

After discussion between Bonacci Water and MWC, the Department of Sustainability and Environment (DSE) ultimately provided a range of reports relating to flood risks and reports on investigations into six star strategy.[87,88] These reports were considered in the development of inputs to the systems analysis and in the evaluation of results. A range of information that was discussed at

[86] DPCD (2008). Victoria in the future 2008. Department of Planning and Community Development.
[87] Halcrow Pacific (2009). Final report. Flood risk reduction – assessment of costs and benefits. Report for the Department of Sustainability and Environment. (Note that DSE have defined this report as "not published")
[88] URS (2008). Benefit cost analysis of changes to the regulation of 5 Star standards for stormwater management. Report for Melbourne Water.

review meetings, such as spatial financial data, was not made available to Bonacci Water during Stage II of the MAC.

The waterways group at MWC provided comprehensive information about Redevelopment Services Schemes (RSS) and Development Services Schemes (DSS). This information was incorporated in the dynamic economic analysis of the requirement for new trunk stormwater infrastructure throughout Greater Melbourne.

A RSS outlines the costs (average of about $125,000/ha) associated with trunk infrastructure required to mitigate the hydraulic and water quality impacts of increases in impervious areas due to the redevelopment and densification of urban stormwater catchments. Note that trunk infrastructure refers to infrastructure required at spatial scales greater than local streets that is subject to oversight by MWC.

The redevelopment schemes provide an understanding of the spatial variations in the costs of trunk stormwater infrastructure throughout Greater Melbourne. Note that these schemes do not consider the costs of flood mitigation and the costs of managing urban stormwater quality are less detailed.

The DSS specifies the costs of trunk infrastructure to manage stormwater in new developments. These schemes provide information on the costs of hydraulic (average of $32,581/ha) and water quality (average of about $15,000/ha) trunk infrastructure required to manage the impacts of stormwater runoff from new developments.

A range of additional reports on stormwater management were provided by MWC for use in the systems analysis, including Building for "Better Stormwater Quality" [89] and "Better Bays and Waterways" [90]. These reports were used to enhance understanding of current stormwater management practices and challenges in Greater Melbourne.

The RWAs provided selected data about the costs and operating rules of key infrastructure in each area that was incorporated within the systems analysis. For example, City West Water provided detailed information about the characteristics and operation of the Altona wastewater treatment plant.

Sequences of daily data from water demand or water pressure zones and from wastewater catchments were provided by MWC and the RWAs for use in the validation of the systems model. This process proved to be a difficult task due to a range of uncertainties about the quality of monitored data, aging monitoring systems, incomplete or missing data and inconsistencies in the recording of data between the different water authorities.

It is noteworthy that the water and sewage networks within Greater Melbourne are highly connected systems that include considerable co-dependencies and overlap across the different water authorities. The regulatory boundaries of the water authorities are inconsistent with the operation of water and wastewater systems. In addition, much of the recent historical information about the performance of the water and sewage systems was not available due to a range of problems with monitoring systems and storage of data.

Wherever possible, Bonacci Water utilised this "middle scale" spatial data to verify the performance

[89] Environment & Land Management and Ecological Engineering (2008). Building for better stormwater quality. How water sensitive urban design can improve water quality and enable reuse. Report for EPA Victoria.
[90] MWC and EPA (2009). Better Bays and Waterways.

of the systems model during the hindcasting process.

5.2 Previous calibration of water demands

The stakeholder inputs, assumptions and discussions during the MAC II process revealed considerable confusion about the simulation of long term behavioural water demands employed by Bonacci Water in Stage I. An overview of the calibration process used in Stage I that was the basis of additional calibration during Stage II are provided in this Section for clarity.

The previous report by Bonacci Water for Stage I of the MAC process combined total quarterly water use and demographic data from each LGA with climate data to derive long sequences of water use that responded to climatic and socioeconomic variability. Water use from 2006 was chosen as the base year for water demands in response to the availability of data and a lower level of water restrictions during that year. This allowed derivation of the base level behavioural household water demands in the systems model that then respond to climate, demographic and socioeconomic drivers, and water restrictions.

Quarterly water use data was previously provided for LGAs throughout Greater Melbourne by DSE for the 2006 calendar year. However, the usefulness of this data for understanding household water use behaviour was limited because this data is derived from rolling and combined quarterly metering programs with variable periods of observation. The total residential water use in each area is influenced by the unique demographic and socioeconomic characteristics. The Australian Bureau of Statistics (ABS) provides information about household size and the distribution of dwelling types for each LGA. This data was used to unlock the characteristics of water use for each household type and for various household sizes within a given area in Stages I and II for the MAC.

Average monthly indoor and outdoor water use was estimated for each location using published and peer reviewed relationships for behavioural water use.[91,92] This information was used to develop an initial estimate of central boundary conditions that guide the continuous simulation of behavioural water use. These behavioural relationships include a range of drivers including season, household size, rainfall, dryness, population growth, income and temperature.

A combination of the central boundary conditions of indoor and outdoor water use, demographic and climate data was utilised to develop water use profiles for a variety of household sizes (one to five people) and types (detached, semi detached and units) in each area. Long daily records of temperature and rainfall at each location were combined with pluviograph (6 minute) rainfall records to create synthetic pluviograph records of suitable length for robust simulation of water use in the PURRS (Probabilistic Urban Rainwater and wastewater Reuse Simulator) model. A diurnal pattern was employed to disaggregate household water use into sub-daily time steps.

The sequences of water use for each location derived using continuous simulation in the PURRS model and quarterly water use records provided by DSE were used to calibrate the central boundary conditions to local conditions. Distributions of end uses of water provided by peer reviewed

[91] Coombes P. J., G. Kuczera and J.D. Kalma, 2000. A behavioural model for prediction of exhouse water demand, 3rd International Hydrology and Water Resource Symposium, 793-798, Perth, Australia.
[92] Cui L., M. Thyer., P.J. Coombes and G. Kuczera, 2007. A hidden state Markov model for identifying the long term dynamics of indoor household water uses. Rainwater and Urban Design 2007 Conference. Sydney Australia.

publications in the Yarra Valley Water region were also used in the simulation of household water use.[93] The process of generating and simulating behavioural water demands is shown in Figure 5.3.

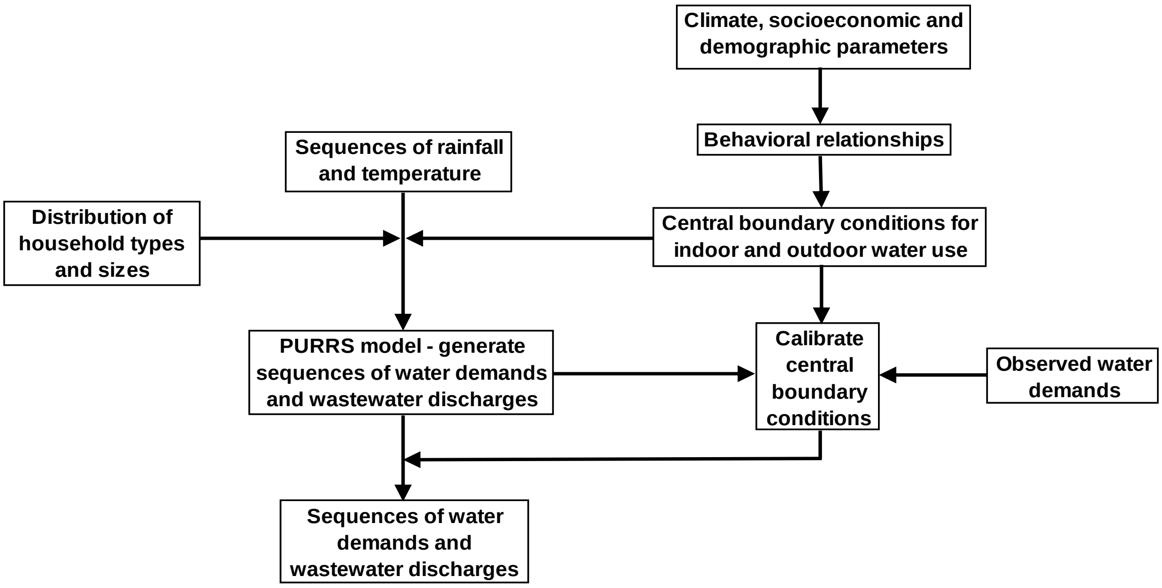

Figure 5.3: Process for continuous simulation of behavioural water demands

Figure 5.3 highlights that the behavioural water demand process employs long sequences of climate data and central boundary conditions that govern the behavioural influences on water use. The process also considers the local distribution of demographics (household type and size) to generate long sequences of water demands.

The calibration process for the model compares the simulated water demands to observed water demands at the timescale of the observed water demands and adjusts the central boundary conditions. This process was employed during Stages I and II of the MAC.

5.3 The hindcasting and validation process

Following the extensive stakeholder, data collation and collection exercises, a detailed validation of systems model was carried out at three scales. As previously discussed, the systems model of Greater Melbourne includes the different behaviours of the water cycle at different scales including the lot, middle and regional scales.

The systems model for Greater Melbourne was created in 2006 and continuously developed during the period prior to Stage I of the MAC process using data provided by a wide range of agencies. A limited amount of additional data was provided during Stage I of the MAC process that was employed to enhance the model. As discussed in the previous Section, the base water demands used in the model were calibrated to observed water use from 2006. Nevertheless, insufficient information was provided during the first Stage of the MAC process to completely verify the behaviour of systems model.

[93] Roberts P. (2006). End use research in Melbourne suburbs. Water. Australian Water Association. 51-55.

Verification or, if necessary, calibration to observed sequences of events from the past was carried out during Stage II of the MAC process to achieve the highest level of confidence in the systems model. As such the systems model was used to hindcast the behaviour of the Greater Melbourne system for the period from 1990 to 2010. This process was used to examine the model performance for a range of known events, including

- Water levels at key storages
- Total water demands at key locations in the system
- Inflows to wastewater treatment plants

The total water demands of the Greater Melbourne system and events that had a major influence on the hindcasting process are presented in Figure 5.4.

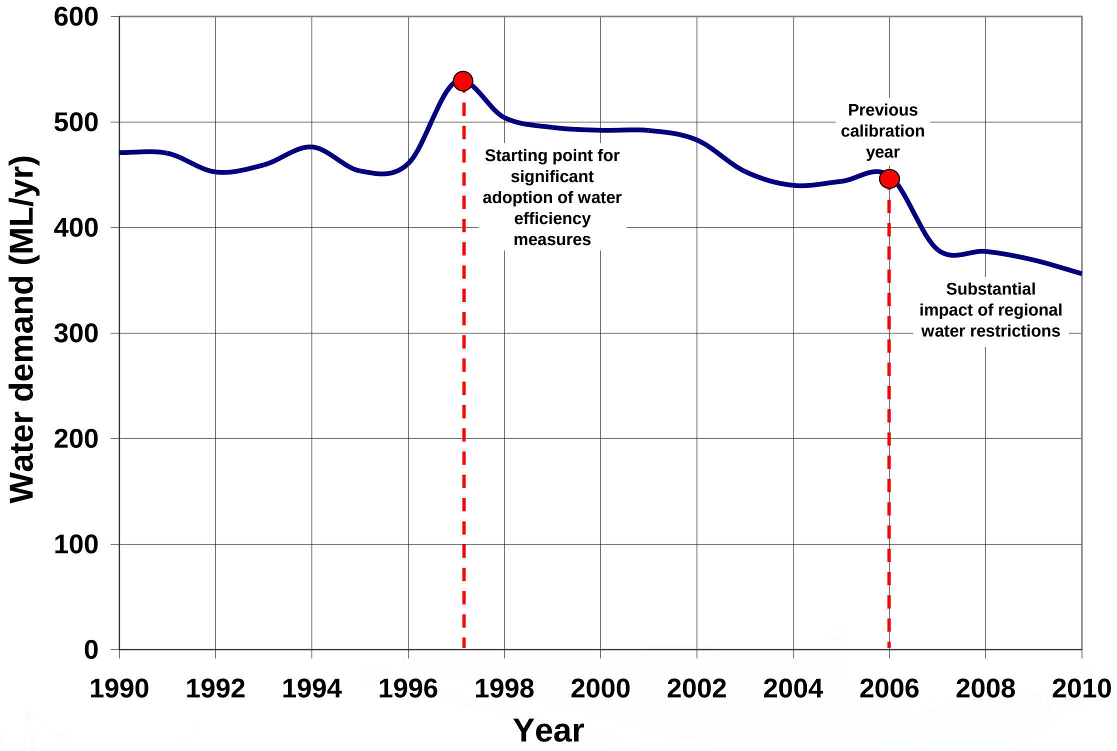

Figure 5.4: Hindcasting process

Figure 5.4 reveals that total water demands have varied substantially throughout the period from 1990 to 2010. The highest water demands were experienced in 1997 during a period of higher water use behaviour and the systems model was calibrated to water demands in 2006 that represented a period of relatively lower water use. In addition, the Greater Melbourne region was subject to ongoing drought and high levels water restrictions during the period 2006 to 2010 that significantly modified total water demands. Note that the Greater Melbourne region is also subject to considerable population growth during the hindcasting period.

It was clear that the hindcasting process required additional processes in the systems model to account for past behaviour, in particular:

- Use of a factor to transform more efficient water using behaviours in 2006 to less efficient water using behaviours during the 1990s. This hindcasting process indicated that a multiplier of 1.42 was required in the water demand equations to allow the model to successfully replicate past water use.
- The gradual adoption of significant water efficiency that commenced in 1997. Water efficient appliances and rainwater harvesting were adopted in half of all new and redeveloped dwellings during the period 1997 to 2010. This parameter was named BAU-efficiency.
- Parameters that accounted for the regional impacts of dryness, higher temperatures, wet weather and smoothing effect of the distribution system on daily water demands were included.

The systems model used in the hindcasting process also included the additional information and data provided in the stakeholder process. Wastewater discharges to the Western and Eastern wastewater treatment plants were also used to derive reductions in indoor water use during water restrictions as shown in Table 5.5.

Table 5.5: Reductions in indoor water use derived from wastewater discharges

Year	Savings (ML/day)	Savings (%)
2002	19	2
2003	44	5
2004	39	4
2005	97	10
2006	110	12
2007	213	23
2008	219	23
2009	239	25
2010	190	19

Table 5.5 shows that water restrictions and behaviour change programs produced considerable reductions in indoor water use. Note that the calibrated water demand model used to derive reductions in indoor water use included the incremental adoption of water efficient appliances. This information was used to derive the rules for water restrictions used in the model as shown in Table 5.6.

Table 5.6: Regional water restrictions derived from the hindcasting process

Total Water storage (%)	Reduction in water use (%)	
	Indoor	Outdoor
55		
	5	20
44		
	10	50
39		
	17	70
32		
	23	100
0		

Lot or local Scale

Performance of the water cycle at the lot scale was continuously simulated using the PURRS model that includes climate and behavioural inputs for a range of different household types and sizes. The scale transition framework within the systems model was used to combine the lot scale behaviour using demographic information for each LGA. The predicted and observed residential water demands in 2006 for selected LGAs are presented in Figure 5.5.

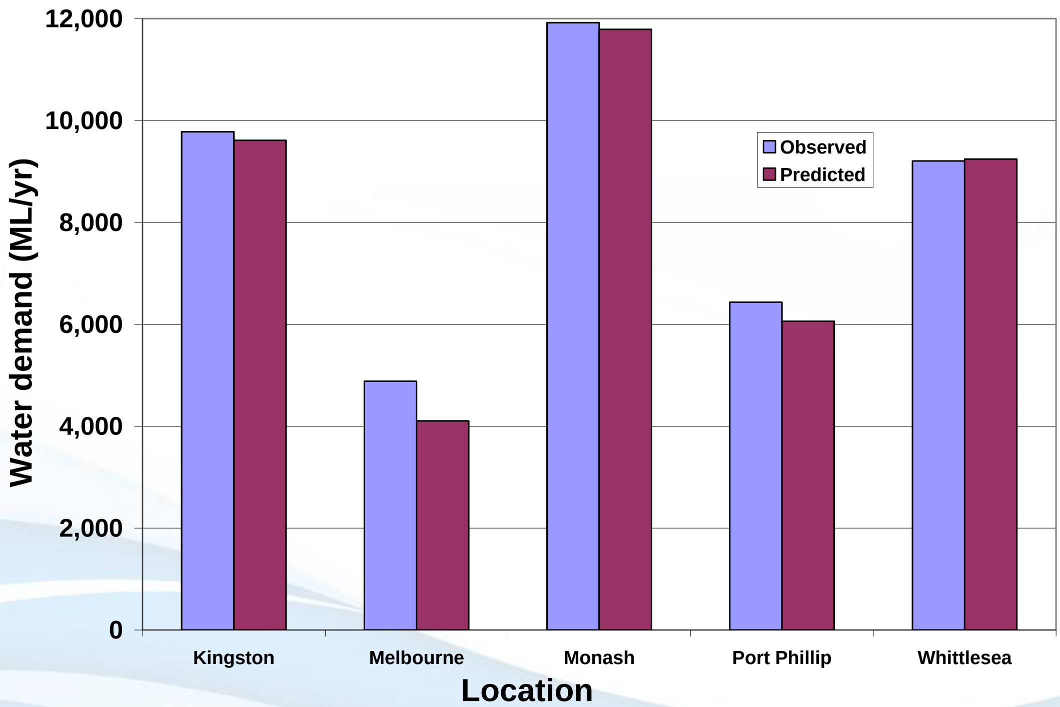

Figure 5.5: Verification of residential water demands for 2006

Figure 5.5 demonstrates that the systems model was able reproduce the local residential water demands throughout Greater Melbourne in 2006. This outcome provides a good example of the capability of continuous simulation methods that allow interrogation and collation to reproduce water demands for the required time period and interval.

The predicted and observed total water demands for selected LGAs in 2010 are presented in Figure 5.6.

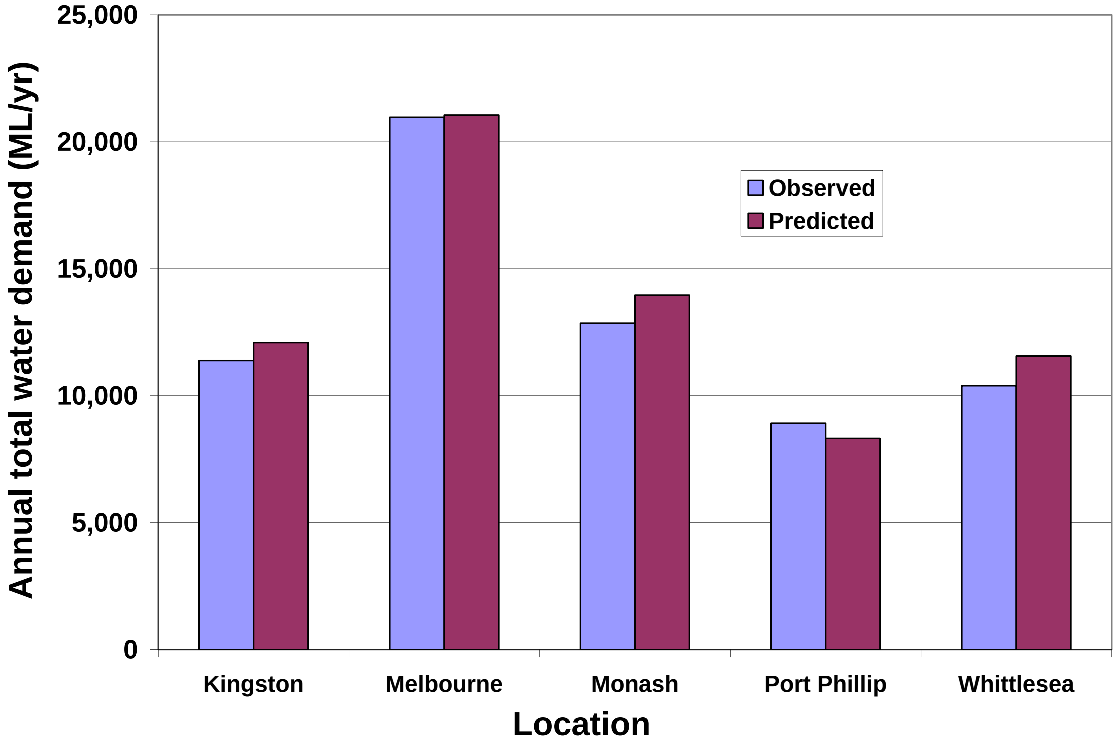

Figure 5.6: Verification of total annual water demands for each location in 2010.

Figure 5.6 shows that the systems model also generated similar total annual water demands to the observed water demands in each LA. This result also validates the performance of the behavioural water demand algorithms and the framework for water restrictions used in the systems model.

Note that the systems model also includes losses in the water distribution network and the local water use data provided by the RWAs is reported for calendar years. This may be an explanation for the small differences between observed and predicted water demands at some locations. In any event, the prediction of the local annual water demands is less than ± 2% different to observed demands for most locations.

Middle scale

The middle scale is defined by pressure reservoir, discrete urban water supply or wastewater catchments. Water cycle sequences at this scale are generated using a transition model which scales up the local results and converts them into relevant input files in the large scale and regional simulations.

Verification of results at this scale within the systems model was not required as lot scale simulations were calibrated and scaled up to LGA based data, and the entire systems model was calibrated at the regional scale. Nevertheless, validation at this scale was performed to provide additional confidence in the spatial and temporal performance of the model at a scale relevant to water retailers. Note that a range of inadequacies with the data provided by the RWAs (See Chapter 6) limited the opportunities for this type of verification.

Middle scale verification process

The middle scale verification or calibration process included the following steps:

- Combine gauged data using zone formulas provided by RWAs to determine water demands in each pressure zone
- Combine water demands from pressure zones to determine water demands for LGAs. The LGA formulas were derived using GIS analysis of LGA and water zone boundaries.
- Check observed data using total annual demands provided for 2009/2010 year.
- Correct observed data wherever possible to remove observation and storage errors
- Calibrate the transition framework within the systems model at each LGA to observed water demands using behavioural and climate parameters

The relationship employed to generate calibrated water demands (CalDem) for each LGA from the predicted demands (DEM) produced by the transition framework and observed water demands is:

$$CalDem = Hol1.Hol2.\left(a + b\left[Temp - avetemp \right] dry - c\left[\frac{Rain}{averain} \right] \right) Dem \qquad \text{............5.1}$$

where the parameters are:

- BAU-efficiency is the annual proportion of dwellings that adopt higher efficiency appliances and outdoor use, and rainwater harvesting from 1997 (not included in equation),
- Hol1 is the increase or decrease in water demand for the December, January and February period,
- Hol2 is the increase or decrease in water demand for the November and March period,
- a is a multiplier to account for differences in population or zone boundaries and water use in different eras,
- b is a multiplier to account for the impact of dryness and temperatures above daily average maximum, and
- c is a multiplier to account for days with higher than daily average rainfall.

Note that the BAU-efficiency parameter is used in the transition framwork that also includes equation 5.1 in the calibration process. This process accounts for the magnitude of daily water use that is impacted by different water efficiency regimes and climate.

The smoothing of water demands in the system created by the variable timing and alignment of lot scale demands, and the impacts of storage throughout water distribution networks is captured using the climate parameters.

Melbourne – An example

The Melbourne LGA is supplied with water via the Preston Reservoir by the retail water authorities City West Water (CWW) and South East Water (SEW). Each RWA authority provides water from Preston Reservoir to a proportion of the Melbourne LGA and other LGAs as shown in Figure 5.7.

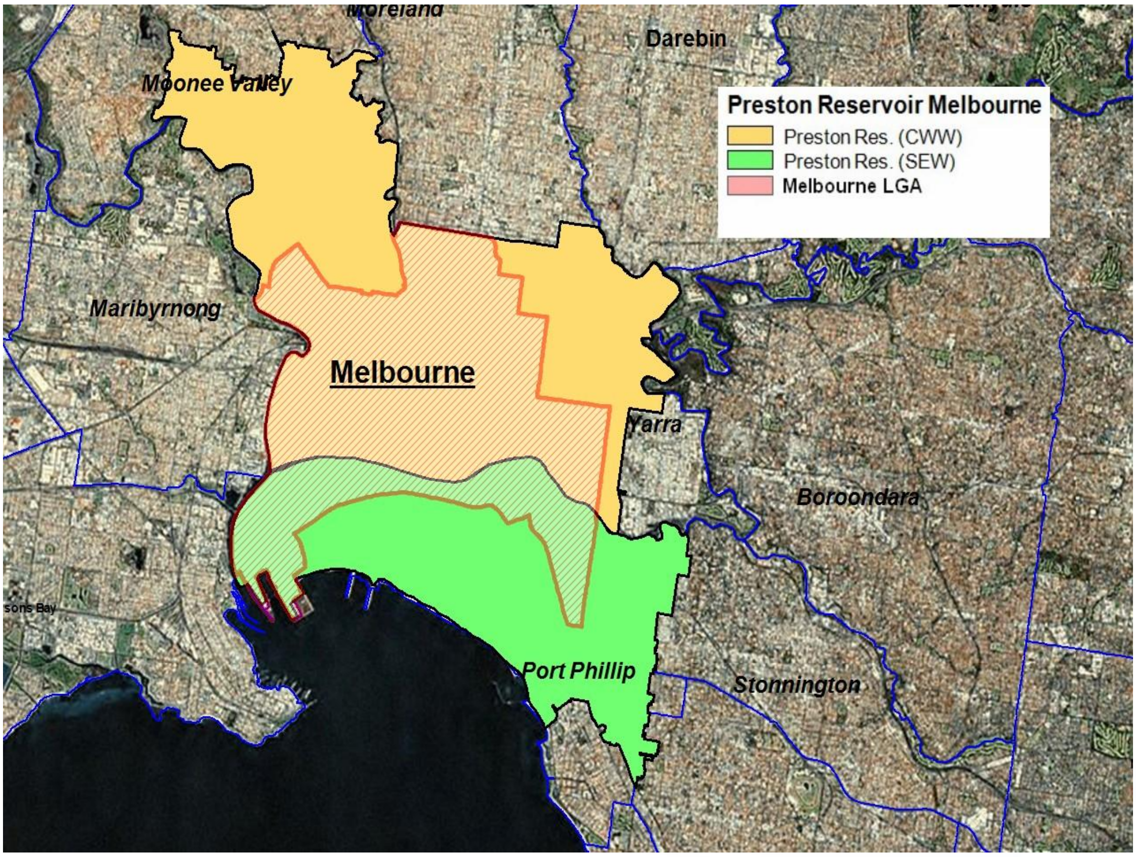

Figure 5.7: Provision of water from Preston Reservoir to Melbourne LGA by CWW and SEW

Figure 5.7 highlights that the Melbourne LGA is supplied by two RWAs and the LGA is a smaller proportion of the zones supplied from Preston Reservoir for each RWA. In addition, determination of the daily water supply from Preston Reservoir is the product of a zone formula involving 10 flow gauges for SEW and 27 flow gauges for CWW.

The process to derive daily water supply for the Melbourne LGA highlights a difficulty encountered using the data from the water distribution networks throughout Greater Melbourne. Missing or incorrect data at any of the 37 gauges used to determine water supply to Melbourne from Preston reservoir diminishes the ability to understand the spatial characteristics of water supply.

The determination zone formulas were also complicated by ownership of gauges by multiple authorities with each authority using different naming conventions for the same gauges.

Considerable effort was required to develop the water daily supply from Preston Reservoir by each authority presented in Figure 5.8.

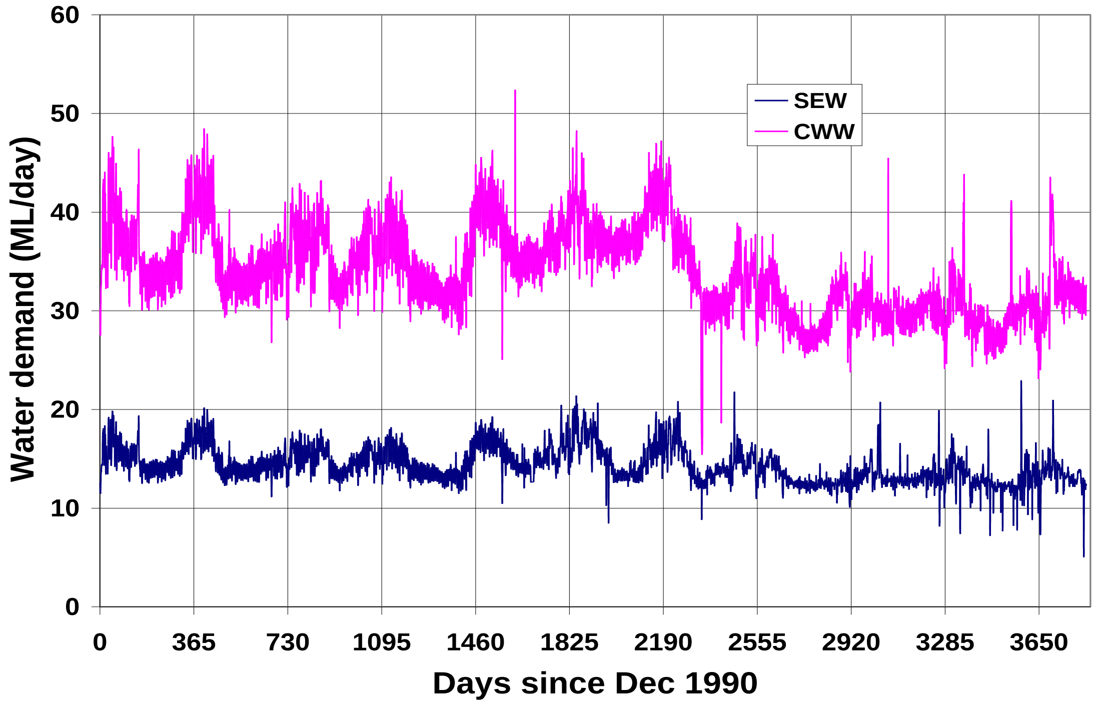

Figure 5.8: Water supply from Preston Reservoir to Melbourne LGA from South East Water and City West Water

The sequences of water supply presented in Figure 5.8 were combined and the periods with a minimum of missing data were used for the calibration of the water supply to Melbourne LGA. The values for the calibration parameters were derived as follows:

- BAU-efficiency = 0.5 (same as regional calibration)
- Hol1 = 1.1
- Hol2 = 1.04
- a = 1.42 (same as regional calibration)
- b = 0.001
- c = 0.005

Importantly, the calibration process verified the values for adoption of water efficiency and for the multiplier of water demand to account for past water using behaviours (a) derived from the regional calibration. The Melbourne LGA is also subject to increases in water demands during holiday periods.

Verification of the daily and monthly water demands for the Melbourne LGA is presented in Figures 5.9 and 5.10 respectively. Figures 5.9 and 5.10 demonstrate that the systems model was able to generate daily and monthly water demands that were consistent with regimes of the observed demands. Importantly the model replicated the seasonal regimes in water demands.

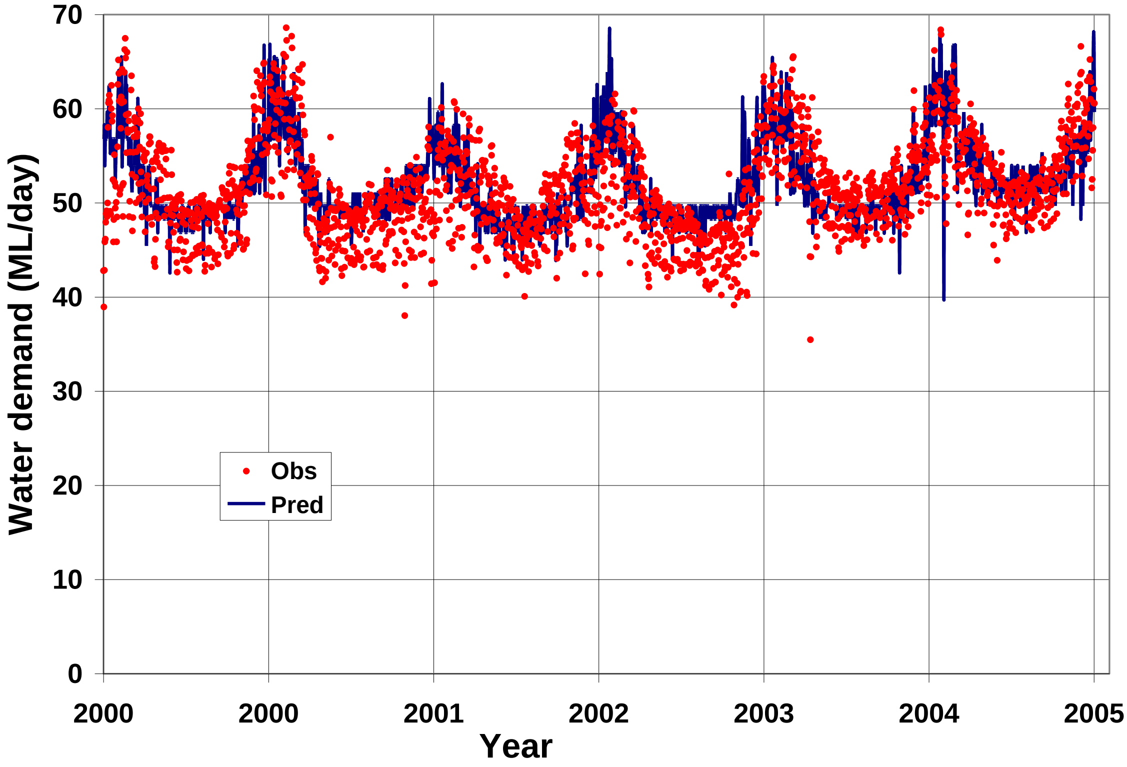

Figure 5.9: The predicted and observed daily water demands for the Melbourne LGA

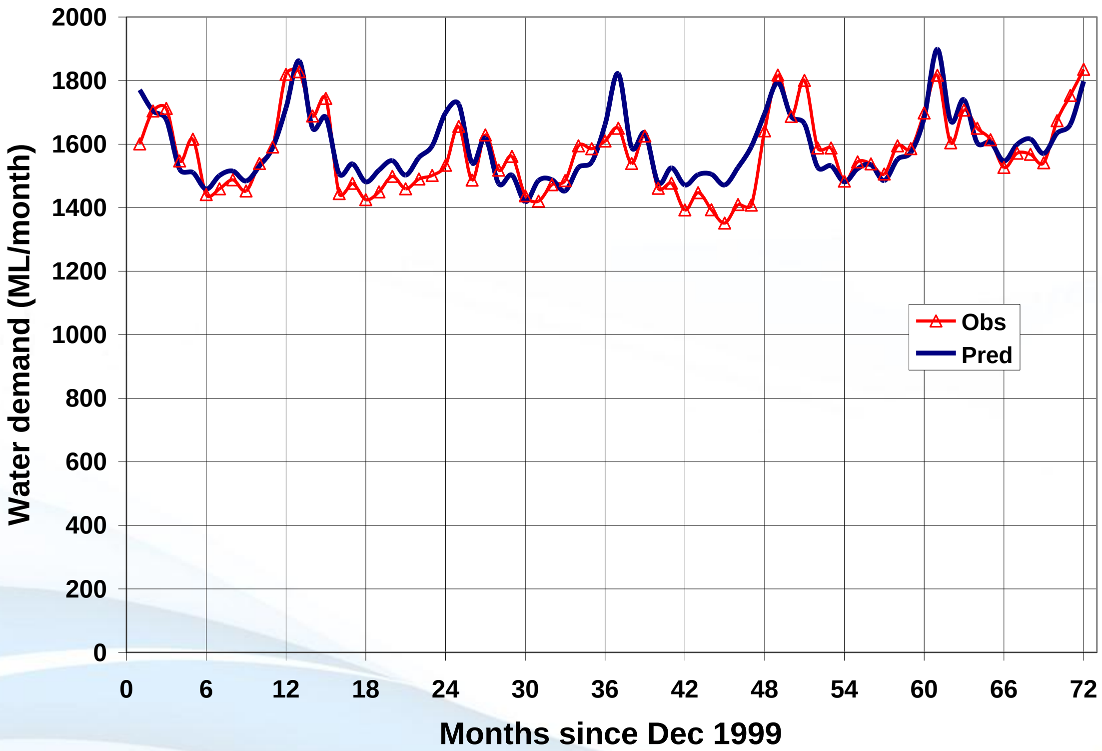

Figure 5.10: The predicted and observed monthly water demands for the Melbourne LGA

The predicted daily and monthly water demands are compared to observed water demands in the scatter plot presented in Figures 5.11 and 5.12 respectively.

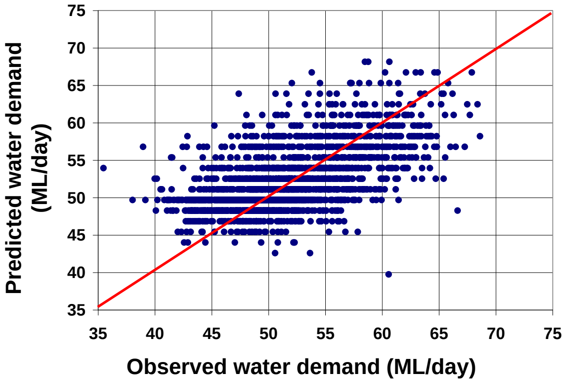

Figure 5.11: Scatter plot of predicted and observed daily water demands for the Melbourne LGA

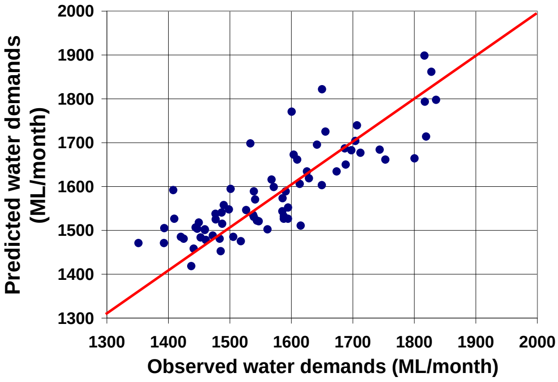

Figure 5.12: Scatter plot of predicted and observed monthly water demands for the Melbourne LGA

The scatter of the results shown in Figures 5.11 and 5.12 demonstrates that the model did not generate any systematic bias in the prediction of water demands for the Melbourne LGA. The values for co-efficient of determination (R^2) were 0.35 and 0.7 for the predicted daily and monthly water demands.

The robustness of the systems model has been verified by the comparison of predicted and observed results at the Melbourne LGA. It is important to note that the systems analysis was able to reproduce the regimes and patterns of observed water demands. This outcome provides confidence in the overall accuracy of the systems model given that the systems model did not attempt a detailed simulation of the water distribution networks at the middle scale and the uncertainties associated with the observed data.

Hume – An example

The Hume LGA is supplied with water via the Greenvale, Mt Ridley, Craigieburn, Gladstone Park and Somerton Reservoirs by CWW and YVW. A cumulative total of 37 gauges were utilised in the five zone formulas to define the observed daily water use at Hume. Note that this location is subject to considerable missing data. The values for the calibration parameters were derived as follows:

- BAU-efficiency = 0.5 (same as regional calibration)
- Hol1 = 1.1
- Hol2 = 1.0
- a = 1.42 (same as regional calibration)
- b = 0.001
- c = 0.005

The calibration process again verified the values for the adoption of water efficiency and for the multiplier of water demand from the regional calibration. The Hume LGA is also subject to increases in water demands during holiday periods. Verification of predicted daily and monthly water demands for the Hume LGA is presented in Figures 5.13 and 5.14 respectively.

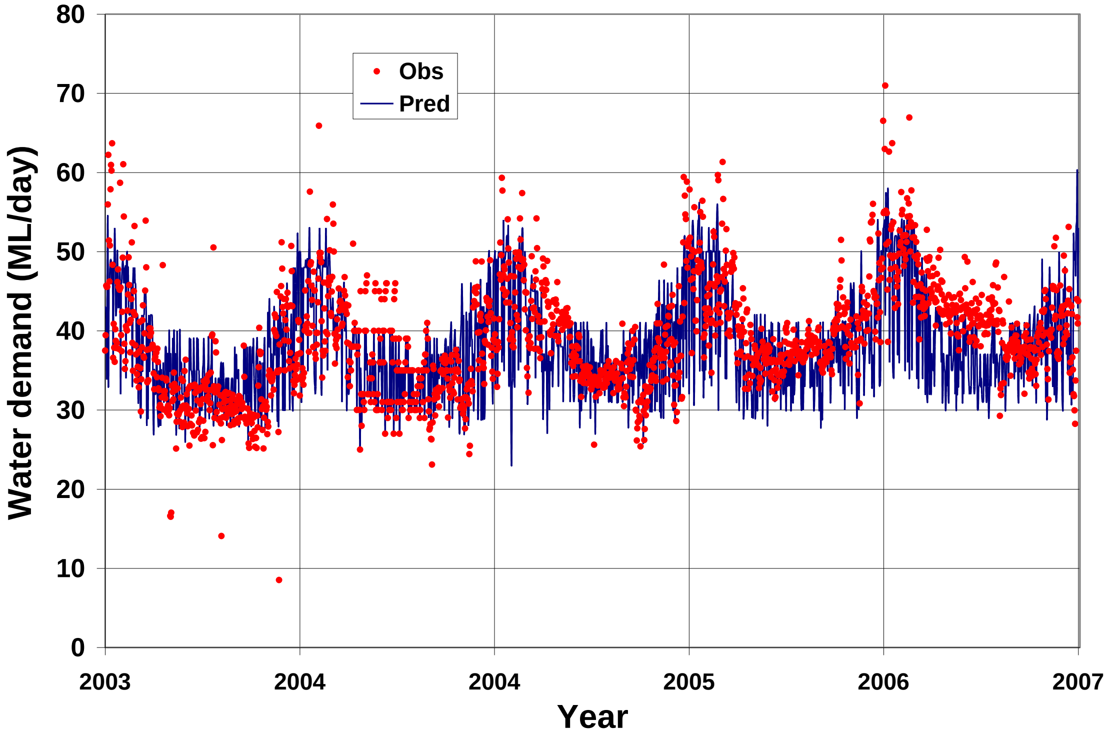

Figure 5.13: Calibration of the predicted and observed water demands for the Hume LGA

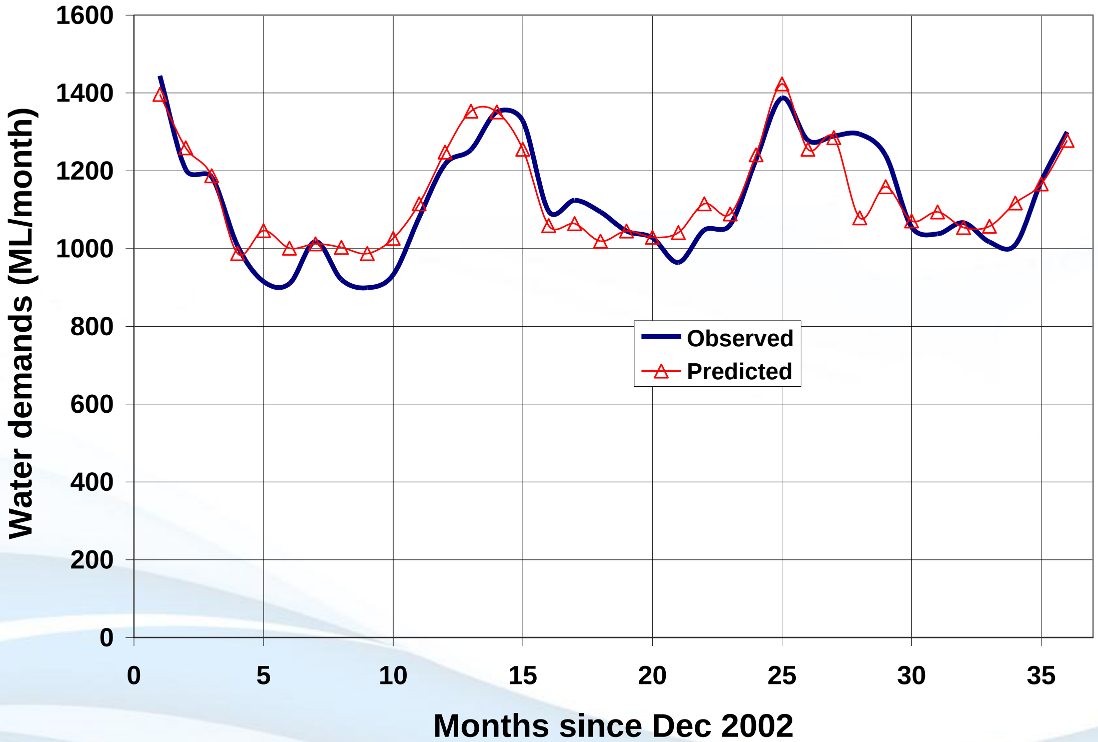

Figure 5.14: Calibration of the predicted and observed water demands for the Hume LGA

Figures 5.13 and 5.14 highlight that the systems model generated water demands for the Hume LGA that have similar magnitudes and regimes as the observed demands. The predicted daily and monthly water demands are compared to observed water demands in the scatter plot presented in Figures 5.15 and 5.16 respectively.

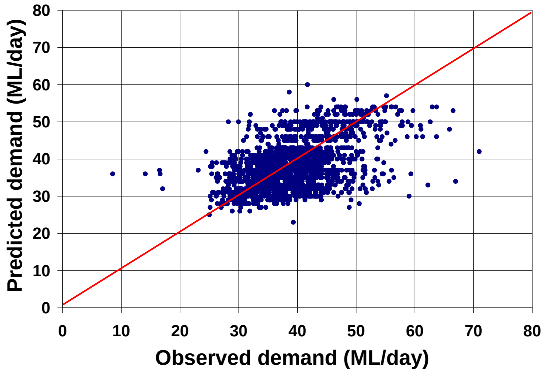

Figure 5.15: Scatter plot of predicted and observed daily water demands for the Hume LGA

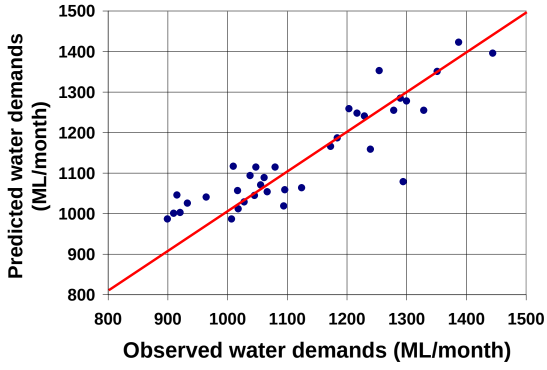

Figure 5.16: Scatter plot of predicted and observed monthly water demands for the Hume LGA

The scatter of the results shown in Figures 5.15 and 5.16 demonstrates that the model did not generate any systematic bias in the prediction of water demands for the Hume LGA. The values for co-efficient of determination (R^2) were 0.30 and 0.79 for the predicted daily and monthly water demands.

The results of the middle scale processes presented in this Section highlight that the systems analysis was able to provide similar magnitudes and regimes of water demands as the observed data within the Greater Melbourne system.

5.4 Regional Scale

The regional scale processes in the systems model simulates the behaviour of the entire Melbourne system including water supply, wastewater discharges and stormwater runoff. Note that the model only considers stormwater runoff from urban areas. Sequences of water, wastewater, stormwater and river flows generated by the systems model are linked to networks and nodes in the WATHNET model. The systems model was hind cast for the period 1990 to 2010 using the previous 2006 calibration period as central boundary condition. Verification of the systems model using hindcasting indicated some changes to the demand processes in the original model:

- Modified water restriction regimes
- Modified uptake of rainwater tanks, water efficient appliances and gardens

Hindcasting also revealed the changes to water cycle processes in the original model including:

- Modified water extraction and transfer rules
- Modified supply processes including the Yarra Balance flows
- Anecdotal advice on how storages were operated at various times

This process generated considerable insights into the actual operation of the water system for Greater Melbourne. Daily sequences of total dam storage generated by the systems model are compared to observed total dam storage in Figure 5.17.

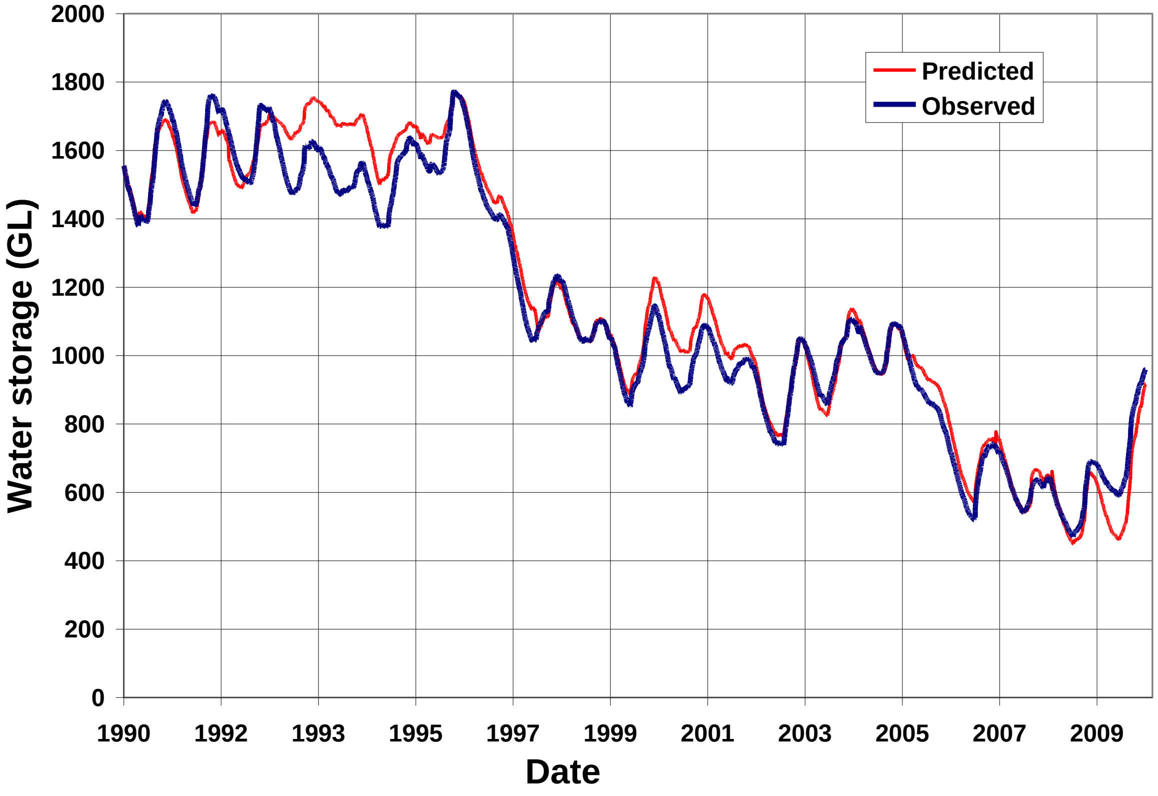

Figure 5.17: Verification using sequences of predicted and observed total dam storage

Figure 5.17 verifies that the systems model was able to accurately reproduce the historical behaviour of the total water storages in the Greater Melbourne system. This indicates that the past daily balance of water demands, streamflows and system behaviour has been reproduced by the systems model for the entire Greater Melbourne region. Thus the performance of the systems model has been verified by the hindcasting process.

Sequences of predicted daily and monthly mains water demands for the region are compared to observed water demands in Figures 5.18 and 5.19 respectively.

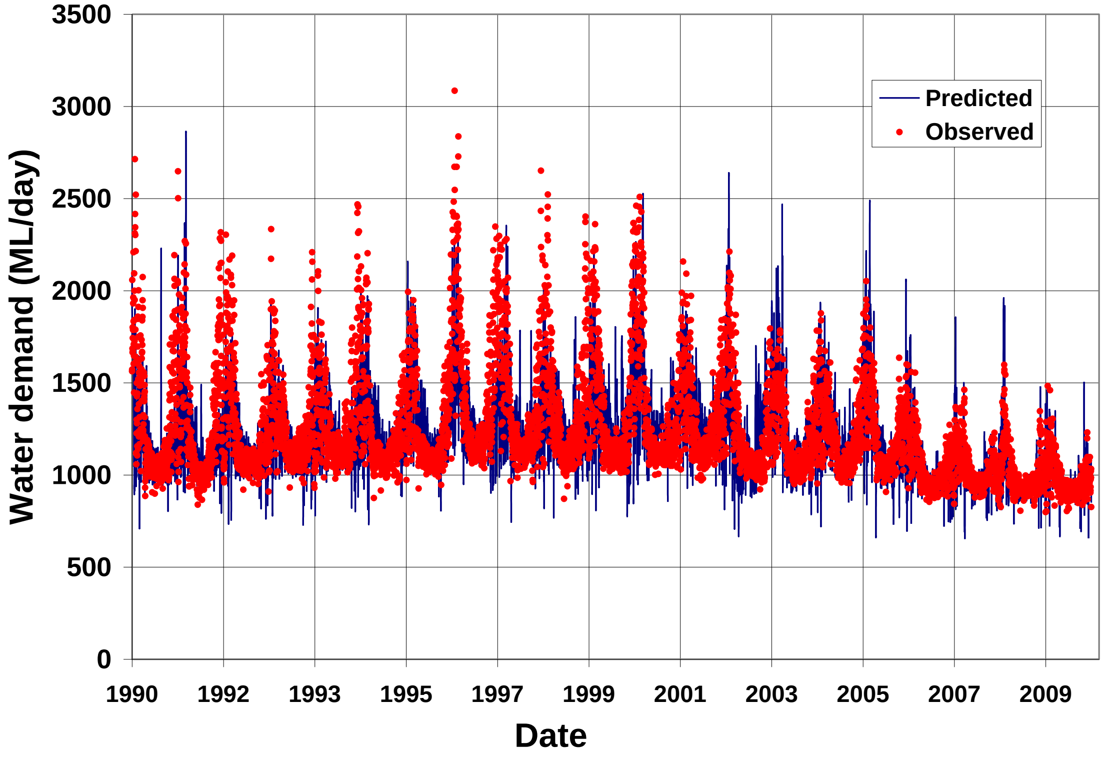

Figure 5.18: Predicted and observed daily potable mains water demand for the region

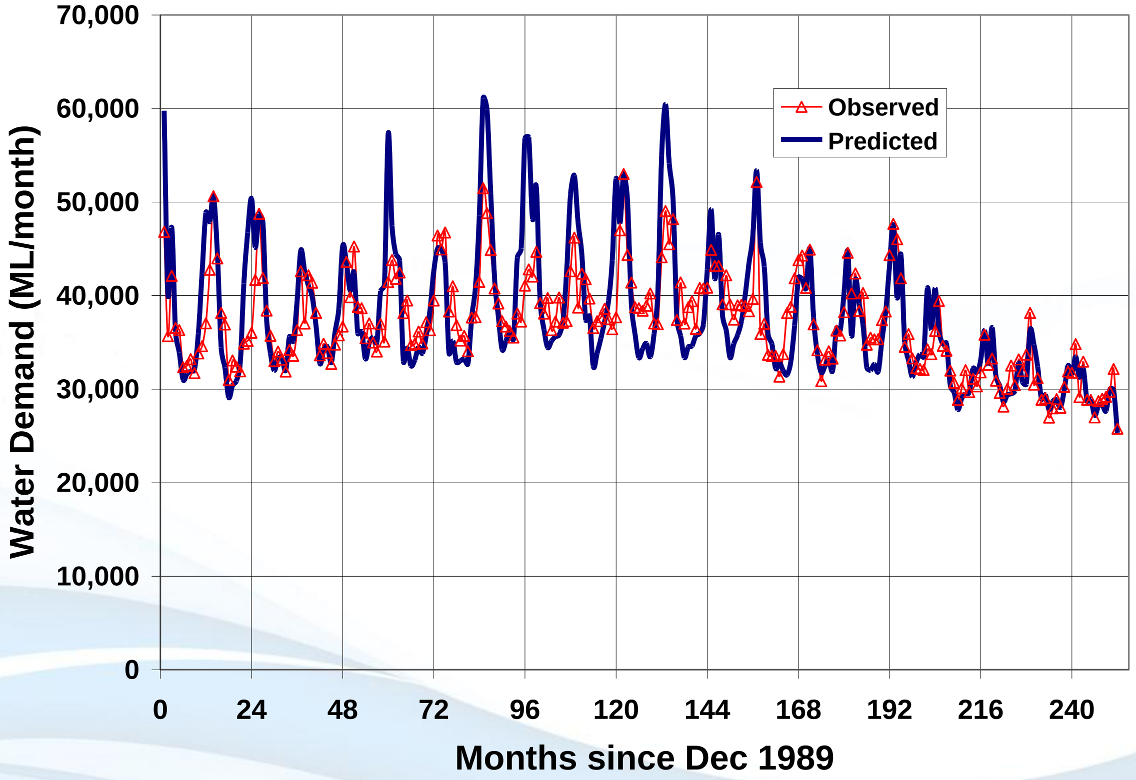

Figure 5.19: Predicted and observed monthly potable mains water demand for the region

Figures 5.18 and 5.19 reveal that the systems model produced similar sequences of potable mains water demands to the observed data for the Greater Melbourne region. Figure 5.19 demonstrates that the systems model provided similar monthly water demands to the historical observations. In particular, the predicted monthly water demands are in excellent agreement with observed water demands for the period after 2000.

The predicted daily and monthly water demands are compared to observed water demands in the scatter plot presented in Figures 5.20 and 5.21 respectively.

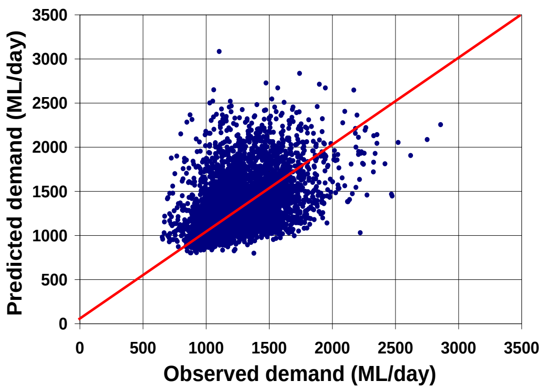

Figure 5.20: Scatter plot of predicted and observed daily water demands for Greater Melbourne

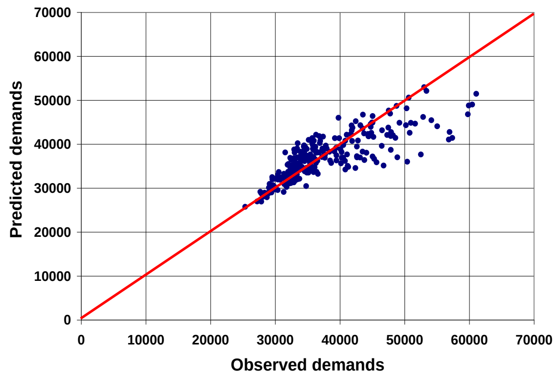

Figure 5.21: Scatter plot of predicted and observed monthly water demands for Greater Melbourne

The scatter of the results shown in Figures 5.19 and 5.20 reveal that the model did not generate any systematic bias in the prediction of water demands for the Greater Melbourne. The values for co-efficient of determination (R^2) were 0.30 and 0.67 for the predicted daily and monthly water demands. Note Figure 5.21 shows that the model has under-estimated some of the higher monthly water demands in the period prior to 2000. Otherwise, the model has successfully reproduced the observed water demands.

These results indicate that the demographic and climate processes within the systems model generated similar regimes of water demands to the historical demands for the Greater Melbourne. Moreover, the similar behaviour of the predicted water demands during the recent drought also indicates that restriction rules in the model are robust.

Wastewater verification process

The generation of regional wastewater discharges from each LGA was verified using the observed daily wastewater discharges at the Eastern and Western Wastewater Treatment Plants. Wastewater discharges from LGAs were combined for each wastewater treatment plant. Formulas that derive wastewater discharges from each LGA were established using GIS analysis of LGA and wastewater zone boundaries.

A transition framework for each LGA within the systems analysis was calibrated to observed wastewater discharges using behavioural and climate parameters. The calibrated wastewater discharges CalWW were derived at a function of predicted wastewater discharges WW and predicted stormwater runoff SW in the following equation:

$$CalWW = A.WW + Inf.SW \qquad \text{.......5.2}$$

Where A is a multiplier of wastewater discharges in the transition framework and Inf is the proportion of stormwater runoff that infiltrates into the wastewater systems for each LGA.

The calibration of wastewater discharges from each of the LGAs to the Eastern Wastewater Treatment Plant produced values for the multiplier A and the infiltration parameter Inf of 1.38 and 0.12 respectively.

The value for the multiplier A for wastewater runoff is similar to the multiplier used for the hindcasting of water demands to 1990 which indicates that wastewater calibration is consistent with the calibration of water demands. These results also indicate that 12% of stormwater runoff from urban areas infiltrates into the wastewater system discharging to the Eastern Wastewater Treatment Plant. The daily sequences of predicted and observed wastewater discharges to Eastern Wastewater Treatment Plant are compared in Figure 5.22.

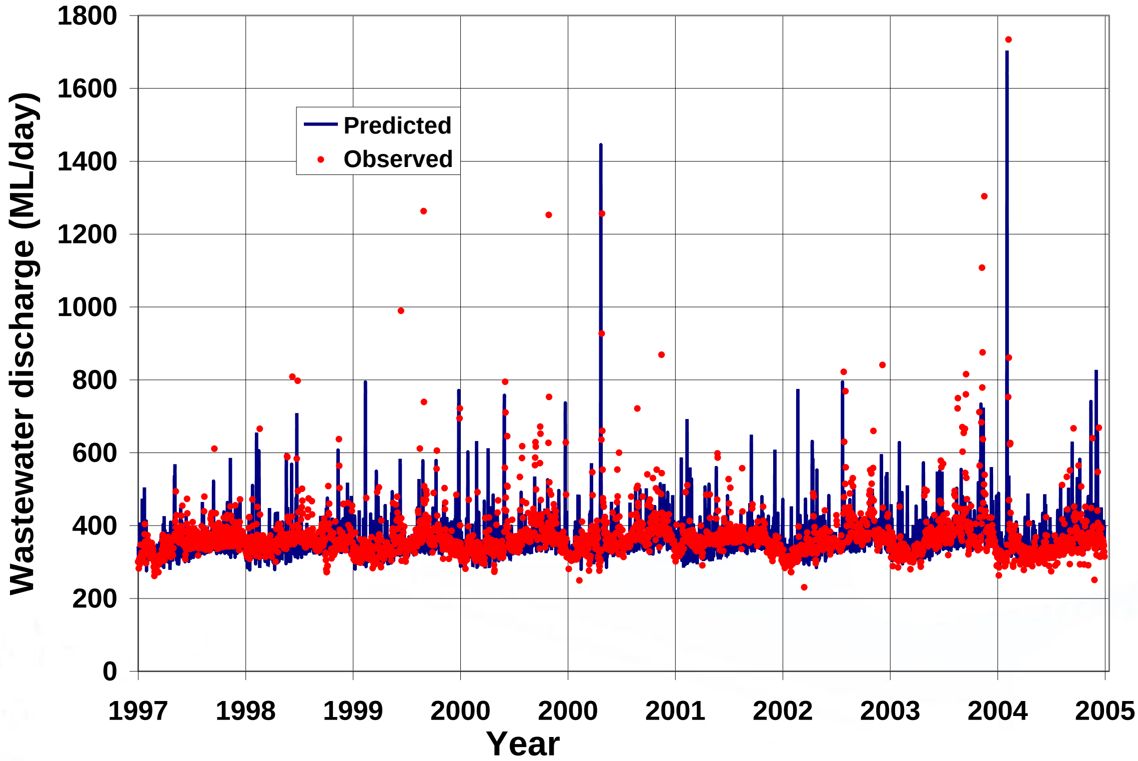

Figure 5.22: Predicted and Observed daily sewage flows into the Eastern Wastewater Treatment Plant

Figure 5.22 reveals that the systems model generated wastewater discharges to the eastern wastewater treatment plant that are similar to the observed discharges. Importantly, the predicted wastewater discharges display similar responses to rainfall to the observed data. This result ensures that the systems model has accurately captured the impacts of stormwater runoff on sewage flows.

The monthly sequences of predicted and observed wastewater discharges to eastern wastewater treatment plant are compared in Figure 5.23.

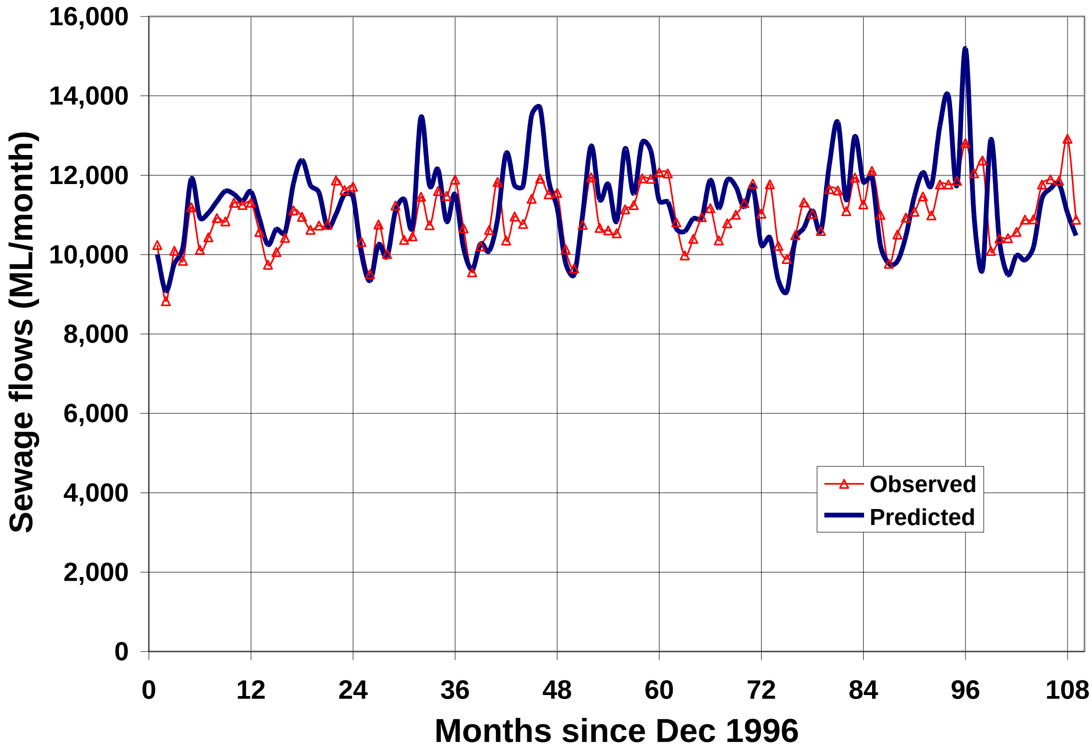

Figure 5.22: Predicted and Observed monthly sewage flows into the Eastern Wastewater Treatment Plant

Figure 5.22 demonstrates that the sequences of predicted monthly wastewater discharges to the eastern treatment plant are similar to the observed discharges. These results indicate that the systems model was successfully verified using observed data in the hindcasting process. The predicted daily and monthly sewage flows to the Eastern Wastewater Treatment Plant are compared to observed sewage flows in the scatter plots presented in Figures 5.23 and 5.24 respectively.

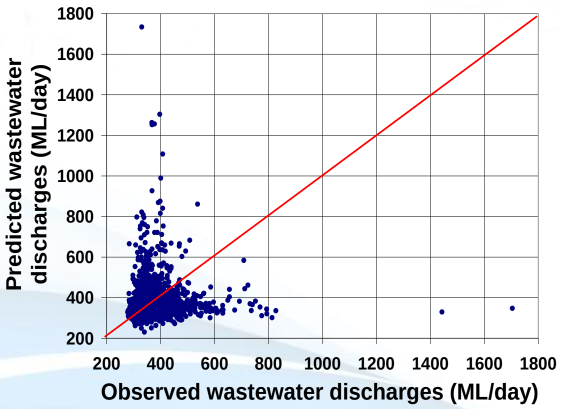

Figure 5.23: Scatter plot of predicted and observed daily sewage flows to Eastern Wastewater Treatment Plant

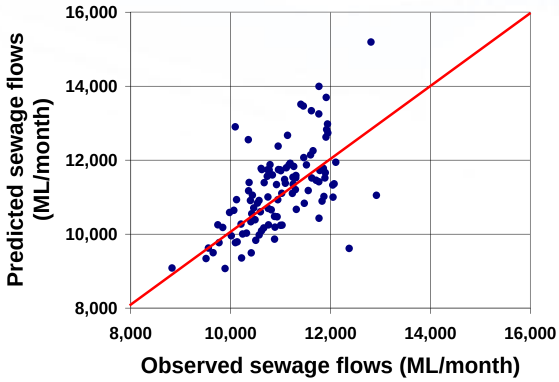

Figure 5.24: Scatter plot of predicted and observed monthly sewage flows to Eastern Wastewater Treatment Plant

Figures 5.23 and 5.24 shows that the prediction of wastewater discharges to the Eastern Wastewater Treatment Plant is relatively evenly distributed about the correlation line and is, therefore, free of systematic bias. The distribution of the points indicates that the magnitude of the predicted wastewater discharges is consistent with the observed discharges but the timing of the discharges is different at times. The systems model is focused on reproducing water balances throughout the region and has not been calibrated to reproduce local hydraulic effects such as variable timing of flows in the sewage system due to storage effects. The value of the co-efficient of determination (R^2) of 0.61 indicates that predicted monthly sewage flows have consistent magnitudes to observed flows.

The calibration of wastewater discharges from each of the LGAs to the Western Wastewater Treatment Plant produced values for the multiplier A and the infiltration parameter Inf of 1.47 and 0.09 respectively.

The value for the multiplier A for wastewater runoff is similar to the multiplier used for the hindcasting of water demands to 1990 which indicates that wastewater calibration is consistent with the calibration of water demands. The slightly higher multiplier indicates that base flow into the wastewater systems in the west is higher due to the influence of a higher groundwater levels and aging infrastructure as compared to impacts on the Eastern Wastewater Treatment Plant.

In contrast, these results indicate that 9% of stormwater runoff from urban areas infiltrates into the wastewater system discharging to the Western Wastewater Treatment Plant represent the lower infiltration rates of the predominately clay soils in the west. The daily and monthly sequences of predicted and observed wastewater discharges to Western Wastewater Treatment Plant are compared in Figures 5.25 and 5.26 respectively.

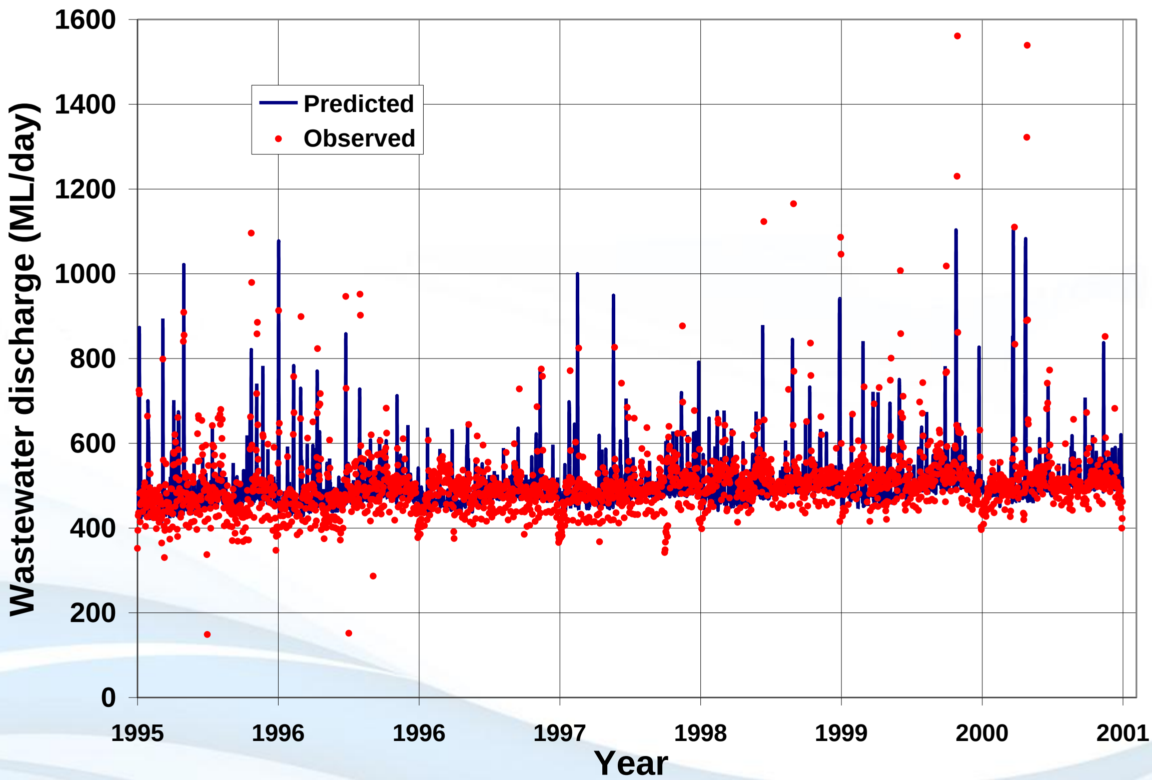

Figure 5.25: Sequences of predicted and observed daily flows into the Western Wastewater Treatment Plant

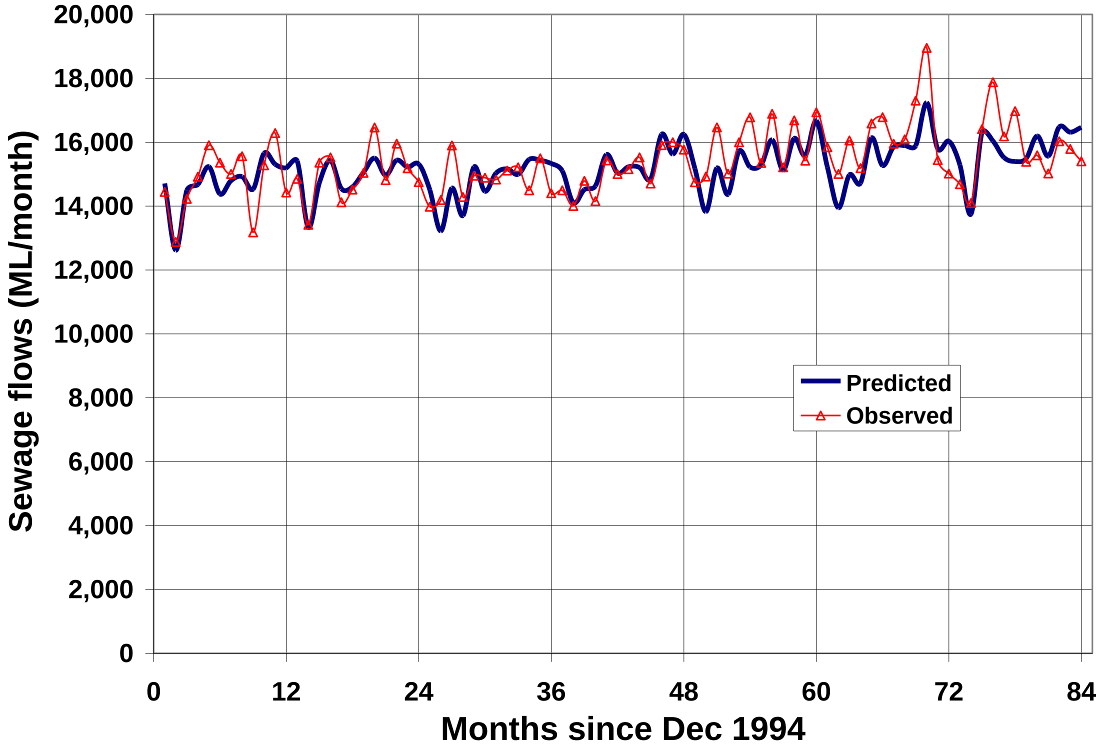

Figure 5.26: Sequences of predicted and observed monthly flows into the Western Wastewater Treatment Plant

Figures 5.25 and 5.26 reveal that the systems model generated sewage flows to the Western Waster Treatment Plant that were similar to the observed flows. Importantly, the predicted wastewater discharges displayed similar responses to rainfall as the observed wastewater discharges. The predicted daily and monthly sewage flows to the Western Wastewater Treatment Plant are compared to observed sewage flows in the scatter plots presented in Figures 5.27 and 5.28 respectively.

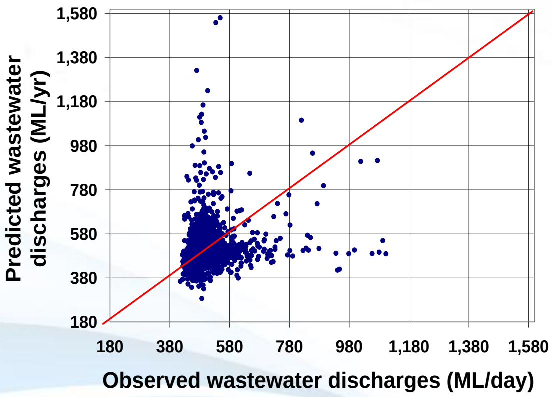

Figure 5.27: Scatter plot of predicted and observed daily sewage flows to Western Wastewater Treatment Plant

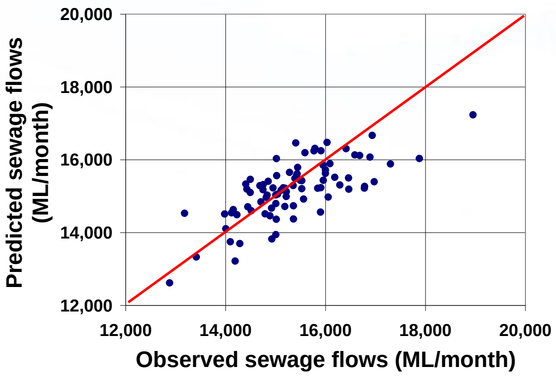

Figure 5.28: Scatter plot of predicted and observed monthly sewage flows to Western Wastewater Treatment Plant

Figures 5.27 and 5.28 demonstrate that the prediction of wastewater flows to the Western Treatment Plant are evenly distributed about the correlation line which indicated a lack of systematic bias. The distribution of the points indicates that the magnitude of the predicted wastewater flows is consistent with the observed flows but the timing of the discharges is different at times. The value of the co-efficient of determination (R^2) of 0.52 indicates that predicted monthly sewage flows have consistent magnitudes to observed flows.

These results indicate that the demographic and climate processes within the systems model generated similar regimes of sewage flows to historical flows for the Greater Melbourne.

5.4 Economics

The hindcasting process was also utilised to verify the key economic transactions within the biophysical systems model for the 2009/10 financial year. This financial year was chosen for verification to reflect the end of the hindcasting period and the commencement of the planning horizon used in this investigation.

Note that the systems model includes dynamic economic processes that account for the extension, renewal and operating costs of providing water and wastewater services to Greater Melbourne. The analysis also includes dividends and taxes paid to state government, and bulk charges paid to Melbourne Water.

The systems analysis includes the economic transactions at all of the water authorities including Melbourne Water. However, verification of the model accounted for the total costs of delivering services to Greater Melbourne – this is the total costs of the water retailers (excluding taxes and dividends) plus the bulk charges paid to Melbourne Water. It was assumed for the verification that the bulk charges paid to Melbourne Water were sufficient to allow provision of bulk services.

A wide range of published information was combined with data of variable completeness provided by MWC and the retail water authorities, including:

- Annual reports published by each authority [94,95,96,97],
- National performance report for each authority [98],
- Determinations by the Essential Services Commission [99], and
- Various information about asset management costs provided by each water authority.

The observed and predicted costs of providing water and wastewater services to Greater Melbourne are presented in Table 5.7.

94 City West Water (2011). Annual report 2011.
95 South East Water (2011). Annual report 2011-11.
96 Yarra Valley Water (2011). Annual report 2010/11.
97 Melbourne Water (2011). Annual report 2010-11.
98 NWC and WSA (2011). National performance report 2009/10 – major urban utilities.
99 Essential Services Commission (2008). 2008 final water price review. Determination for City West Water, determination for South East Water, determination for Yarra Valley Water and determination for Melbourne Water.

Table 5.7: Verification of the dynamic economic model using total annual costs

Water authority	Total annual costs ($m)		
	NWC and WSA	Annual reports	Predicted
City West Water	309.6	357.3	340.8
South East Water	457.9	398.5	430
Yarra Valley Water	547.7	613.2	580.2
Total	**1,315.3**	**1,368.9**	**1,351**

Table 5.7 demonstrates that the systems model provided reasonable agreement to the total annual costs for each retail authority and for the entire Melbourne system. It is noteworthy that the various publications provided a range of total costs for water and wastewater services. Note that the verification excluded the write down of assets and depreciation. In any event the systems model provided an accurate quantum of expenses for the entire system.

The distribution of costs in the systems model was verified against data provided by the National Water Commission (NWC) and Water Services Association (WSA) as shown in Table 5.8.

Table 5.8: Verification of the distribution of costs in the dynamic economic model

Water authority	Water costs ($m)		Wastewater costs ($m)	
	NWC and WSA	Predicted	NWC and WSA	Predicted
City West Water	184.6	189.7	125.0	128.4
South East Water	203.9	209.4	254.1	261.0
Yarra Valley Water	252.4	259.2	295.3	303.4
Total	**640.9**	**658.3**	**674.4**	**692.7**

Table 5.8 reveals that the systems model has successfully predicted the distribution of water and wastewater costs for each water authority.

5.5 Greenhouse gas emissions

Greenhouse gas emissions generated by the biophysical systems model were verified using data published by NWC and WSA for the 2009/10 financial year as shown in Table 5.9.

Table 5.9: Verification of greenhouse gas emissions in the systems model for the 2009/10 year

Source	Greenhouse emissions (tonnes)		
	Water	Wastewater	Total
NWC and WSA	123,689	348,894	472,583
Model	124,863	348,900	473,763

Table 5.9 demonstrates that the greenhouse gas emissions predicted by the systems model are consistent with the observations for the 2009/10 year. The distribution of greenhouse gas emissions predicted by the systems model is compared to observed results in Table 5.10.

Table 5.10: Verification of the distribution of greenhouse gas emissions in the systems model for the 2009/10 year

Water retailer	Water emissions (tonnes)		Wastewater emissions (tonnes)	
	NWC and WSA	Predicted	NWC and WSA	Predicted
City West Water	801	800	12,920	10,299
South East Water	6,092	6,098	29,819	28,640
Yarra Valley Water	10,030	8,853	23,719	18,270
Melbourne Water	107,940	107,938	282,442	291,685
Total	**124,863**	**123,689**	**348,900**	**348,894**

Table 5.10 reveals that the distribution of greenhouse gas emissions predicted by the systems model are consistent with the observed emissions as published by NWC and WSA.

5.6 Climate change

The systems model also includes climate processes. Incremental increases in average maximum daily temperature (0.025°C/year and 0.05°C/year) were used to generate climate replicates for the region to estimate the responses of local climate to a low and high emissions climate change scenario. The results for average maximum temperature, average potential evaporation, annual rainfall at Thomson Dam and inflows to Thomson Dam are shown in Table 5.11.

Table 5.11: Verification of the climate change processes in the systems model

Criteria	Average change			
	Temperature (°C)	Annual rainfall (%)	Evaporation (%)	Streamflow (%)
Predicted low emissions	0.85	-8.5	+3.9	-21
Predicted high emissions	2.05	-18.2	+8.7	-45
IPCC low emissions	0.5 to 1.5	+5 to -5	+4	0 to -30
IPCC high emissions	1.5 to 3.0	+5 to -15	+7	0 to -30
Melbourne drought	1.27	-18	+7	
Thomson Dam drought		-16		-30

Table 5.11 demonstrates that the systems model was able to predict the expected increases in average maximum temperature and potential evaporation, and reductions in annual rainfall depths and inflows to Thomson Dam. A summary of the latest results for 2050 from the IPCC's global climate models was provided by the Bureau of Meteorology (BOM).

The climate change replicates produced similar average results for average maximum temperature and potential evaporation to the estimates by CSIRO and IPCC.[100] The results for annual rainfall from the climate change replicates are more severe than the estimates from CSIRO. Nevertheless, these results are consistent with reductions in rainfall and inflows experienced during the recent drought.

The systems model provides similar or more conservative results than the estimates provided by CSIRO and IPCC.

5.7 Summary

A stakeholder, review and hindcasting process was utilised to obtain data and information that was not made available during Stage 1 of the MAC investigation. This process allowed enhancement of the systems model to include a considerable amount of additional data, local knowledge and operational rules. This information included:

- Water diversions to supply licensed irrigators, irrigation districts, external authorities and hydro-electricity,
- Additional knowledge about streamflow resulting in Yarra balance flows,
- Rules for operation of water and sewage networks,
- The distribution of water demands at each LGA,
- The latest population predictions for Greater Melbourne, and
- Comprehensive data and information about stormwater systems throughout Melbourne.

[100] Department of Sustainability and Environment (2008). Climate change in Victoria: 2008 summary

Inclusion of this additional knowledge in the systems model was aided by a high level of cooperation from the majority of the review panel and associated stakeholders. However, sufficient information and assistance was provided to substantially enhance the robustness and accuracy of the systems model.

Collection of data to enhance the middle scale processes in the systems model revealed considerable problems. The quality of monitored data from within the water and sewage networks was uncertain due to aging monitoring systems, incomplete or missing data and inconsistencies in the recording of data between the different water authorities.

Water and sewage networks within Greater Melbourne are highly connected systems that include considerable co-dependencies and overlap across the different water authorities. Regulatory boundaries of the water authorities are inconsistent with the operation of water and wastewater systems. Much of the recent historical information about the performance of the water and sewage systems was not available due to a range of problems with monitoring systems and storage of data.

The hindcasting process from 2010 to 1990 proved to be a successful process for enhancing the accuracy of the systems model and included the following amendments:

- Demand models were previously calibrated using the 2005/06 water year – calibration of water demands for the period 2010 to 1990 required a multiplier of 1.42 to account for an era of higher water use habits
- The calibration of water demands also involved adoption of significant water efficiency measures that commenced in 1997.
- Analysis of sewage discharges revealed that water restrictions created significant reductions in indoor water use throughout Greater Melbourne – these reductions were included in the systems model.

The systems model successfully reproduced local residential and total water demands at each LGA, the behaviour of regional storages, water demands and wastewater discharges. Analysis of middle scale processes also confirmed the spatial robustness of the systems model for water demands and wastewater discharges. Costs and greenhouse gas emissions in the systems model were also successfully verified against all available data. The systems model provided similar or more conservative results for the impacts of expected climate change than the estimates provided by CSIRO and IPCC.

6 System understanding and stakeholder engagement

This Chapter describes the key processes and institutional transactions associated with the systems modelling undertaken across the entire course of the MAC work to ensure that the lessons learnt are captured and applied to the planning and management of Melbourne's (and other Victorian cities) water systems.

Comprehensive understanding of a biophysical system supported by high quality data and engagement with key stakeholders is necessary to successful completion of a robust systems analysis. Application of systems analysis to sectors and locations where this approach has not previously been undertaken can present significant challenges. The challenges for an investigator include obtaining the necessary understanding of the system in a sector that is unfamiliar with this form of investigation.

The process of engaging in this type process can be highly demanding of the involved staff and require intense commitments of time from organisations. This impact is particularly likely for organisations that do not regularly interrogate their data for analytical or policy development purposes. In many cases organisations have to understand the different requirements and develop the necessary processes to prepare data to satisfy the specifics of a forensic analysis. The process of preparing operational and historical data for the rigours of this type of analysis is often not easily accommodated within the normal operations of water authorities. The more traditional types of analysis common to the water sector is reliant on discreet assumptions that in most cases limits the understanding of the dynamics of a specific system.

The LV MAC process represents a useful case study that details evolution of the investigation and the attitudes and behaviours that emerged. It also provides an important insight to the behaviours, attitudes and responses of the Victorian water sector to alternative water cycle management strategies.

As described in the Methods Section (Chapter 4), this study employed integrated systems analysis to understand the performance of alternative water cycle Options for Greater Melbourne. This unusual and demanding analysis is dependent on detailed inputs such as demographic profiles, and linked systems that account for water supply, wastewater discharge, stormwater runoff and environmental considerations.

The analysis technique (developed by Dr Peter Coombes over 30 years of research, investigation and practical application) has been designed to handle the dynamic nature of water systems and variations in the quality and quantity of data. This systems approach has been applied previously in a wide range of regions including the Hunter and Central Coast regions of NSW[101], Sydney[102], all of NSW[103,104],Melbourne[105] and Perth[106].

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[101]Coombes P.J., G.A. Kuczera, J.D. Kalma and J.R. Argue, 2002. An Evaluation Of The Benefits Of Source Control Measures At The Regional Scale', Urban Water, Vol. 4 pp. 307-320.
[102]Coombes P.J., 2005. Integrated water cycle management: analysis of resource security. Water.Australian Water Association.Vol. 32 pp. 21- 26.
[103]Coombes P.J., 2007. Energy and impacts of rainwater tanks on the operation of regional water systems.Australian Journal of Water Resources.Vol. 11, No. 2. pp. 177 - 199.
[104]Beatty, R., Hadiardja, G., Pryor, E., Kozarovski, P., Coombes, P. & Jewell, C. 2009, A regional approach to drought proofing central NSW, MWH, Kozarovski and Partners, Bonacci Water, C.M.Jewell& Associates.

Information and understanding from a wide range of sources, disciplines and geographic scales was incorporated into the analysis. This process involves a range of stakeholders including water authorities, Victorian Government agencies, regulators, Australian Government institutions and international organisations. The analysis technique used in this investigation provides a robust and proven process to overcome the many issues that emerge from developing new understanding of long established challenges.

This investigation included a broad range of human interactions, individual responses of employees and organisations that proved to be difficult to manage especially for an outside consultancy. The specific areas of concern related to the quality and the detail of data requirements that were essential inputs for the systems analysis as required by the MAC in a timely manner. The process of identifying and collecting this essential data exposed a potential weakness of the Victorian water industry – it appears that adequate spatial and temporal understanding of the Greater Melbourne system has not been previously established.

There also seemed to be a lack of capability within most organisations in handling these types of requests in a timely and effective manner. This issue was more significant for collection of historical data. As this data will be a foundation of any future reform of systems and operations there is need to address this issue. This investigation discovered the issues relating to collection and maintenance of data more by accident than by design. But there is a wider issue here which will need to be addressed – the limited availability and use of spatial and temporal data is a barrier to development of innovative strategies and establishment of competion. It has to be stressed that the MAC process and the required system analysis introduced technical and methodological approaches which most authorities had not been exposed to in the past and some of delivery issues may be related to a hesitation of staff to enter new territory.

6.1 MAC Stages I and II

MAC Stage I

The Ministerial Advisory Council (MAC) was appointed in January 2011 and Dr Peter Coombes with Bonacci Water were subsequently engaged to provide systems analysis and advice. A critical element of the process since inception of the MAC was the understanding the Greater Melbourne system, obtaining data and sharing insights of investigations. This investigation had two clear phases – MAC Stage I and MAC Stage II.

The purpose of MAC Stage I was to provide a systems analysis of the water cycle within Greater Melbourne. A holistic analysis of the existing system was presented in an independent and transparent manner. The existing system was compared to a series of alternative Options. This enabled identification of the impacts and benefits of alternative future states and an understanding of the processes to implement alternatives. The MAC Stage 1 process was completed within a very demanding timetable. Only four weeks were allocated to complete the investigations for Stage 1 and present the findings. The MAC was involved in considerable stakeholder engagement during this

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[105]Bonacci Water and Urban Water Cycle Solutions (2008).Rainwater tank evaluation study for Greater Melbourne. Report for the Department of Sustainability and Environment.
[106]Coombes P.J and S. Lucas, 2006. Towards Sustainable Water Strategies in the Perth Region of Westerns Australia: Inclusion of Decentralised Options. 2nd International Hydropolis Conference.Engineers Australia.Western Australia.

period. However the investigation for the first Stage of the MAC process by Dr Peter Coombes and Bonacci Water was focused on completing the analysis and obtaining the necessary information. The processes associated with MAC Stage I are presented in Figure 6.1.

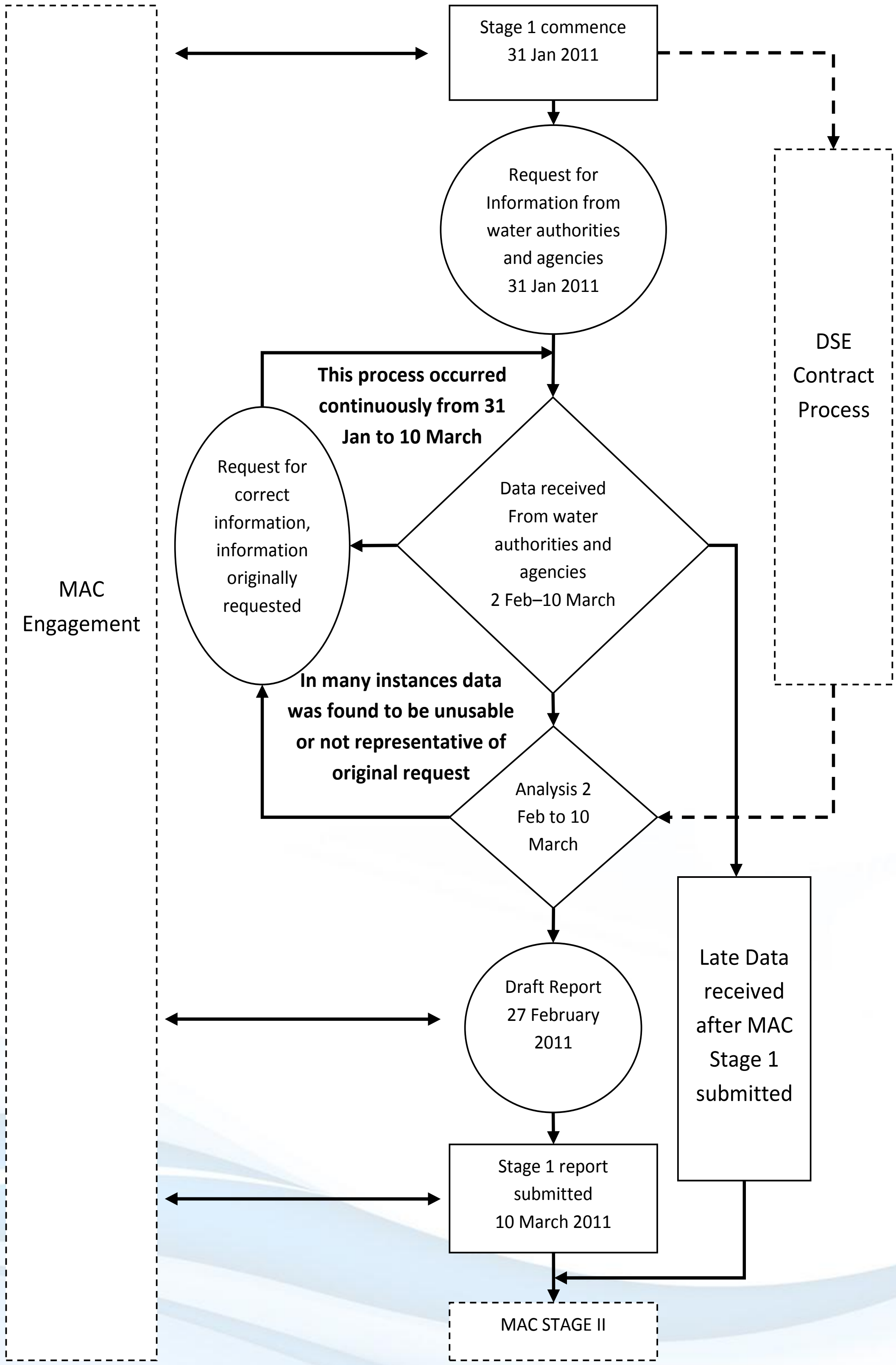

Figure 6.1: The data gathering and engagement process for MAC Stage I

Figure 6.1 represents the key processes, transactions and interactions that occurred during the investigations underpinning the first Stage. This process generated important insights and issues that arepertinent to the structure and operation of the water sector within Metropolitan Melbourne.

The experiences in completing the investigations for Stage I of the MAC process provides important context to the approach, outcomes, and results contained in the MAC Stage I report[107].

Bonacci Water had constant engagement throughout the project with the MAC via formal workshops, meetings, answering questions and providing clarifications.

The requests forand receipt of data continued across the entire Stage 1 process of the MAC. Although the Secretariat appointed to the MAC (Office of Water at DSE) were originally delegated the role of facilitating collection of information, Bonacci Water quickly assumed responsibility for this important task to ensure successful completion.

A combination of factors such as lack of understanding, perceived contractual and confidentiality issues, and in some cases the lack of in-house capabilities provided substantial challenges. As a consequence of these unexpected hurdles Bonacci Water did either not receive a majority of requested data or data was provided very late in the process. A major proportion of the requested data was received after submission of the report for Stage I of the MAC.

In spite of these problems the investigation was successfully completed. The systems analysis, philosophy and approach developed by Dr Peter Coombes provide versatile and flexible analysis methods. Multiple layers of redundancy and feedback loops in the biophysical systems process enable significant insights to be generated using a variety of methods, sources and types of data.

MAC Stage II

The process of analysis and investigation underpinning MAC Stage I can be viewed as a preliminary phase of the overall MAC process which led to investigations supporting the MAC Stage II. The processes associated with investigations supporting the MAC Stage II are illustrated in Figure 6.2.

[107]Coombes, P., Want, S., Wilkinson, B., Colegate, M., and McBride J., 2011. Study 1 – Transforming to a resilient, liveable and sustainable Greater Melbourne (system wide study), For the Living Victoria Ministerial Advisory Council, March 2011

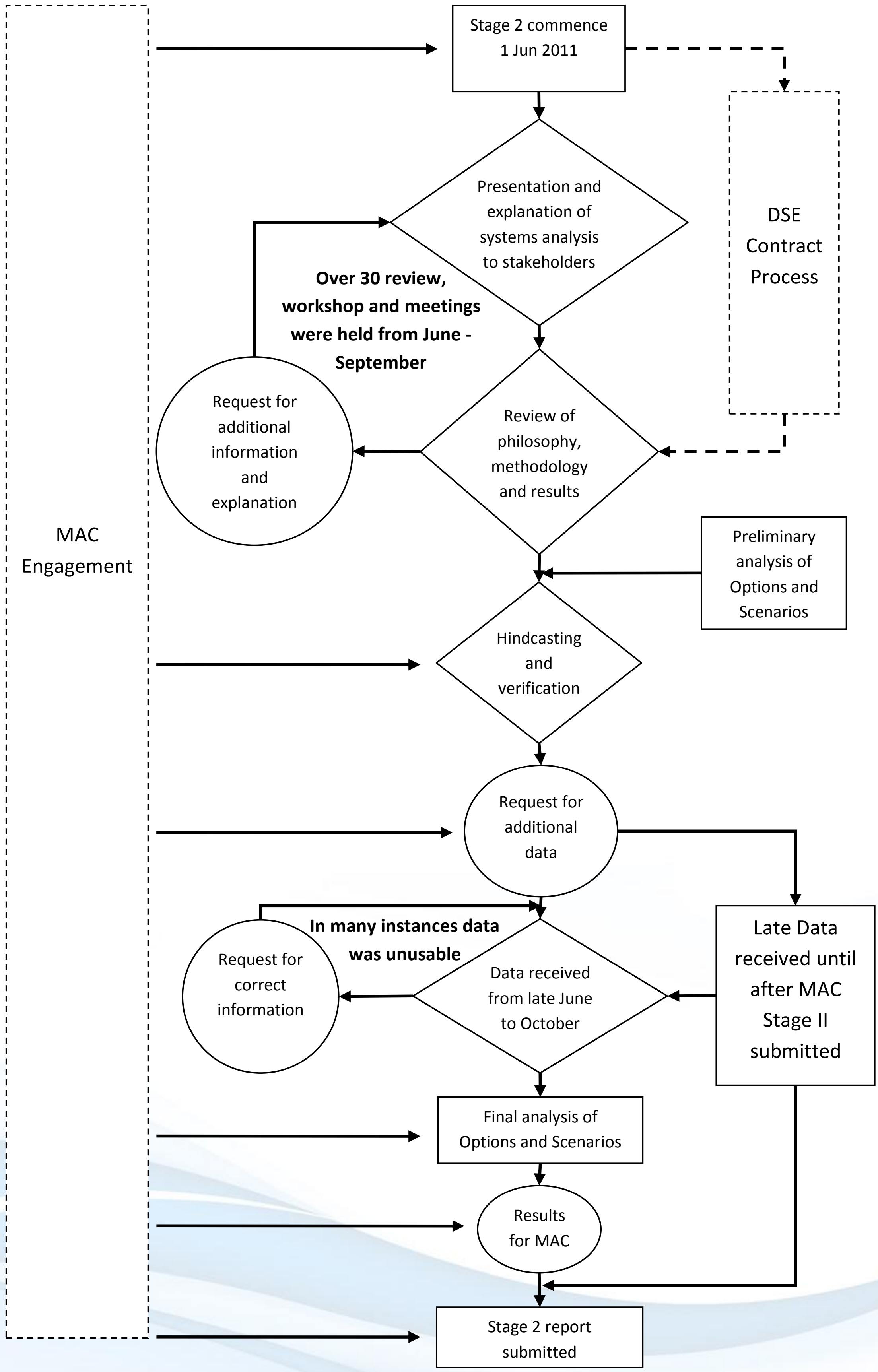

Figure 6.2: The data gathering and engagement process for MAC Stage 2

Figure 6.2 shows that the investigations for the MAC Stage II process represented a longer, more formal, thorough and inclusive process than the investigations associated with MAC Stage I.

The purpose of the investigations supporting MAC Stage II was to build on the analysis provided for Stage I, obtain outstanding data from Stage 1 by streamlining the process, refine understanding of the system and provide insights and policy recommendations to support the overall MAC process.

An additional key aspect of the investigations supporting Stage II was an extensive series of workshops, reviews, discussions and explanations generated by the systems analysis. More than 30 formal meetings were undertaken between June and September 2011 to explain the investigation in greater detail to key stakeholders throughout the urban water industry. An objective of this process was to develop greater understanding and engagement from key organisations, to bolster support for the process and expedite receipt of information to enable completion of the systems analysis. A greater understanding of the analysis was achieved by all stakeholders that took part in the process that generated an improved awareness of the need for the investigation.

A large proportion of participants in the process demonstrated strong engagement, support and desire to see the project succeed. This support contributed to the successful completion of systems analysis that supported the MAC Stage II process and enabled greater insights from the project. A smaller proportion of participants was resistant to the process and chose not to engage sufficiently which limited their contribution and benefit from the process.

Another dominant element of the process was ongoing interaction with the water authorities involved in access to data which led to a difficult process of continued requests for, review and often rejection of data provided by the water authorities. This will be explored in greater detail within this Section. The collection of information from water authorities proved to one of the most challenging aspects of the investigation.

Importantly the MAC Stage II process facilitated refinement of the systems analysis using a process of validation and verification. Validation and Verification was undertaken to provide confidence to the MAC that the investigation was robust, accurate and reflected the variability of the system.

A final key process in Stage II was the refinement of the Options and Scenarios tested as part of the analysis. The Options and Scenarios are described in Sections 2 and 3 respectively. The Options and Scenarios testing process provided the critical information for the policy reform – the evidence based justification of the need for change and benefits of alternative strategies.

A set of preliminary options and scenarios were established and tested in MAC Stage I (and the early stages of MAC Stage II) as an illustration of future opportunities. The results from Stage I provided an insight of future system challenges and opportunities. The power of Options and Scenarios played an important role in improving the understanding of those involved in the process and shaping the recommendations of the MAC by the end of Stage II. More than 40 discrete combinations of Options and Scenarios were tested that provided a very rich data set for understanding the future challenges and opportunities for Greater Melbourne's water cycle.

The overall process is outlined below.

6.2 A holistic, inclusive and transparent process

The LV MAC processes were underpinned by openness, transparency, frequent communication and engagement. This investigation represents a holistic and inclusive process that was facilitated by a formal communication process and the sharing of data and information.

The organisations which Bonacci Water engaged with and sourced information from during the process included:

Victorian Government Agencies

- Department of Sustainability and the Environment (DSE)
- Office of Water (OoW) at DSE
- Department of Planning and Community Development (DPCD)

Independent authorities

- The Essential Services Commission (ESC)
- The Victorian Competition and Efficiency Commission (VCEC)
- The Growth Area Authority (GAA)

Water authorities

- Melbourne Water Corporation (MWC)
- City West Water (CWW)
- YarraValley Water (YVW)
- South East Water (SEW)
- Barwon Water (BW)
- Western Water (WW)
- Gippsland Water (GW)
- South Gippsland Water (SGW)

Australian Government Agencies and Authorities

- The National Water Commission (NWC)
- The Australian Bureau of Statistics (ABS)
- Bureau of Meteorology (BoM)
- The International Panel for Climate Change (IPCC)

Industry organisation

- Water Services Association of Australia (WSAA)

It is important to recognise the contribution of the organisations and individuals from the above group that, in some cases,allocated substantial time to engagement in the process and to providing information required for the investigation.

It is acknowledged that it is impossible conduct a perfect process and to obtain all of the information requested. Nevertheless, this investigation supporting the MAC process has provided a rich tapestry of insight, data and information which has an extent that has not been previously compiled about the water cycle system for Greater Melbourne.

The engagement process with representatives of key organisations and stakeholders, particularly during Stage II, was a significant achievement of the MAC process. Strong stakeholder engagement was essential to assist in providing a greater understanding of the purpose and philosophy of the investigation. Moreover, it was important to highlight the differences to previous and current analysis, and to outline the incorporation of stakeholder contributions into the systems analysis.

This engagement process was facilitated by a number of forums that were established to enable greater understanding and a transfer of information. These include:

- The Ministerial Advisory Council Stage I Working Group
- The Ministerial Advisory Council Stage II Working Group
    - The Expert Review Panel
    - Independent Verifiers
    - Economic Review Groups

The effort invested in this holistic and inclusive process as well as the search for and inclusion of information from a wide range of sources was ultimately a very successful process. A data set of this magnitude or scope has not previously been compiled for the Greater Melbourne water sector. The full benefits of this outcome may take many years to be fully realised.

Engagement and conversations with stakeholders across the sector met with mixed success. It was a wholly positive experience for those that engaged in and contributed to the process. However, the full benefits of the process and consequent opportunities were not realised for those individuals and organisations that were reluctant and reticent to contribute.

6.3 Impact on data access and work scheduling of contractual, confidentiality and procurement issues

For both Stage 1 and 2 of the modelling processes, standardised government procurement processes and terms (e.g. in relation to intellectual property) presented challenges in terms of work timetable and access to critical data sets. As a result, water authorities and associated government agencies did not provide data that was not publicly available until the contracts were signed, arguing they could not release essential data because it was commercially confidential. The MAC required the immediate commencement of the investigation and Bonacci Water was ready to start work but delays in finalisation of the contracts created long delays. [108]

In the event, the majority of useful information that was argued to be protected by confidentiality requirements contained little or no confidential information that would pose a risk upon release.

[108] Verbal conversation Bonacci Water and Melbourne Water Corporation, 16 February 2011.

These raises important issues about transparency of and access to water system data held by public bodies that are discussed further below.

6.4 Availability, quality and consistency of data

This investigation provided the first holistic, integrated and linked systems analysis of the entire water cycle for Greater Melbourne. The unique spatial and temporal process of combining information from water authorities and agencies with climate, population and demographics, built form and infrastructurehas revealed a range of technical and practical challenges.

Availability, quality, and consistency of data varied significantly with the organisation responsible for the data and throughout Greater Melbourne. Data was found to highly variable characteristics that are dependent on the unique attributes of the each spatial location (such as the age of infrastructure or the entity responsible for providing services and collecting information).

The metropolitan water authorities (MWC, CWW, SEW and YVW) are responsible for the collection and management of data related to the supply of water,disposal of wastewater and management of stormwater across Greater Melbourne. MWC is responsible for bulk water and wastewater services and stormwater management (in conjunction with Local Government). CWW, SEW and YVW are geographical authorities with responsibility for providing water and wastewater services.

The statutory framework for management of retail water authorities relies on "competition by comparison" that was intended to improve the level of services and deliver better value for money. This investigation revealed that this framework has realised a range of sub-optimal outcomes.

Each water authority has a different approach to management, collection and use of data. Some authorities have invested in upgrading and improving data management systems. For example, MWC has established a reliable SCADA system enabling the provision of reliable information with relative ease for a relatively recent time period. However MWC struggled to provide accurate historical information about parts of the network including at meters that provide observations about distribution of water to retail authorities. Most water authorities highlighted the "fickle or sensitive" nature of their SCADA system. The SCADA system and information management processes at City West Water are currently being upgraded. Other water authorities have not upgraded their information management systems.

The operation and management of water and wastewater networks differs between water authorities. Some authorities have retained operational responsibility for their information management systems and have retained significant corporate knowledge within the organisation. In contrast, other authorities have outsourced the operation of data management systems leaving a paucity of knowledge about the detail of water cycle systems within the jurisdiction of the authority. This problem was highlighted by YVW admitting that they do not have staff "on-the-ground" to provide the required information. This discussion followed the provision of an initial data set by a contractor that bore no resemblance to observations about flows in the network. This data proved to be unusable computer machine code that resulted from the provision of data from an outsourced proprietary database.

There was also considerable uncertainty about observations across the jurisdictions of water authorities and networks shared by water authorities. Bonacci Water was provided with data with different naming conventions for the same gauges, duplication of boundaries and areas of responsibility, and inconsistent values. For example compiling observations for distribution of water to the Melbourne LGA was a challenge with each water authority responsible for different areas of the network. This investigation also revealed considerable problems with monitoring resulting in a classification of "non-revenue water" – water authorities are billed for water that simply flows through their network to other jurisdictions due to inaccuracies with monitoring processes. As a consequence the water authority does not receive revenue for this perceived water supply.

It was common for water authorities to have access to a limited historical record. All authorities were either unable to or found it very difficult to provide continuous long term records of water use and wastewater generation. For example one water authority required over 24 hours to locate and extract observations from a single gauge (some zones required observations from more than 20 gauges to define water use). It was clear that water authorities had not previously attempted analysis and understanding of the behaviour of water demands or sewage discharges at this spatial and temporal scale throughout Greater Melbourne.

There was inadequate documentation of operating protocols and rules that water authorities used to manage their networks. The rigor, consistency and accuracy of documentation and access to this documentation is markedly different between authorities. It would be very challenging to obtain a consistent understanding of the performance of water and wastewater systems throughout Greater Melbourne.

The variances and inconsistencies highlighted in this investigation indicated that it has been (until now) very difficult to develop a strong spatial understanding of the performance of Greater Melbourne's water cycle. As such (prior to this investigation) it has not been possible to identify the actual costs of providing services to discrete spatial locations throughout Greater Melbourne.

It was commonly claimed that regulation and policies for provision of water services have not encouraged or stipulated spatial understanding of the performance ofthe water cycle throughout Greater Melbourne. In any event this investigation and interaction with stakeholders has provided a compelling argument for a better spatial understanding of the performance of the water cycle to enable improved decision making and planning for water services.

6.5 The use and control of information

An issue associated with the collection and management of information about water systems is the manner in which the information is shared and made available to third partiescollected, stored and maintained. The MAC exercise has identified a series of deficiencies in this regard.

Forexample, the MWC Waterways Group promptly provided detailed and accurate information about the future cost and timing of stormwater infrastructure for each LGA throughout Greater Melbourne. In contrast, a different division of MWC were unable to provide the spatial costs and timing of water and wastewater infrastructure despite acknowledging the existence of, and ability to provide, the data. In addition, an RWA provided a limited amount of information because "we decided this was all you needed".

The commonplace actions of individuals that act as "gatekeepers" of information within the Victorian water sector must to be reviewed as a priority. Transparent protocols and procedures must be developed to facilitate equal and transparent access to data for all stakeholders. Clearly, operation of publicly owned water authorities should embrace efficient and transparent processes, and allow balanced consideration of all alternatives.

Access to information determines the evenness and equality of the water sector – equal access to data and consistent knowledge throughout the sector allows innovation and competition in the development of water cycle strategies. A significant bias and asymmetry currently exists for those that manage the system and collect data - a dominant understanding exists and this results in strong control that limits innovation, development of alternative solutions and new ideas.

6.6 The planning for future needs and consideration of alternatives

Development of alternative water cycle Options requires an understanding of the current approach to planning, consideration of options and determination of preferred alternatives. The Melbourne water system has generated a wealth of data over the past century. This data is of great value for analytical exercises that are the basis of policy development and decision making. However the value of this great resource of knowledge is limited when data are not managed or maintained. Given the multitude of organisations with responsibility for parts of the entire system a clear convention for data management should be developed.

This study has confirmed that traditional water planning processes remain focused on separate and siloed analysis of the key elements of the water cycle - water, wastewater and stormwater. The interactions and synergies between the elements of the water cycle are not adequately considered.

The planning and operation of the system is currently limited toa macro (whole of system) or micro (individual plant, pump or pipe) scale considerations. Stakeholders commonly failed to understand the need for systems analysis and the value of analysing the water cycle as a holistic linked system. Many believed the process was unnecessary, unreliable and a waste of time.

This insight was indeed revealing in the context of current water cycle planning processes and recent decisions for large scale augmentations of water resources for Metropolitan Melbourne.

Discussion with water authorities and the expert review panel revealed that historical investigation shave been restricted to the specific piece of infrastructure and a narrow definition of costs and benefits. Whole of system impacts beyond a preferred physical asset are not considered. For example the time cost of money, or the financial saving of deferring investment is not considered.

The challenge of extending the infrastructure network to new Greenfield suburbs is an example. The cost of new infrastructure at the end of the system was considered. However increased loadings on the capacity of existing infrastructure required to transfer water and wastewater to and from the new area were not counted. This process does not consider the reduction in capacity of the overall network that may include locations with limited capacity.

This insight implies that the full costs (and benefits) of projects for water cycle management are not considered. This is likely to create a bias towards augmentation using large scale infrastructure in decision making about future water cycle planning.

6.7 The aspirational support of a sector

One of the most significant outcomes of the MAC process was the large number of individuals who demonstrated significant good will and willingness to generate change across the sector.

Bonacci Water was provided with substantial advice, information, understanding, ideas and encouragement throughout the process. Many participants demonstrated a real desire to see an evolution in the planning and provision of water cycle services for Greater Melbourne. This was a heartening experience and encouraging for the success of future reform.

6.8 Summary

This investigation included a broad range of interactions, ranging from individual responses of managers at different levels to widely differing organisational responses. This process also exposed vastly different levels of capabilities that proved to be difficult to manage. These issues of quality of data and information will have to be taken seriously and will require attention as future evidence based policy decisions will depend on the quality of available data.

The results from Stage I provided an insight of future system challenges and opportunities, the purpose and power of Options and Scenarios in systems analysis was better understood by those involved in the process by the end of Stage II. More than 40 discrete combinations of Options and Scenarios were tested that provided a very rich data set for understanding the future challenges and opportunities for Greater Melbourne's water cycle.

Engagement and conversations with stakeholders across the sector met with mixed success. It was a wholly positive experience for those that engaged in and contributed to the process. However, the full benefits of the process and consequent opportunities were not realised for those individuals and organisations that were reluctant to contribute.

The time delays and costs created by contractual or confidentially issues generate significant transaction costs. These hidden transaction costs are a substantial barrier to third parties seeking to engage in the sector. Moreover, this process may result in otherwise viable and successful projects being considered to be unviable.

The variances and inconsistencies in data highlighted in this investigation indicates that it has been (until now) very difficult to develop accurate spatial understanding of the performance of Greater Melbourne's water cycle. As such (prior to this investigation) it has not been possible to identify the actual costs of providing services to discrete spatial locations throughout Greater Melbourne.

Regulation and policies for provision of water services have not encouraged spatial understanding of the performance ofthe water cycle throughout Greater Melbourne. This investigation and interaction with stakeholders has provided a compelling argument for a better spatial understanding of the performance of the water cycle to enable improved decision making and planning for water services

The commonplace actions of individuals that act as "gatekeepers" of information within the Victorian water sector must to be reviewed as a priority. Transparent protocols and procedures must be developed to facilitate equal and transparent access to data. Clearly, there is a need for a comprehensive data bank of key data from publicly owned water authorities that will allow analytical work across the entire water sector. For example, the full costs (and benefits) of projects for water cycle management are not currently considered. This is likely to create a bias towards augmentation using large scale infrastructure in decision making processes. However, it will require detailed work across the whole metropolitan sector to clearly identify those policy options. Access to the relevant data will be an essential element of this work.

One of the most significant outcomes of the MAC process was the large number of individuals who demonstrated significant good will and willingness to generate change across the sector. This was a very heartening experience and encouraging for the success of future reform that is needed to ensure Melbourne's water systems met the challenges of the next decades.

7 Results and Discussion

The results of the systems analysis of climate, demographic and water cycles throughout Greater Melbourne are presented in this Section. The results include discussion of financial, economic and greenhouse gas emissions. An explanation of climate processes and the potential of water cycle management Options to manage Melbourne's water cycle at spatial and regional scales is provided.

This systems analysis has provided a wealth of information about the behaviour of the Greater Melbourne region that will continue to inform discussion for some time. A selection of this information is presented in this Chapter.

An overview of the key insights and discussions generated by the analysis are described in this Chapter in the following Sections:

- Climate – this Section provides a summary of long term climate processes within the Melbourne Metropolitan and water supply catchments. A comparison is made to climate processes within the recent drought.
- Residential water demands – the influences on residential water demands are discussed in this Section.
- Regional analysis of Greater Melbourne – this Section provides an overview of regional results for water demands, wastewater discharges, stormwater runoff and water balances. A summary of the performance of the Options in response to the Scenarios and the impacts of using averages on understanding security of water supplies is presented.
- Economics of water and wastewater systems – This Section provides the results of the dynamic economic model for the traditional aspects of water and wastewater services provided by water authorities. A summary of the performance of the Options in response to Scenarios is also provided.
- Flooding and health of waterways – An overview of the performance of the Options in response to Scenarios for management of the costs of trunk stormwater infrastructure, flooding and management of nutrients discharging to waterways.
- Greenhouse gas emissions – this Section provides the results from analysis of the greenhouse gas emissions of Option in response to the Scenarios.
- Spatial capacity and performance of local strategies – towards lot and precinct scale policies – This Section presents a summary of the spatial capacity and performance of Options throughout Greater Melbourne.
- Land savings, holding costs and the time value of money – This section provides an overview of the impacts of land values and potential holding costs on urban development throughout Greater Melbourne.
- Summary of results – A summary of results is presented in this Section. Note that this also report provides results in Chapters 5, 6 and 7.

7.1 Climate

Within the Greater Melbourne region

BONACCI

This study utilised the longest available daily rainfall records that include the recent drought for each zone within the region. Considerable spatial variation of average annual rainfall depths ranging from 486 mm to 1,337 mm was observed for the Greater Melbourne region. This is a significant result given that many studies into the effectiveness of alternative water cycle management strategies for the Greater Melbourne region have used rainfall from the Melbourne RO rain gauge that has lower rainfall.[109],[110]

Analysis of the rainfall sequences at each location revealed a high variability of annual rainfall across the Greater Melbourne region and the also relative reliability of rainfall – annual rainfall depths range from 250 mm to over 2,000 mm and annual rainfall depths of less than 300 mm are rare. Importantly, these areas have not experienced a year without rainfall and the rainfall sequences display cycles of higher and lower rainfall as demonstrated in Figure 7.1.

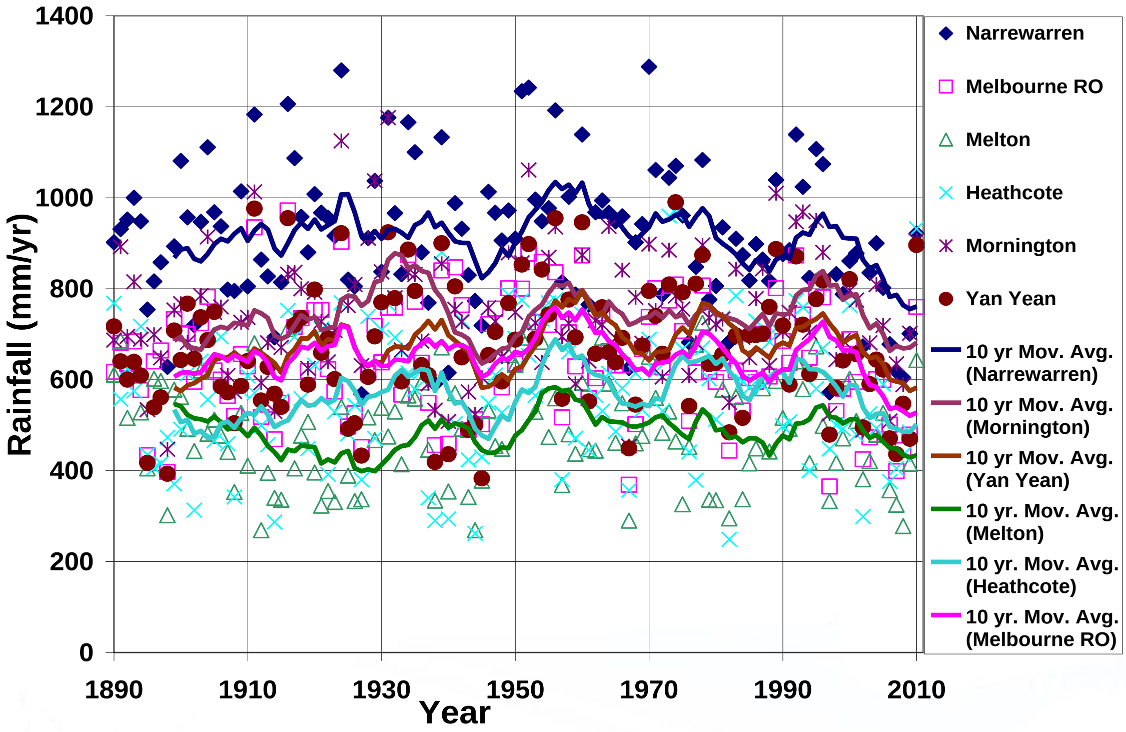

Figure 7.1: Selected rainfall sequences within Metropolitan Melbourne

Figure 7.1 reveals that annual rainfall is highly variable over time and throughout the Greater Melbourne region (as shown by the points on the graph). It is also clear that the region has not been subject to a "step change" in rainfall regime. The rainfall regime for the region can best be described as cyclic patterns of wet and dry periods throughout recorded history and this is demonstrated by the sequences of 10 year moving averages. Note that the 10 year moving averages in Figure 7.1 also indicate an increase in annual rainfall after 1950.

The rainfall records within the Greater Melbourne region display a range of long term trends of declines and increases in annual rainfall depths, and some locations are not subject to changes in annual rainfall depths at all. Clearly the behaviour of rainfall throughout Greater Melbourne cannot

109 Hallmann, M., Grant, T. and Alsop, N., 2003. Yarra Valley Water – Life Cycle Costing of Water Tanks as a Supplement to Mains Water Supply, Centre for Design at RMIT University, Melbourne
110 Lucas S. A., P.J. Coombes, M.J. Hardy, and P. Geary, 2006. Rainwater Harvesting: Revealing the Detail', Water Journal of the Australian Water Association, Vol. 33 pp. 50-55.

be described in general terms and rainfall throughout Greater Melbourne cannot be represented by a single rain gauge (such as Melbourne RO).

The patterns of rainfall within entire rainfall records were examined to understand the impact on annual rainfall depths created by the recent drought by comparing the average rainfall from entire records to rainfall during the recent drought (the period from 2000 to 2010). In addition, evidence of a step change in annual rainfall depths was sought by comparing the average annual rain depth of the entire records to the average annual rain depths in the period after 1950 (the period 1950 to 2010). In addition the average rainfall depths from the period prior to 1950 were compared to the average rainfall depths of the period after 1950. The results of this investigation are provided in Table 7.1 for rainfall records within the Greater Melbourne region.

Table 7.1: Change in annual rainfall throughout Greater Melbourne

Criteria	Max (%)	Min (%)	Avg (%)
Recent drought (2000 to 2010)	+4.1	-24.4	-13.2
Change (post 1950 versus entire record)	+8.8	-4.8	0.0
Change (post 1950 versus prior 1950)	+22.9	-6.7	+3.1

Table 7.1 reveals that rainfall within the Greater Melbourne region displayed a highly variable response to the recent drought ranging from an increase in annual rainfall to a significant decrease. Nevertheless, the average response to the recent drought was a 13.2% decrease in rainfall. However, there was no evidence that rainfall would cease at any location throughout Greater Melbourne.

It is noteworthy that daily maximum temperatures observed at the Melbourne RO gauge increased by 6% during the recent drought.

It is also revealed in Table 7.1 that there was no evidence of a step change to reduced rainfall throughout the Greater Melbourne region. This outcome of the investigation is also demonstrated in Figure 7.1. However, there was a clear trend to increased rainfall throughout the region in comparison to pre 1950 rainfall. Daily maximum temperatures were observed to increase by 3% in comparison to pre 1950 temperatures.

The lengths of rainfall records used in this study were sufficient to capture the natural variation and extremes in rainfall at each location. Use of this data allows robust understanding of the performance of existing systems and alternative strategies. There is sufficient depth of annual rainfall, even during low rainfall years, for significant rainwater and stormwater yields at all locations throughout Greater Melbourne (see Section 7.7).

Greater Melbourne is subject to a wide variation of the frequency of rainfall in a year as defined by the number of days with rainfall greater than 1 mm and a relatively even distribution of rainfall across seasons. A majority of the region is subject to relatively high number of average annual rain days with only a small proportion of the region experiencing less than 92 average annual rain days. The frequency of rain days across Greater Melbourne ranges from rainfall occurring every 3 to 5 days. The rainfall regimes are eminently suitable for highly efficient rainwater and stormwater harvesting strategies.

Climate processes

Longer rainfall records from the Greater Melbourne region demonstrate the natural spatial and temporal variability of rainfall across the region. It is important to incorporate this variability in the analysis of integrated water cycle management and alternative water management strategies. This can be achieved by using the most relevant long sequence of rainfall to capture the natural variability of rainfall patterns whilst overlying the expected patterns of climate change.

This approach to analysis of water cycle management strategies for Greater Melbourne will have the best potential to identify solutions that are resilient to the potential impacts of climate change and variability. The approach captures the uncertainty about the different aspects of climate change and underlying variability – we are fairly certain about increases in temperature but far less certain about impacts on rainfall regimes.

The use of short rainfall sequences from the recent drought or average rainfall in analysis of any water strategy will not account for the risks associated with a variable climate and the potential for climate change, and can also lead to the incorrect dismissal of viable strategies.

Water supply catchments

Rainfall in selected water supply catchments is presented in Figure 7.2 and is mostly characterised by significantly higher rainfall during the period 1950 to 1990, lower rainfall prior to 1950 and lower rainfall during the recent drought.

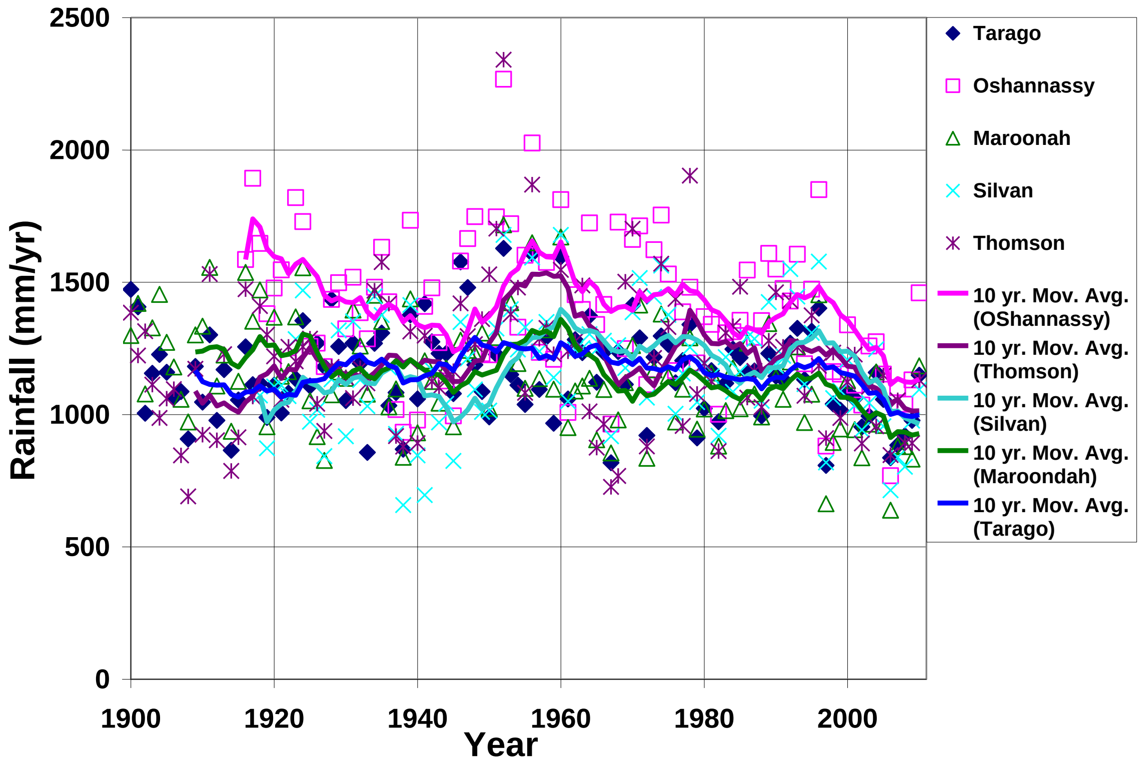

Figure 7.2: Sequences of rainfall in a selection of water supply catchments for Greater Melbourne

Figure 7.2 reveals that the water supply catchments are subject to highly variable annual rainfall ranging from 600 mm to 2,400 mm. The rainfall regimes include cyclic patterns of wet and dry periods.

The Tarago, O'Shannassy and the Maroondah water supply catchments are subject to a trend to decreased rainfall throughout the rainfall records whereas Thomson and Silvan catchments are not subject to changes in annual rainfall depths.

The rainfall records do display considerable variation in annual rainfall but do not reveal evidence of a step change in rainfall regime. These rainfall records were used to assist with determination of the hydrology of the water supply catchments.

The rainfall depths within entire rainfall records were examined to understand the impacts created by the recent drought by comparing the average rainfall from entire records to rainfall during the recent drought (the period from 2000 to 2010). In addition, evidence of a step change in annual rainfall depths was sought by comparing the average annual rain depth of the entire records to the average annual rain depths in the period after 1950 (the period from 1950 to 2010). Average rainfall depths from the period prior to 1950 were compared to the average rainfall depths of the period after 1950. The results of this investigation are provided in Table 7.2 for rainfall records within the water supply catchments.

Relative catchment efficiency

The observed annual rainfall and runoff into Thomson Dam supplying Melbourne are shown in Figure 1.

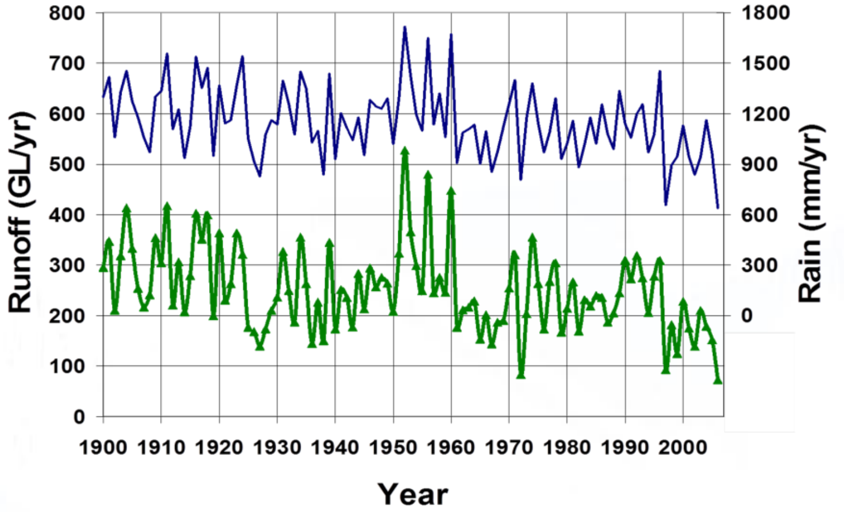

Figure 1: Rainfall and runoff sequences at Thomson Dam supplying Melbourne

Figure 1 shows that the catchment supplying Thomson Dam is subject to cycles of lower and higher rainfall. The recent drought has generated the longest period of low runoff in the record. It is also evident that Thomson catchment may have been subject to a trend to declining runoff during the entire period. The variation in runoff into Thomson Dam supplying Melbourne and yield from 3 kL rainwater tanks in Melbourne[I] is presented in Figure 2.

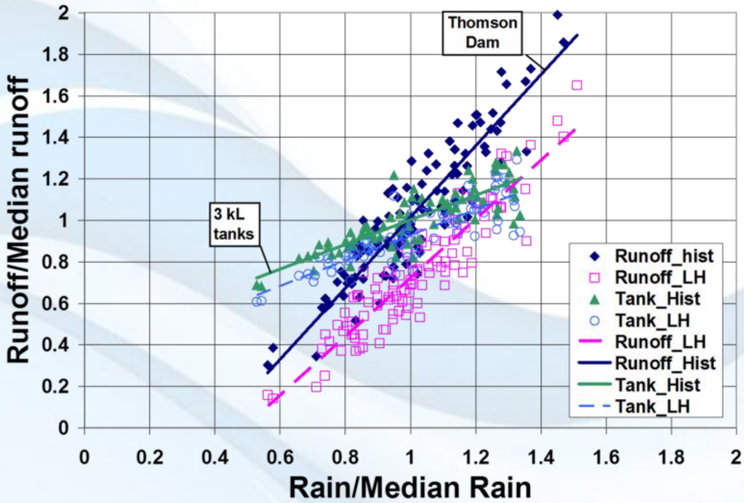

Figure 2: Comparative response of catchments and rainwater tanks to climate variation and change in Melbourne

Figure 2 reveals that yields from 3 kL rainwater tanks in Melbourne are less dependent on the natural variation in rainfall than runoff into Thomson Dam supplying Melbourne. Median annual rainfall and yield from 3 kL rainwater tanks in Melbourne was 638 mm and 62 kL respectively. Median annual runoff into Thomson Dam from the worst case scenario for climate change in 2030 was 174 GL which represents a 28% reduction in average annual runoff. In contrast median annual yields from rainwater tanks in Melbourne were 58 kL which represents a 7% reduction in yield. The relative efficiency of water supply catchments and rainwater tanks supplying Melbourne is highlighted by the response to a 50% decrease in median rainfall of an 85% reduction in runoff and a 30% reduction in rainwater yield. This is due to the pervious nature of catchments that generally require significant re-wetting following reduced rainfall in order to generate appreciable runoff. In contrast, rainwater tanks have highly impervious roof catchments and are, therefore, largely immune to the hysteresis exhibited by catchments in runoff generation. [119]

Table 7.2: Change in annual rainfall in the water supply catchments

Criteria	Max (%)	Min (%)	Avg (%)
Recent drought (2000 to 2010)	-8.5	-19.4	-15.8
Change (post 1950 versus entire record)	+3.4	-3.9	+0.4
Change (post 1950 versus prior 1950)	+10.5	-7.7	+1.5

Table 7.2 reveals that significant decreases in rainfall were experienced within the water supply catchments during the recent drought. The average response to the recent drought was a 15.8% decrease in annual rainfall depths. However, there was no evidence that rainfall would cease at any location throughout water supply catchments.

It is also revealed in Table 7.2 that there was no evidence of a significant step change to reduced rainfall throughout the water supply catchments. Indeed, there was a trend to increased rainfall throughout the water supply catchments in comparison to pre 1950 rainfall regimes.

Clearly the rainfall regimes have returned to "normal" or pre 1950 patterns throughout the water supply catchments supplying Greater Melbourne. Importantly, during periods of droughts small reductions in rainfall generate large reductions in runoff into inland dams because increasing temperature regimes produce large losses in water supply catchment due to evapotranspiration. In contrast, rainwater harvesting within the city is not subject to the same impacts.[111] In addition, the rapid population growth throughout the Greater Melbourne region has generated larger water demands on the water supply systems that limit the ability of the system to cope with lower regimes of runoff.

7.2 Residential water demand

Metered quarterly water use from households, distribution of household sizes and dwelling types, average weekly income, average age and a range of climate parameters from each location were utilised to derive the lot scale water demands employed in this study.

Importantly, household water use was found to be dependent on climate and demographic parameters that vary widely across the Greater Melbourne region. The spatial variation of household water use across Greater Melbourne is influenced by income, minimum and maximum temperatures, rainfall depths and frequency of rainfall. This understanding was generated by the systems analysis employed in this study that includes spatial data from multiple sources.

The range of spatial variation in processes and behaviours that influence water use indicates that the use of global averages (in space or time) to represent water demands for the Greater Melbourne region will produce misleading understanding of water planning, analysis of alternative water sources and water conservation strategies. Importantly, household sizes and dwelling types are not normally

111 Coombes P.J. and M.E. Barry, 2008. The relative efficiency of water supply catchments and rainwater tanks in cities subject to variable climate and the potential for climate change. Australian Journal of Water Resources. Vol. 12. No. 2. pp. 85 – 100

distributed or spatially consistent throughout the region which renders the use of averages unreliable. The pattern of these distributions is also highly variable across Greater Melbourne.

This study has revealed a paucity of knowledge about household water use behaviour throughout Greater Melbourne. Current and historical metering programs do not provide sufficient information to allow a robust understanding of the highly variable water use behaviour throughout Greater Melbourne. There is only limited information available to understand the drivers for indoor and outdoor water use. The ongoing focus on averaging or generalising water use generates a limited understanding.

Influence of demographic and climate parameters on water use

The influence of demographic and climate parameters on water use was evaluated using statistical analysis of the correlation between the parameters. This type of analysis allows an understanding of the extent to which parameters vary together. Results are shown in Table 7.3.

Table 7.3: Correlation of annual average demographic and climate parameters

Criteria	Rain (mm/yr)	Ave Max temp (°C)	Ave min Temp (°C)	Annual Rain days	Income ($/pp/wk)	Age (yrs)	Demand (kL/yr)
Rain (mm/yr)	1						
Ave Max temp (°C)	-0.68	1					
Ave min Temp (°C)	-0.29	0.13	1				
Annual Rain days	0.80	-0.63	-0.26	1			
Income ($/pp/wk)	-0.23	0.12	0.15	-0.22	1		
Age (yrs)	0.37	-0.29	0.09	0.21	-0.10	1	
Demand (kL/yr)	-0.15	0.24	-0.17	-0.26	0.17	-0.03	1

Table 7.3 reveals that the strongest influence on domestic water use was annual average maximum daily temperatures and annual average number of rain days. The average age parameter was observed to have a limited impact on water use.

Higher values of average annual rainfall, average annual minimum temperature, annual average number of rain days and average age correlate with lower water demands. Greater values for average annual temperatures and average incomes correlate with higher water demands. These results indicate that demographic and climatic parameters have significant influence on the magnitude and variation in water use across Melbourne.

7.3 Regional analysis of Greater Melbourne

Water supply

The cumulative demands for mains water supplies for Metropolitan Melbourne from each Option in response to the high emissions climate change Scenario for the period 2010 to 2050 are shown in Figure 7.3. Note that this analysis includes mains water demands from all LGA areas within the Greater Melbourne region. Analysis of the cumulative changes in demands for mains water highlights the magnitude of the changes over the entire planning horizon.

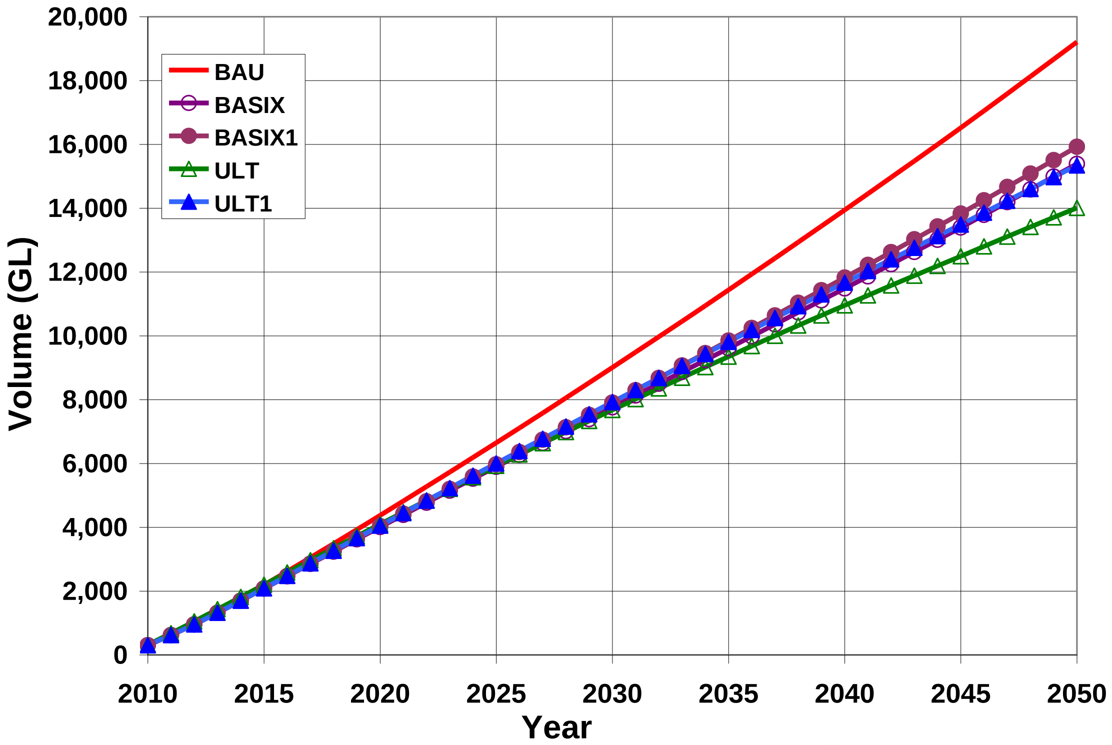

Figure 7.3: Cumulative metropolitan water demand from 2010 to 2050 (High Emissions Climate Change Scenario)

Figure 7.3 reveals 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 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 that includes water efficient gardens. 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 reduced water savings than the ULT Option because treated wastewater is not utilised for laundries 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.

Wastewater discharges

Wastewater generated within the Greater Melbourne region is currently treated by a number of wastewater treatment plants that discharge to the ocean or inland waterways. About 87% of Melbourne's wastewater currently discharges to the ocean or Port Phillip Bay via, mostly, the Eastern and Western Wastewater Treatment Plants. An additional network of smaller wastewater treatment plants manages about 10% of Greater Melbourne's wastewater and approximately 3% of Melbourne's wastewater remains untreated.

Additional development generated by population growth in the planned growth areas is expected to increase the proportion of wastewater that must be treated by the network of smaller wastewater treatment plants and additional plants located inland. Otherwise, wastewater generated from inland areas that are remote from the coast will require additional infrastructure to transport wastewater across long distances.

The expected additional wastewater loads cannot readily be managed by the major coastal treatment plants due to the expanding nature of Melbourne's growth areas that increase the distance that wastewater must be transported to central locations. This study has examined the changes in wastewater loads discharging to existing wastewater treatment plants and waterways in response to different Options and Scenarios.

The analysis also includes the infiltration of stormwater into wastewater systems prior to treatment and disposal. The cumulative wastewater discharges from Metropolitan Melbourne from each Option for the period 2010 to 2050 are shown in Figure 7.4. Note that this analysis includes wastewater discharges with some stormwater infiltration from all LGA areas within the Greater Melbourne region.

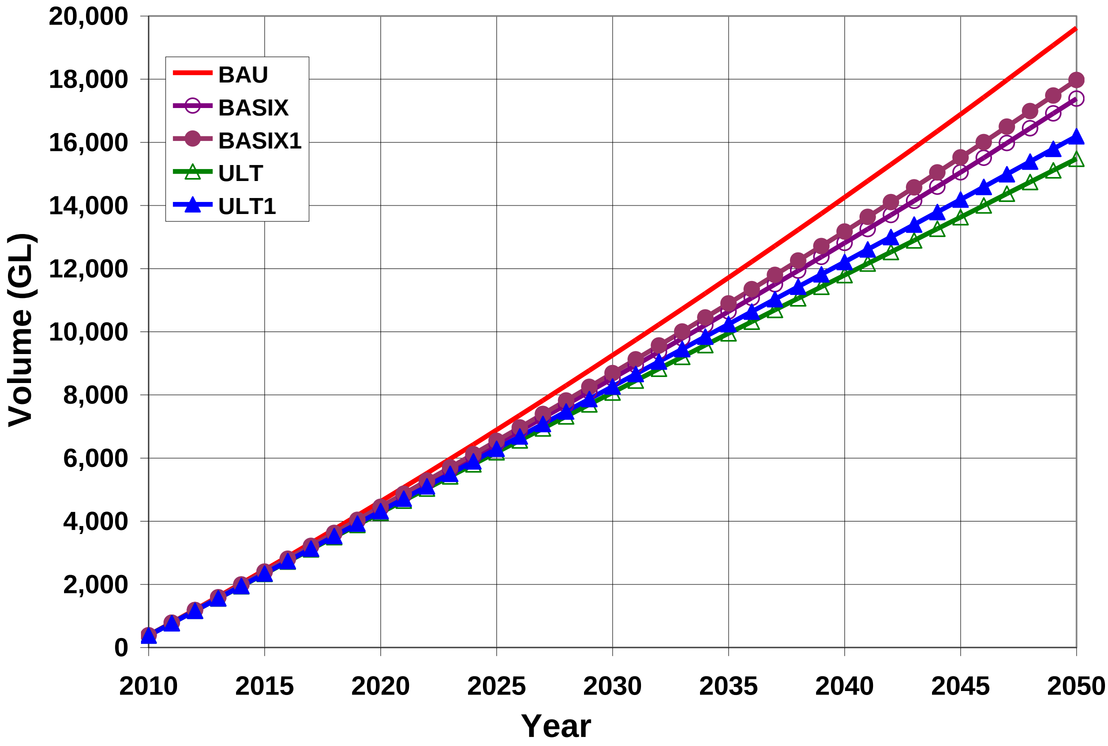

Figure 7.4: Cumulative metropolitan wastewater discharge from 2010 to 2050 (High Emissions Climate Change Scenario)

Figure 7.4 show that the alternative water cycle management strategies create substantial reductions in cumulative wastewater discharges from the Melbourne Metropolitan region. The use of water efficient buildings and precinct scale wastewater reuse schemes in the ULT Option has produced a 21.1% 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.

Stormwater runoff

The cumulative stormwater runoff volumes from the Options are shown in Figure 7.5. This analysis has only considered stormwater runoff from urban allotments and roads (residential and non-residential). It does not account for open spaces or other land uses within each of the zones. This approach was chosen to directly indicate the impact of each Option on managing stormwater runoff generated by urban development and management interventions whilst avoiding reductions in stormwater runoff from non-urban areas.

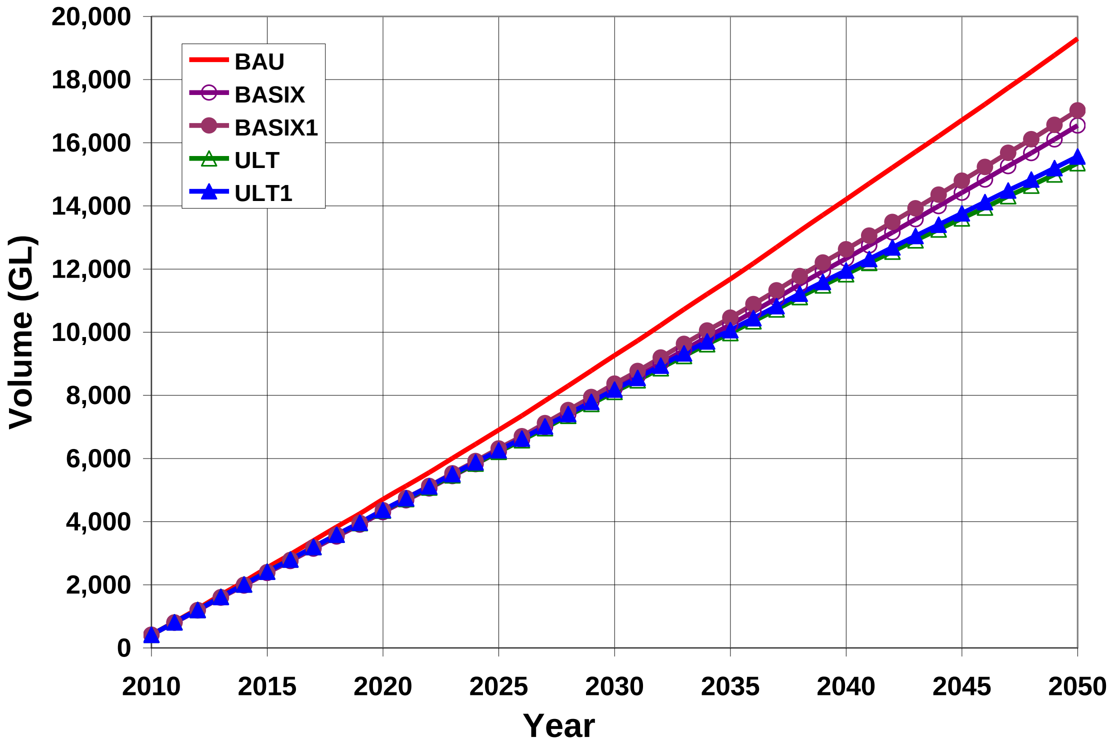

Figure 7.5: Cumulative metropolitan stormwater runoff from 2010 to 2050 (High Emissions Climate Change Scenario)

Figure 7.5 reveals the impact of alternative water cycle management on cumulative stormwater runoff from the Greater Melbourne region. The ULT and ULT1 Options reduce cumulative stormwater runoff by 20.5% and 19.4% respectively. This equates to avoidance of over seven years of stormwater runoff generated by urban areas within Greater Melbourne which will impact positively on the health of waterways. Reductions in the cumulative volumes of stormwater runoff ranging from 14.3% to 11.8% are generated by the BASIX and BASIX1 Options.

Population growth, new dwellings and associated impervious areas will generate large increases in stormwater runoff volumes discharging from urban areas within the planning horizon. Alternative water cycle management Options mitigate the increases in stormwater runoff because all new and renovated buildings include rainwater harvesting and precinct scale stormwater harvesting that reduce stormwater impacts on waterways.

Water balances

The Options for water cycle management include a range of water sources that are components of each water balance in 2050. A water balance for each Option is presented in Figure 7.6.

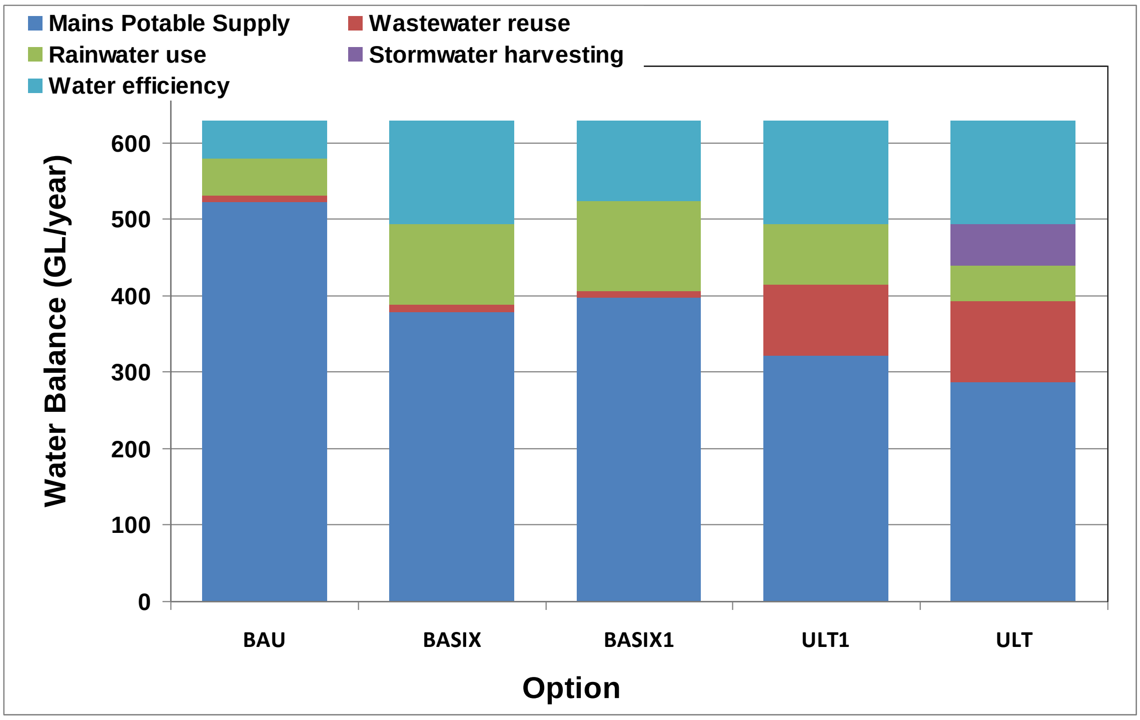

Figure 7.6: Metropolitan water balance in 2050 for each Option (High Emissions Climate Change Scenario)

Figure 7.6 reveals that the BAU Option includes mains water (81%), wastewater reuse (1.5%), rainwater harvesting (7.5%) and water savings from efficient buildings (9.6%) in 2050.

In contrast, the BASIX Option includes 59% mains water, 16.5% rainwater and 23.1% savings from water efficient gardens and buildings. The BASIX1 Option includes 61.8% mains water, 18.5% rainwater and 18.2% savings from water efficient buildings. These Options produce similarly high impacts on reducing water use in 2050.

The ULT Option includes 44.6% mains water, 16.5% wastewater reuse, 7.5% rainwater, 8.4% stormwater harvesting and 23.1% savings from water efficient buildings and gardens. Components in the ULT1 Option include mains water (50%), wastewater reuse (14.5%), rainwater (12.3%) and water efficient buildings and gardens (23.1%). Multiple water sources combine to produce substantial reductions in demands for mains water – this is typical of an IWCM strategy.

The performance of each Option in 2050 is compared to the BAU Option in Table 7.4 for mains water supply, wastewater discharges and stormwater runoff from the Greater Melbourne region.

Table 7.4: Summary of water balances for the Options for 2050

Criteria	Option				
	BAU	BASIX	ULT	BASIX_1	ULT_1
Water Demand 2050 (ML)	521,827	377,681	286,111	396,089	321,438
Change (%)		-28	-45	-24	-38
Wastewater Discharge 2050 (ML)	551,855	466,354	377,502	489,533	377,553
Change (%)		-15	-32	-11	-32
Stormwater Runoff 2050 (ML)	527,000	451,454	439,477	463,740	487,732
Change (%)		-14	-17	-13	-7

Table 7.4 shows that the alternative Options will produce significant reductions in demands for mains water, wastewater discharges and stormwater runoff in 2050. The replacement of the BAU Option with alternative Options for water cycle management for all new and redeveloped buildings creates significant change by 2050.

Water balance scenarios

The performance of each Option can also be influenced by a range of events that were examined in this study as scenarios. The impact of different scenarios on the BAU Option is presented in Table 7.5. As presented previously, the scenarios that were examined included high emissions climate change (HE), low emissions climate change (LE), all new development in green field areas (GF), all new development in infill areas (IF), 0% population growth (0), 2% population growth (2) and economic change (EC). Note that the performance of each scenario is compared to the base BAU scenario.

Table 7.5: Summary of water balances for scenarios – Business as Usual

Criteria	Scenario							
	BAU	0	2	LE	HE	IF	GF	EC
Water Demand 2050 (ML)	521,827	424,064	558,428	537,243	540,703	527,148	512,190	474,421
Change (%)		**-19**	**7**	**3**	**4**	**1**	**-2**	**-9**
Wastewater Discharge 2050 (ML)	551,855	468,931	584,174	548,104	550,652	554,788	540,735	551,855
Change (%)		**-15**	**6**	**-1**	**0**	**1**	**-2**	**0**
Stormwater Runoff 2050 (ML)	527,000	411,771	574,745	502,374	502,100	525,670	543,399	527,000
Change (%)		**-22**	**9**	**-5**	**-5**	**0**	**3**	**0**

Table 7.5 reveals that 0% population growth will provide significant reductions in mains water demands, wastewater discharges and stormwater runoff in comparison to the current population projections. In contrast, the 2% population growth scenario will generate increases in mains water

demands, wastewater discharges and stormwater runoff, as expected. Changes in population have the most significant impact on the future water balances in Greater Melbourne.

The climate change scenarios generated increased demands for mains water and reduced stormwater runoff. Higher temperatures are a driver for higher water demands and reduced rainfall with consequent decreases in stormwater runoff.

Limiting all new development in either green field or infill areas has an insignificant impact on future water balances. Interestingly, the water balances for the GF and IF scenarios are similar. Reduction in industrial and commercial water demands due to a potential decline of the manufacturing industry and efficiency gains in the EC scenario results in significant reductions in water demands.

The impact of different scenarios on the BASIX Option is presented in Table 7.6.

Table 7.6: Summary of water balances for scenarios – BASIX (2050)

Criteria	Scenario								
	BAU	BASIX	0	2	LE	HE	IF	GF	EC
Water Demand 2050 (ML)	521,827	377,681	334,168	395,380	395,399	399,163	385,474	367,317	335,167
Change (%)		**-28**	**-36**	**-24**	**-24**	**-24**	**-26**	**-30**	**-36**
Wastewater Discharge 2050 (ML)	551,855	466,354	414,076	488,559	466,391	468,595	472,846	455,792	468,707
Change (%)		**-15**	**-25**	**-11**	**-15**	**-15**	**-14**	**-17**	**-15**
Stormwater Runoff 2050 (ML)	527,000	451,454	374,161	488,453	409,248	425,174	450,185	471,786	451,454
Change (%)		**-14**	**-29**	**-7**	**-22**	**-19**	**-15**	**-10**	**-14**

Table 7.6 demonstrates that the BASIX Option provides relatively consistent results that are resilient to the impacts of the different scenarios. The consistent results for this Option are generated by linking the strategy to all new and renovated buildings which mitigates variable demands on the water cycle. In addition, use of water efficient buildings and gardens, and rainwater harvesting from impervious roof surfaces within Greater Melbourne provide resilience to a variations in climate.

The impact of different scenarios on the BASIX1 Option is presented in Table 7.7.

Table 7.7: Summary of water balances for scenarios – BASIX1 (2050)

Criteria	Scenario								
	BAU	BASIX1	0	2	LE	HE	IF	GF	EC
Water Demand 2050 (ML)	521,827	396,089	345,404	419,672	414,796	418,483	401,134	378,674	322,753
Change (%)		**-24**	**-34**	**-20**	**-21**	**-20**	**-23**	**-27**	**-38**
Wastewater Discharge 2050 (ML)	551,855	489,533	426,341	517,871	484,016	492,088	493,343	475,807	474,169
Change (%)		**-11**	**-23**	**-6**	**-12**	**-11**	**-11**	**-14**	**-14**
Stormwater Runoff 2050 (ML)	527,000	478,097	367,767	483,724	467,586	441,648	459,582	475,363	478,097
Change (%)		**-9**	**-30**	**-8**	**-11**	**-16**	**-13**	**-10**	**-9**

Table 7.7 shows that the BASIX1 Option generates similar performance and resilience to the BASIX Option with small decreases in mains water savings. The higher demand for mains water in this Option is attributed to the absence of water efficient gardens. Nevertheless, the building scale strategies in the BASIX and BASIX1 Options mitigate the potential impacts of variable climate and population on the water cycle in Greater Melbourne.

The impact of different scenarios on the ULT Option is presented in Table 7.8.

Table 7.8: Summary of water balances for scenarios – ULT (2050)

Criteria	Scenario								
	BAU	ULT	0	2	LE	HE	IF	GF	EC
Water Demand 2050 (ML)	521,827	286,111	311,409	270,894	300,764	296,304	270,861	310,063	252,594
Change (%)		**-45**	**-40**	**-48**	**-42**	**-43**	**-48**	**-41**	**-52**
Wastewater Discharge 2050 (ML)	551,855	377,502	365,082	355,295	378,934	365,881	366,842	385,128	381,893
Change (%)		**-32**	**-34**	**-36**	**-31**	**-34**	**-34**	**-30**	**-31**
Stormwater Runoff 2050 (ML)	527,000	439,477	390,542	467,970	401,991	413,361	424,116	462,801	439,477
Change (%)		**-17**	**-26**	**-11**	**-24**	**-22**	**-20**	**-12**	**-17**

Table 7.8 shows that the IWCM strategies, such as the ULT Option, combine multiple solutions to provide large reductions in demands for mains water, sewage discharges and stormwater runoff that are resilient to a range of scenarios including climate change and variation in population growth. The Option was targeted at new and redeveloped buildings in precinct scale strategies. This ensures that IWCM strategies can utilise various planning schemes, such as Precinct Structure Plans, to provide gradual adoption of alternative water cycle strategies. This ultimately leads to substantial changes in demands on traditional services as shown in Table 7.8.

The impact of different scenarios on the ULT1 Option is presented in Table 7.9.

Table 7.9: Summary of water balances for scenarios – ULT1 (2050)

Criteria	Scenario								
	BAU	ULT	0	2	LE	HE	IF	GF	EC
Water Demand 2050 (ML)	521,827	321,438	327,330	341,384	359,749	366,831	349,168	329,433	312,763
Change (%)		**-38**	**-37**	**-35**	**-31**	**-30**	**-33**	**-37**	**-40**
Wastewater Discharge 2050 (ML)	551,855	377,553	391,602	409,707	395,684	399,212	409,287	396,036	416,462
Change (%)		**-32**	**-29**	**-26**	**-28**	**-28**	**-26**	**-28**	**-25**
Stormwater Runoff 2050 (ML)	527,000	467,473	402,929	517,600	438,487	471,912	494,186	506,779	467,473
Change (%)		**-11**	**-24**	**-2**	**-17**	**-10**	**-6**	**-4**	**-11**

Table 7.9 reveals that the ULT1 Option also provides resilience to the scenarios and considerable reduction in demands on the water cycle, albeit diminished benefits in comparison to the ULT Option. Nevertheless, the ULT1 Option also ultimately generates substantial changes in demands for traditional water cycle services. It is noteworthy that the ULT1 Option includes both building scale (rainwater harvesting) and precinct scale strategies (wastewater reuse) in the IWCM portfolio of solutions.

Security of water supplies

This Section provides the results from each Option in response to the Scenarios for security of water supplies as defined by a requirement to augment regional water supply. The requirement to augment regional water supply is triggered by annual probability of water restrictions greater than 10% in response to diminished total storage in Melbourne's dams. This investigation has also optimised the requirement for use of desalination in response to each Option and Scenario. A summary of results for the BAU Option is presented in Table 7.10.

Table 7.10: Summary of Water Security for BAU scenarios

Comment	Scenario	Augment?
Full desal and NS pipe when dams < 30%	BAU	no
Full desal, 50 GL in 2014 and 100 GL in 2026, 50 GL in 2045 and NS pipe when dams < 30%	HE	2014, 2026, 2045
Full desal, 50 GL in 2015, 50 GL in 2032 and NS pipe when dams < 30%	LE	2015, 2032
Full desal and NS pipe when dams < 30%	GF	no
Full desal and NS pipe when dams < 30%	IF	no
Desal when dams <65% and NS pipe when dams <30%	Zero	no
Full desal, 50 GL in 2042 and NS pipe when dams < 30%	Two	2042
Desal when dams <65% and NS Pipe when dams <30%	EC	No

Table 7.10 shows that the full use of the current desalination plant and use of the North South Pipeline to extract water from the Goulburn River when dams have low water levels will provide adequate security of water supplies until 2050 for most scenarios. The ongoing adoption of water efficient buildings and practices will greatly assist this process. However, the scenario with no population growth (Zero) and economic change (EC) allow use of the desalination plant to be limited to when storage in dams is less than 65%.

Importantly, the high and low emissions climate change scenarios require three and two augmentations of the water supply with desalination respectively. Note that the Low Emissions (LE) scenario is similar to the currently expected high emissions trajectory and the High Emission (HE) scenario includes increases in temperature that are in the upper range of expectations from IPCC global climate models. The higher population growth scenario also generates a requirement for augmentation.

A summary of results for the BASIX Option is presented in Table 7.11.

Table 7.11: Summary of Water Security for BASIX scenarios

Comment	Scenario	Augment?
Desal when dams < 65% and NS pipe when dams < 30%	BASIX	no
Full Desal, 50 GL in 2023 and 100 GL in 2039, NS pipe when dams <30%	HE	2023, 2039
Desal when dams < 65%, 50 GL in 2034, 50 GL in 2045, NS pipe when dams < 30%	LE	2034, 2045
Desal when dams < 65% and NS pipe when dams < 30%	GF	no
Desal when dams < 65% and NS pipe when dams < 30%	IF	no
Desal when dams <65% and NS Pipe when dams <30%	Zero	no
Full Desal and NS pipe when dams < 30%	Two	no
Desal when dams <65% and NS Pipe when dams <30%	EC	no

Table 7.11 reveals that the BASIX Option allows diminished dependence on desalination and the North South Pipeline whilst improving the security of Melbourne's water supply.

BASIX also provides significant delays in requirement for regional augmentation and reductions in the magnitude of augmentation. Augmentation of regional water supplies was only required in the scenarios with climate change.

A summary of results for the BASIX1 scenarios is presented in Table 7.12.

The BASIX1 Option does not include water efficient gardens – this is the only difference to the BASIX Option. Removal of water efficient gardens from the BASIX Option results in additional water demands for rainwater and increases the yields from rainwater tanks – greater reductions in stormwater runoff are generated. The overall impact is a slight increase in regional demands in comparison to the BASIX Option. The additional yields from rainwater tanks has not completely compensated for water savings generated by water efficient gardens in the BASIX Option.

Table 7.12: Summary of water security for BASIX1 scenarios

Comment	Scenario	Augment?
Desal when dams < 65% and NS pipe when dams < 30%	BASIX1	No
Full Desal, 50 GL in 2015, 50 GL in 2023, 50 GL in 2047 and NS pipe when dams <30%	HE	2015, 2023, 2047
Desal when dams < 65%, 50 GL in 2031, 50 GL in 2045 and NS pipe when dams < 30%	LE	2031, 2045
Desal when dams < 65% and NS pipe when dams < 30%	GF	no
Desal when dams < 65% and NS pipe when dams < 30%	IF	no
Desal when dams <65% and NS Pipe when dams <30%	Zero	no
Full Desal, 50 GL in 2042 and NS pipe when dams < 30%	Two	2042
Desal when dams <65% and NS Pipe when dams <30%	EC	no

Table 7.12 reveals that, similar to the BASIX Option, the BASIX1 Option generates significant improvements in the security of Melbourne's water supply and limits or delays requirement for augmentation using desalination. This Option diminishes the impacts of variations in climate and population on the security of water supplies. Nevertheless, exclusion of water efficient gardens from the BASIX Option (the BASIX1 Option) shortens the delay in requirement in augmentation and does not avoid augmentation in the high population growth scenario.

Water efficient gardens are an important aspect of a BASIX Option – which is a "building scale" policy initiative.

A summary of results for the Ultimate (ULT) Option is presented in Table 7.13.

Table 7.13: Summary of water security for ULT scenarios

Comment	Scenario	Augment?
Desal when dams < 65% and NS pipe when dams < 30%	ULT	no
Full Desal and NS pipe when dams <30%	HE	no
Desal when dams < 65% and NS pipe when dams < 30%	LE	no
Desal when dams < 65% and NS pipe when dams < 30%	GF	no
Desal when dams < 65% and NS pipe when dams < 30%	IF	no
Desal when dams <65% and NS pipe when dams <30%	Zero	no
Full Desal, 50 GL in 2042 and NS pipe when dams < 30%	Two	no
Desal when dams <65% and NS pipe when dams <30%	EC	no

Table 7.13 shows that the ULT Option almost eliminates dependence on desalination and the north south pipeline whilst improving the security of Melbourne's water supply. Desalination was only utilised when total storages in dams was less than 65% and the north south pipeline was only required when total storages in dams was less than 35%. The ULT Option also delays the requirement for regional augmentation beyond the planning horizon. This strategy buys sufficient

time to allow the water strategy for Greater Melbourne to transition to a self sufficient solution. The delay in requirement for augmentation represents significant financial value to the State.

A summary of results for the ULT1 scenarios is presented in Table 7.14.

Table 7.14: Summary of water security for ULT1 scenarios

Comment	Scenario	Augment?
Desal when dams < 65% and NS pipe when dams < 30%	ULT1	No
Full Desal and 50 GL in 2045, NS pipe when dams <30%	HE	2045
Desal when dams < 65%, 50 GL in 2038 and NS pipe when dams < 30%	LE	2038
Desal when dams < 65% and NS pipe when dams < 30%	GF	no
Desal when dams < 65% and NS pipe when dams < 30%	IF	no
Desal when dams <65% and NS Pipe when dams <30%	Zero	no
Full Desal, 50 GL in 2042 and NS pipe when dams < 30%	Two	no
Desal when dams <65% and NS pipe when dams <30%	EC	no

Table 7.14 demonstrates that the ULT1 Options almost eliminates dependence on desalination and the north south pipeline whilst improving the security of Melbourne's water supply. Desalination was only utilised when total storages in dams was less than 65% and the north south pipeline was only required when total storages in dams was less than 30%. ULT1 also delays the requirement for regional augmentation and limits requirement for augmentation to the currently planned upgrade of the desalination plant for the climate change scenarios in 2038 (LE) and 2045 (HE). Note that the HE climate change scenario requires the full use of the desalination plant.

The ULT1 Option does not include the use of precinct scale stormwater harvesting for potable water supply (the ULT Option) – this strategy is replaced with use of rainwater tanks for laundry and hot water uses. Similarly, ULT1 includes use of treated wastewater from precinct scale wastewater treatment plants for toilet and outdoor uses (the ULT option also supplied treated wastewater for laundry uses).

The potential avoidance of regional augmentation in ULT versus the requirement for augmentation in ULT1 demonstrates a significant potential of stormwater harvesting for potable uses.

Impact of using averages and generalisations

It is noteworthy that 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). [112]

The impacts of different assumptions about average water demands in the BAU Option on perceived security of regional water supplies are presented in Figure 7.7. The averages were derived in three ways:

- by multiplying average water demand per person across the entire Greater Melbourne 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 the above assumptions effectively averaged the known spatial and temporal demand patterns with the exception of the third quantity which allowed for seasonal variability. 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%.

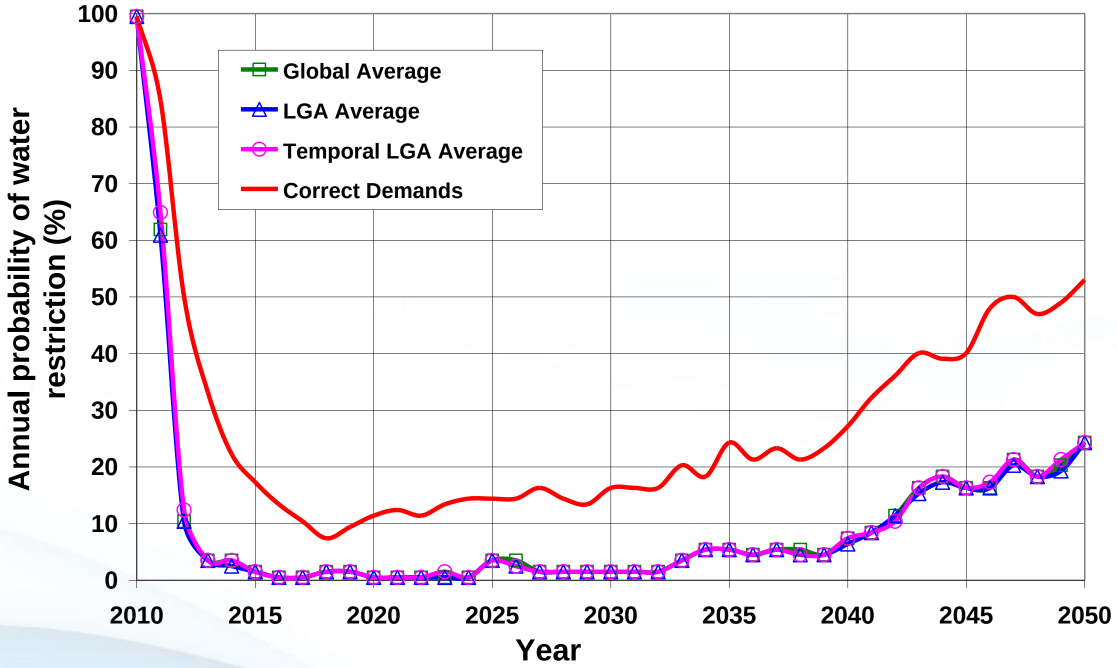

Figure 7.7: impacts of using average water demands on the security of Melbourne's water supply

Figure 7.7 shows that the annual probability of water restrictions decreases from 100% in 2010 as

[112] Coombes P.J. and M.E. Barry (2012). The Impact of Spatial and Temporal Averages on Prediction of Water Security Using Network Analysis – understanding the true potential of WSUD. WSUD2012 Confernce. Engineers Australia. Melbourne.

expected. It is also revealed that the standard practice of using "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, the more detailed inputs to the simulation generate the lowest security for the water supply system. The requirement to augment the water supply systems resulting from each assumption is shown in Table 7.15.

Table 7.15: Augmentation timing for different assumptions about water demands

Option	Timing
Global average	2042
Spatial average	2042
Spatial average with temporal pattern	2042
Detailed water demands	2019

Table 7.15 reveals that the use of increasingly generalised 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.

Although each of the water demand Options includes that same total water demands, different levels of generalisation about water demands creates uncertainty about the security of water supplies for Greater Melbourne. Clearly, increasing generalisation and averaging produces:

- Increasingly optimistic understanding of the security of water supplies
- Dramatic reductions in certainty about system behaviour – leading to incorrect understanding of the performance of the system.

These uncertainties about water security are driven by the multiple interactions in time and space that are typical for a complex system such as a regional water cycle. Importantly, the use of averages is rendered unreliable by different spatial and temporal distributions of water demands. In addition, the variation in the frequencies of demand magnitudes throughout Greater Melbourne creates unreliable results from use of averages. Moreover, the relative timing of water demands and streamflows (and other factors) is also a key driver for understanding water security.

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

The current use of averages and generalisations is also likely to generate an overly pessimistic view of the capacity of alternative solutions to contribute to the security of water supplies for Greater Melbourne.

7.4 Economics of water and wastewater systems

The performance of the water and wastewater networks for each Option were evaluated from the perspective of the regional water manager using an investment analysis that included the costs of providing 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 and wastewater systems. The costs of operating any privately operated water and wastewater treatment plants were included in this analysis. This analysis was conducted to represent the traditional analysis of the economics of water utilities that is dominated by water and wastewater considerations. This process is often limited to "price determinations" and the financial costs of infrastructure.

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 was assumed that these schemes would be operated by a water authority. Note that the alternative precinct water management strategies in the ULT Option can be readily installed and operated by the private sector.

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 Figures 7.8 and 7.9 respectively.

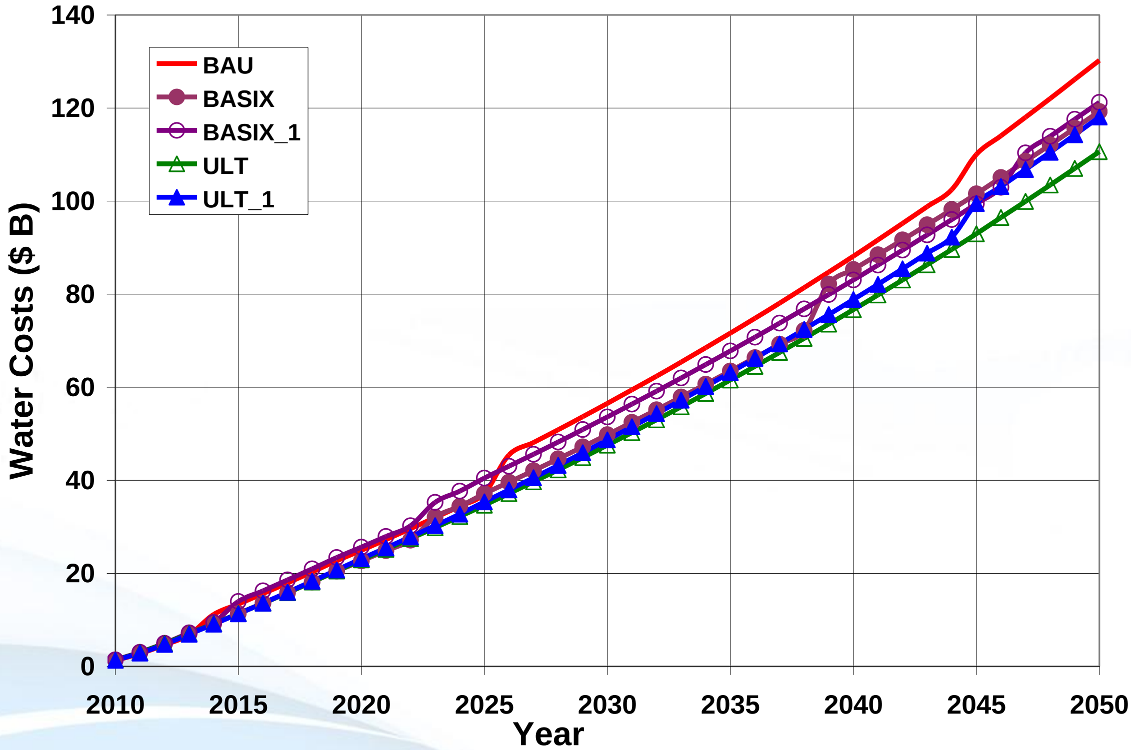

Figure 7.8: Cumulative costs of water services for Options subject to the high emissions climate change scenario

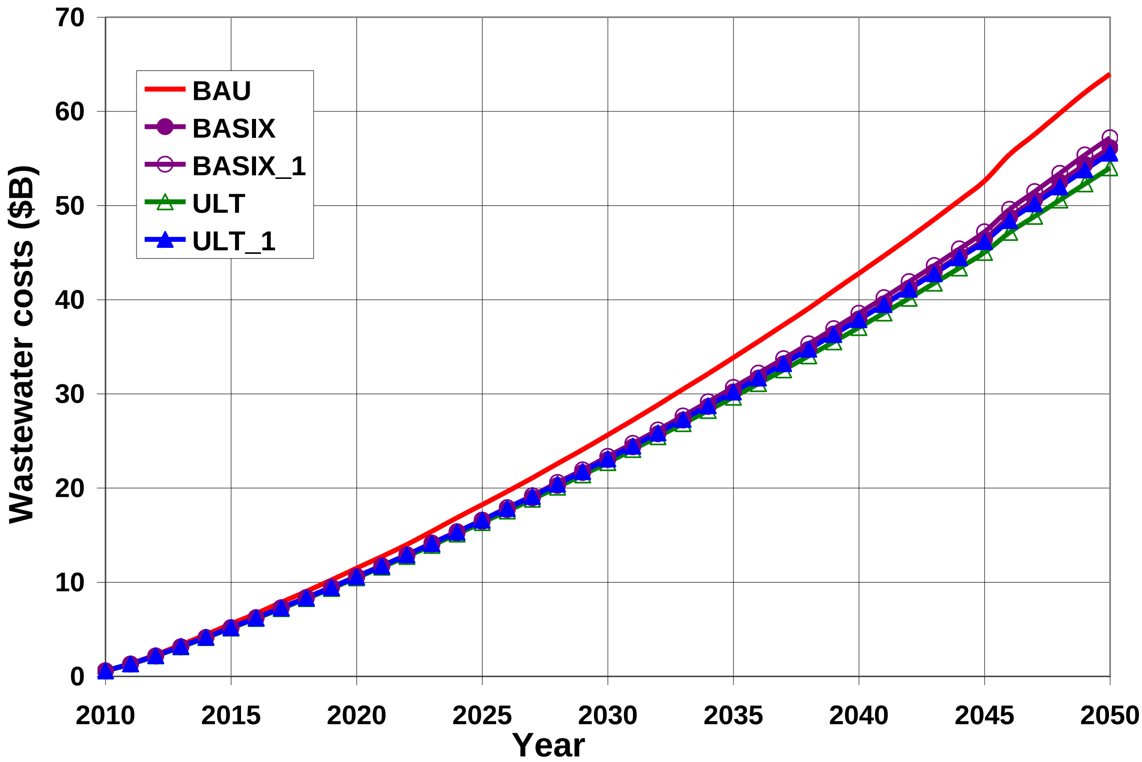

Figure 7.9: Cumulative costs of wastewater services for Options subject to the high emissions climate change scenario

Figure 7.8 reveals that the cumulative costs of water services are significantly reduced by $11 billion for BASIX, $9 billion for BASIX1, $20 billion for ULT and $12 billion for ULT1 over the planning horizon. Figure 7.9 shows that the cumulative costs of wastewater services are also significantly reduced by $8 billion for BASIX, $7 billion for BASIX1, $10 billion for ULT and $8 billion for ULT1 over the planning horizon.

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 and wastewater across Greater Melbourne reduces the costs of augmentation, renewal and operation of infrastructure. In addition, the requirement for regional augmentation of water supplies creates long run economic benefits.

The cumulative costs of water and wastewater services for the Options are shown in Figure 7.10.

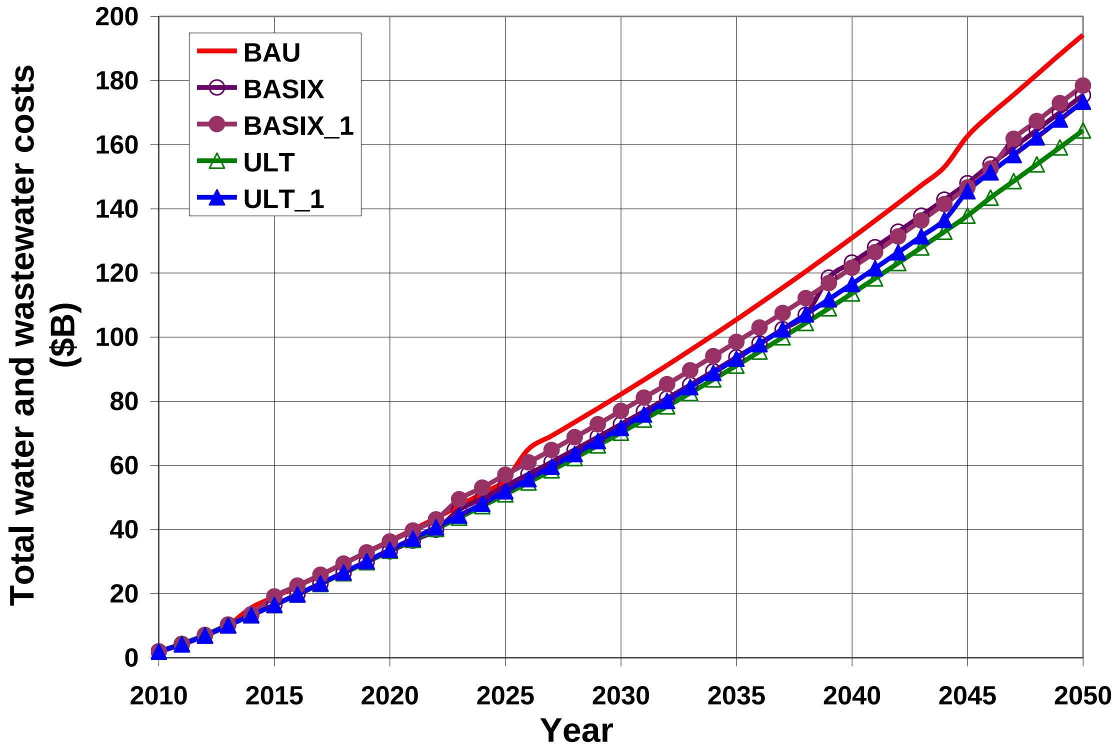

Figure 7.10: Cumulative costs of water and wastewater services for Options subject to the high emissions climate change scenario

Figure 7.10 shows considerable reductions in the total costs of water and wastewater services of $19 billion for BASIX, $16 billion for BASIX1, $30 billion for ULT and 21 billion for ULT1 over the planning horizon. These savings should be considered in the context of the total annual expenses documented in the 2011-12 State budget papers of $47.2 billion – the annual (not cumulative) reduction in water and wastewater expenses is equivalent to 1% to 2% of the States annual budget expenses.[113] Alternatively this economic saving is equivalent to 64% of the current State budget expenditure.

The alternative water cycle strategies have a very 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 and reduced environmental impacts.

The analysis of each Option from the perspective of a regional water manager is presented in Table 7.16 as net present costs (NPC) derived from a 40 year planning horizon using a 9% discount rate and an inflation rate of 2.5%.

[113] State of Victoria (2011). 2011-12 budget overview. The Secretary, Department of Treasury and Finance. Melbourne

Table 7.16: Summary of economic results for water and wastewater services for the Options

Criteria	Option				
	BAU	BASIX	ULT	BASIX_1	ULT_1
Water NPC ($B)	$23.8	$23.3	$22.6	$23.6	$23.1
Change (%)		**-2**	**-5**	**-1**	**-3**
Wastewater NPC ($B)	$12.9	$11.4	$10.6	$11.5	$11.0
Change (%)		**-12**	**-18**	**-11**	**-15**
Total NPC ($B)	$36.7	$34.7	$33.2	$35.1	$34.0
Change (%)		**-6**	**-10**	**-4**	**-7**

Table 7.16 demonstrates that the ULT strategy that incorporates IWCM (and WSUD) strategies in all new developments and redevelopments produces the greatest economic benefits from the perspective of a regional water manager. These benefits are generated by reduced requirement for regional water supply, avoidance of augmentation with desalination plants and minimal dependence on the existing desalination plant. Note that these Options include a security payment to the operators of the current desalination plant.

Additional benefits were generated by avoidance of the requirement for regional augmentation of treatment capacity in the regional wastewater system and minimising the transport of water, sewage and stormwater across Greater Melbourne. Note that dividends and taxes paid to the government were included in this analysis. Importantly the higher economic benefits of the alternative ULT Options are primarily dependent on reduced costs to operate the entire regional water and sewage systems. This analysis has not included the depreciation of infrastructure or associated written down values.

Economic scenarios

The economic results for water and wastewater services in the BAU scenarios are summarised in Table 7.17.

Table 7.17: Summary of the economics of water and wastewater services for scenarios – BAU

Criteria	Scenario							
	BAU	0	2	LE	HE	IF	GF	EC
Water NPC ($B)	$23.9	$21.5	$24.7	$26.3	$27.7	$24.0	$24.2	$22.2
Change (%)		**-10**	**3**	**10**	**16**	**1**	**1**	**-7**
Wastewater NPC ($B)	$13.0	$11.9	$13.4	$12.8	$12.9	$13.5	$12.6	$12.9
Change (%)		**-9**	**3**	**-1**	**-1**	**4**	**-4**	**-1**
Total NPC ($B)	$36.9	$33.4	$38.0	$39.2	$40.6	$37.5	$36.7	$35.1
Change (%)		**-9**	**3**	**6**	**10**	**2**	**0**	**-5**

Table 7.17 reveals that the low population growth scenario (0%) generates substantial reductions in the Net Present Costs of water and wastewater services. These benefits are derived from lower water demands and wastewater discharges, avoidance of requirement for augmentation of regional water security infrastructure and avoidance of requirement to extend existing infrastructure networks. In contrast, the high population growth scenario (2%) produces higher costs that are attributed to increased requirement for local and regional infrastructure associated with higher water demands and wastewater discharges.

The low (LE) and high (HE) emissions climate change scenarios generates large increases in water costs that are attributed to requirement for additional water security infrastructure. These scenarios also provide lower wastewater costs that are attributed to reduced rainfall and consequent diminished infiltration of stormwater into wastewater systems.

Scenarios for infill (IF) and green field (GF) development generate small changes in the costs of water and wastewater services. The costs of wastewater services is significantly different for the infill and green field development scenarios due to the higher costs of augmenting existing infrastructure in existing areas. The economic change (EC) scenarios create large reductions in water demands and requirement for water security infrastructure which generates lower costs.

The economic results for water and wastewater services in the BASIX scenarios are summarised in Table 7.18.

Table 7.18: Summary of economics of water and wastewater services for scenarios – BASIX

Criteria	Scenario								
	BAU	BASIX1	0	2	LE	HE	IF	GF	EC
Water NPC ($B)	$23.9	$22.7	$21.5	$23.9	$23.9	$25.3	$23.0	$23.2	$21.6
Change (%)		**-5**	**-10**	**0**	**0**	**6**	**-3**	**-3**	**-9**
Wastewater NPC ($B)	$13.0	$11.6	$11.1	$11.8	$11.6	$11.6	$12.0	$11.4	$11.6
Change (%)		**-11**	**-15**	**-9**	**-11**	**-11**	**-8**	**-12**	**-11**
Total NPC ($B)	$36.9	$34.3	$32.6	$35.8	$35.4	$36.9	$35.0	$34.6	$33.3
Change (%)		**-7**	**-12**	**-3**	**-4**	**0**	**-5**	**-6**	**-10**

Table 7.18 demonstrates that the BASIX Option mitigates the impacts of the scenarios, in particular the climate change, population growth and spatial development scenarios. This indicates that the BASIX Option creates a high level of resilience to a range of potential threats.

The BASIX Option includes water efficient buildings that reduce water demands and wastewater discharges, and rainwater harvesting further reduces demands for mains water which diminish the costs of providing water and wastewater services. A reduced requirement to transport water and wastewater, to extend infrastructure and for water security infrastructure has generated that benefits.

The economic results for water and wastewater services in the BASIX1 scenarios are presented in Table 7.19.

Table 7.19: Summary of economics of water and wastewater services for scenarios – BASIX1

Criteria	Scenario								
	BAU	BASIX1	0	2	LE	HE	IF	GF	EC
Water NPC ($B)	$23.9	$23.2	$21.6	$24.7	$24.4	$27.0	$23.7	$23.8	$21.8
Change (%)		**-3**	**-9**	**4**	**2**	**13**	**-1**	**0**	**-8**
Wastewater NPC ($B)	$13.0	$11.7	$11.2	$12.1	$11.7	$11.8	$12.3	$11.5	$11.7
Change (%)		**-10**	**-14**	**-7**	**-10**	**-9**	**-6**	**-12**	**-10**
Total NPC ($B)	$36.9	$34.8	$32.8	$36.8	$36.1	$38.8	$36.0	$35.3	$33.5
Change (%)		**-6**	**-11**	**-0**	**-2**	**5**	**-2**	**-4**	**-9**

Table 7.19 reveals that the BASIX1 Option produces similar but slightly reduced benefits in comparison to the BASIX Option. The difference between the BASIX Options is explained by the presence of water efficient gardens in the BASIX Option.

The impact of different scenarios on the ULT Option is presented in Table 7.20.

Table 7.20: Summary of economics of water and wastewater services for scenarios – ULT

Criteria	Scenario								
	BAU	ULT	0	2	LE	HE	IF	GF	EC
Water NPC ($B)	$23.9	$23.2	$21.4	$23.7	$23.8	$24.2	$23.0	$23.9	$22.1
Change (%)		**-3**	**-10**	**-1**	**0**	**1**	**-4**	**0**	**-7**
Wastewater NPC ($B)	$13.0	$11.6	$11.4	$11.6	$11.6	$11.5	$11.6	$11.6	$11.7
Change (%)		**-11**	**-13**	**-11**	**-11**	**-12**	**-11**	**-11**	**-10**
Total NPC ($B)	$36.9	$34.8	$32.7	$35.2	$35.3	$35.6	$34.5	$35.5	$33.7
Change (%)		**-6**	**-11**	**-5**	**-4**	**-3**	**-6**	**-4**	**-9**

Table 7.20 shows that the ULT Option generates considerable reductions in the costs of providing water and wastewater services to Greater Melbourne for all scenarios. This Option provides an opportunity to mitigate the impacts of population growth, climate change and new development.

The impact of different scenarios on the ULT1 Option is presented in Table 7.21.

Table 7.21: Summary of economics of water and wastewater services for scenarios – ULT1

Criteria	Scenario								
	BAU	ULT1	0	2	LE	HE	IF	GF	EC
Water NPC ($B)	$23.9	$23.5	$21.3	$24.0	$24.1	$24.8	$23.1	$24.3	$23.0
Change (%)		**-2**	**-11**	**1**	**1**	**4**	**-3**	**2**	**-4**
Wastewater NPC ($B)	$13.0	$11.7	$11.2	$11.9	$11.6	$11.7	$11.7	$11.6	$11.7
Change (%)		**-10**	**-14**	**-9**	**-11**	**-11**	**-10**	**-11**	**-10**
Total NPC ($B)	$36.9	$35.1	$32.5	$35.8	$35.7	$36.4	$34.8	$35.8	$34.7
Change (%)		**-5**	**-12**	**-3**	**-3**	**-1**	**-6**	**-3**	**-6**

Table 7.21 shows that the ULT1 Option creates similar responses to the scenarios as the ULT Option with small reductions in economic benefits. Nevertheless, this Option also mitigates the uncertainty created by the potential for climate change, variable population growth and different development fronts.

7.5 Flooding and health of waterways

The additional benefits created by the alternative Options are presented in this Section. Management of stormwater runoff volumes and peak discharges from urban areas can assist with reducing risks associated with flooding, environmental damage created by low frequency events and nutrient loads impacting on waterways. Management of the cumulative loads of nitrogen discharging from urban development in each LGA will assist in managing the health of urban waterways. The cumulative loads of nitrogen generated by the systems analysis for the Options from 2010 to 2050 are shown in Figure 7.11.

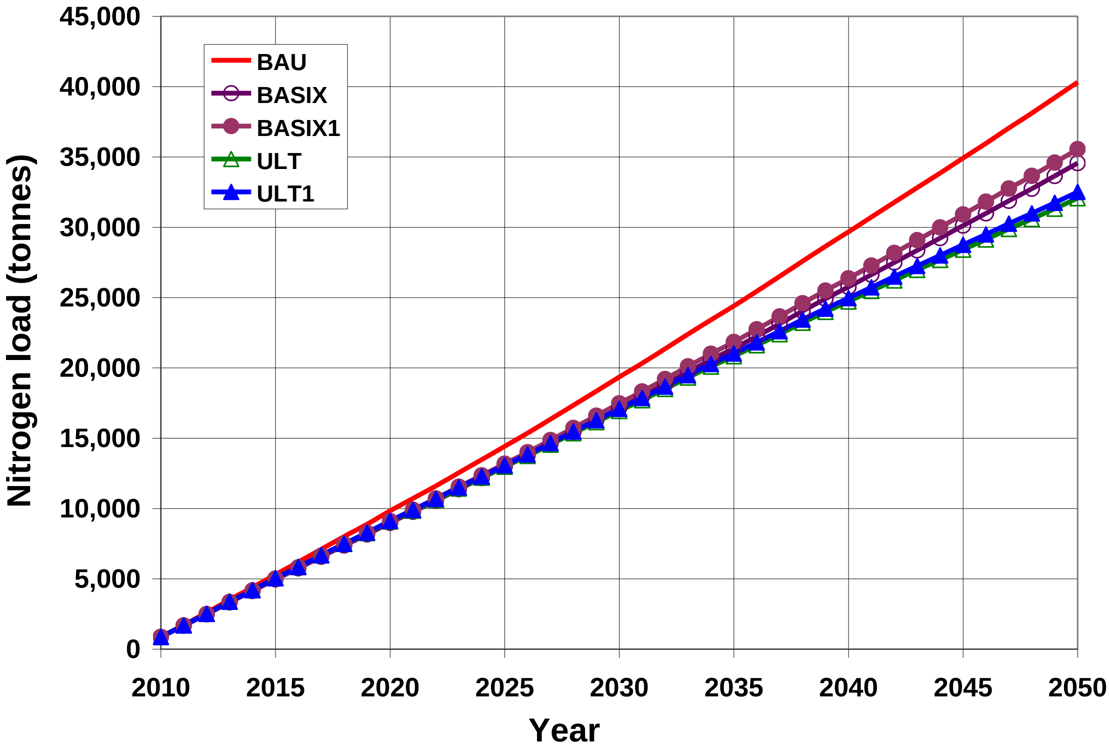

Figure 7.11: Cumulative loads of nitrogen discharging in stormwater runoff to waterways

Figure 7.11 reveals the impact of the Options on cumulative loads of nitrogen discharging in stormwater runoff to waterways from the Greater Melbourne region. The ULT and ULT1 Options reduce cumulative loads of nitrogen by 20% (8,250 tonnes) and 19% (7,800 tonnes) respectively. Reductions in the cumulative loads of nitrogen in stormwater runoff ranging from 14% (5,750 tonnes) to 12% (4,760 tonnes) are generated by the BASIX and BASIX1 Options.

A selection of stormwater benefits derived from the Options in 2050 is presented in Table 7.22. The Average Annual Damage (AAD) from flooding were derived from previous studies into impacts of flooding throughout Greater Melbourne and changes in stormwater runoff generated by the systems analysis.

Table 7.22: Summary of results for trunk stormwater infrastructure, flooding and nutrient loads in 2050

Criteria	Option				
	BAU	BASIX	ULT	BASIX1	ULT1
Stormwater NPC ($B)	$1.61	$1.45	$1.4	$1.46	$1.53
Change (%)		**-10**	**-13**	**-9**	**-5**
Flooding NPC ($B)	$2.9	$2.75	$2.73	$2.8	$2.78
Change (%)		**-5**	**-6**	**-3**	**-4**
Nutrients (tonnes/annum)	1,110	943	918	955	1,018
Change (%)		**-14**	**-17**	**-13**	**-7**
Nutrients NPC ($B)	$2.84	$2.41	$2.35	$2.44	$2.35
Change (%)		**-14**	**-17**	**-13**	**-17**

Table 7.22 reveals that the alternative Options provide considerable reductions in the costs associated with provision of trunk stormwater infrastructure, flooding and management of nutrient loads in 2050. The ULT Option that includes stormwater harvesting from precinct scale strategies provides the greatest benefits and the BASIX Option generated the lowest benefits. Nevertheless, all of the alternative Options provided a range of stormwater benefits.

Note that this analysis only considered the costs of providing trunk stormwater infrastructure at the scale considered by Melbourne Water Corporation. Similarly, the reductions in stormwater impacts that were considered are based on stormwater and rainwater harvesting as outlined for the Options. The addition of local WSUD strategies such as bio-retention and rain gardens to each alternative Option will produce further benefits. Consideration of the impact of the Options on local stormwater infrastructure is also expected to generate considerable additional benefits.

Stormwater management response to scenarios

The results from the BAU scenarios are summarised in Table 7.23.

Table 7.23: Summary of stormwater management results for scenarios – BAU

Criteria	Scenario							
	BAU	0	2	LE	HE	IF	GF	EC
Stormwater NPC ($B)	$1.61	$0.95	$1.92	$1.59	$1.56	$1.72	$1.59	$1.61
Change (%)		**-59**	**20**	**-1**	**-3**	**9**	**-1**	**0**
Flooding NPC ($B)	$2.9	$2.68	$2.99	$2.85	$2.85	$2.9	$2.93	$2.9
Change (%)		**-8**	**3**	**-1**	**-1**	**0**	**1**	**0**
Nutrients (tonnes/annum)	1,110	863	1,211	1,058	1,058	1,101	1,150	1,110
Change (%)		**-22**	**9**	**-5**	**-5**	**-1**	**4**	**0**
Nutrients NPC ($B)	$2.84	$2.21	$3.1	$2.71	$2.71	$2.82	$2.94	$2.84
Change (%)		**-22**	**9**	**-4**	**-4**	**-1**	**4**	**0**

Table 7.23 demonstrates that 0% population growth will generate significant reductions in the costs of trunk stormwater infrastructure, flooding and managing nutrients in comparison to the current population projections. In contrast, the 2% population growth scenario will generate increases in the costs associated with these criteria. Changes in population have the most significant impact on stormwater runoff in Greater Melbourne.

The climate change scenarios generated small reductions in the costs of stormwater management as a consequence of reduced stormwater runoff. Higher temperatures are a driver for reduced rainfall with consequent decreases in stormwater runoff.

Limiting all new development to infill areas produces a significant increase in the costs of trunk stormwater infrastructure due to increased expense of providing additional infrastructure in developed areas. In contrast, limiting all new development to green field areas generates higher flooding and nutrient costs.

The impact of different scenarios on the BASIX Option is presented in Table 7.24.

Table 7.24: Summary of stormwater management results for scenarios – BASIX

Criteria	Scenario								
	BAU	BASIX	0	2	LE	HE	IF	GF	EC
Stormwater NPC ($B)	$1.61	$1.45	$0.63	$1.73	$1.44	$1.43	$1.58	$1.43	$1.45
Change (%)		**-10**	**-61**	**8**	**-11**	**-11**	**-2**	**-11**	**-10**
Flooding NPC ($B)	$2.9	$2.75	$2.6	$2.83	$2.67	$2.7	$2.75	$2.79	$2.75
Change (%)		**-5**	**-10**	**-3**	**-8**	**-7**	**-5**	**-4**	**-5**
Nutrients (tonnes/annum)	1,110	943	782	1,020	855	888	940	986	943
Change (%)		**-14**	**-30**	**-8**	**-23**	**-20**	**-15**	**-11**	**-8**
Nutrients NPC ($B)	$2.84	$2.41	$2.0	$2.61	$2.19	$2.27	$2.41	$2.52	$2.41
Change (%)		**-14**	**-30**	**-8**	**-23**	**-20**	**-15**	**-11**	**-14**

Table 7.24 shows that the BASIX Option mitigates the impacts of the scenarios on stormwater management throughout Greater Melbourne. In particular, the BASIX Option generates considerable reductions in the impacts of climate change and for limiting all new development to infill areas. The additional benefits in the climate change scenarios are attributed to reduced rainfall and the impact of additional stormwater management in the BASIX Option on managing more frequent higher intensity rainfall. The greater benefits for infill development are generated by reducing the requirement for more expensive infrastructure in developed areas.

The impact of different scenarios on the BASIX1 Option is presented in Table 7.25.

Table 7.25: Summary of stormwater management results for scenarios – BASIX1

Criteria	Scenario								
	BAU	BASIX1	0	2	LE	HE	IF	GF	EC
Stormwater NPC ($B)	$1.61	$1.46	$0.62	$1.76	$1.52	$1.46	$1.59	$1.48	$1.46
Change (%)		**-9**	**-61**	**9**	**-5**	**-10**	**-1**	**-8**	**-9**
Flooding NPC ($B)	$2.9	$2.8	$2.59	$2.82	$2.73	$2.73	$2.76	$2.8	$2.8
Change (%)		**-3**	**-11**	**-3**	**-6**	**-6**	**-5**	**-3**	**-3**
Nutrients (tonnes/annum)	1,110	1,002	768	1,038	916	918	961	993	970
Change (%)		**-10**	**-30**	**-6**	**-17**	**-17**	**-13**	**-10**	**-10**
Nutrients NPC ($B)	$2.84	$2.57	$1.97	$2.82	$2.34	$2.35	$2.46	$2.54	$2.57
Change (%)		**-10**	**-30**	**-3**	**-17**	**-17**	**-13**	**-10**	**-10**

Table 7.25 reveals that the BASIX1 Option produces similar but slightly reduced benefits to the BASIX Option. The impact of different scenarios on the ULT Option is presented in Table 7.26.

Table 7.26: Summary of stormwater management results for scenarios – ULT

Criteria	Scenario								
	BAU	ULT	0	2	LE	HE	IF	GF	EC
Stormwater NPC ($B)	$1.61	$1.4	$0.65	$1.67	$1.42	$1.38	$1.56	$1.35	$1.4
Change (%)		**-13**	**-60**	**4**	**-12**	**-14**	**-3**	**-12**	**-13**
Flooding NPC ($B)	$2.9	$2.82	$2.63	$2.79	$2.66	$2.68	$2.7	$2.78	$2.82
Change (%)		**-3**	**-9**	**-4**	**-8**	**-8**	**-7**	**-4**	**-3**
Nutrients (tonnes/annum)	1110	918	653	985	847	871	893	975	918
Change (%)		**-17**	**-41**	**-11**	**-24**	**-22**	**-20**	**-12**	**-17**
Nutrients NPC ($B)	$2.84	$2.35	$2.1	$2.5	$2.15	$2.21	$2.33	$2.47	$2.35
Change (%)		**-17**	**-26**	**-12**	**-24**	**-22**	**-18**	**-12**	**-17**

Table 7.26 demonstrates that the ULT Option generates substantial reductions in the costs of trunk stormwater infrastructure, flooding and stormwater quality infrastructure whilst reducing the nitrogen loads discharging to waterways. These benefits will translate to improvements to the health of waterways (such as the Yarra River and Moonie Ponds Creek) and are created by building scale rainwater harvesting and precinct scale stormwater harvesting.

The impact of different scenarios on the ULT Option is presented in Table 7.27.

Table 7.27: Summary of Results – ULT1

Criteria	Scenario								
	BAU	ULT1	0	2	LE	HE	IF	GF	EC
Stormwater NPC ($B)	$1.61	$1.53	$0.66	$1.83	$1.59	$1.54	$1.56	$1.56	$1.53
Change (%)		**-5**	**-59**	**14**	**-1**	**-6**	**-3**	**-3**	**-5**
Flooding NPC ($B)	$2.9	$2.78	$2.66	$2.88	$2.78	$2.79	$2.83	$2.86	$2.78
Change (%)		**-4**	**-8**	**-1**	**-4**	**-4**	**-2**	**-1**	**-4**
Nutrients (tonnes/annum)	1110	1,018	841	1,106	977	986	1,032	1058	1,018
Change (%)		**-7**	**-24**	**-1**	**-11**	**-11**	**-6**	**-3**	**-7**
Nutrients NPC ($B)	$2.84	$2.35	$2.16	$2.83	$2.5	$2.52	$2.64	$2.71	$2.35
Change (%)		**-17**	**-24**	**-1**	**-11**	**-11**	**-7**	**-4**	**-17**

Table 7.27 shows that the ULT1 Option will also produce significant mitigation of the impacts of the scenarios on stormwater management and the health of waterways. These benefits are derived from use of rainwater for laundry and hot water uses.

7.6 Greenhouse gas emissions

The cumulative greenhouse gas emissions of each Option in response to the high emissions climate change scenario were derived as a function of sourcing, treating and transporting water and sewage throughout the entire Greater Melbourne system as presented in Figure 7.12.

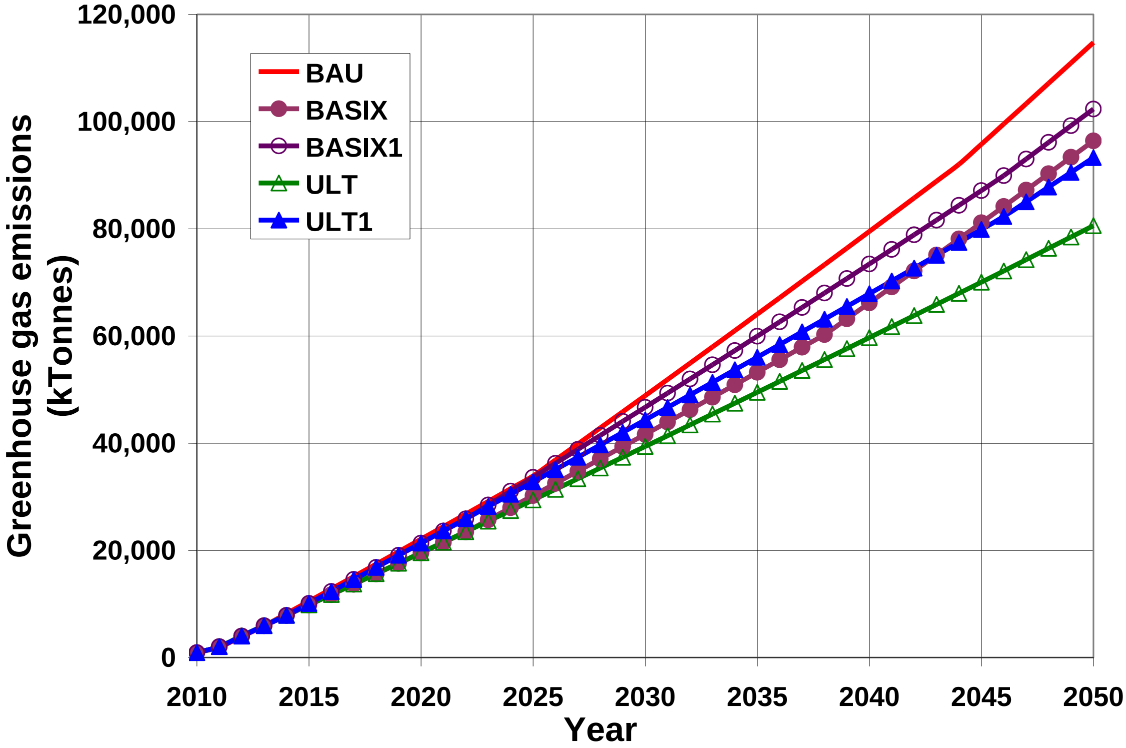

Figure 7.12: Cumulative greenhouse gas emissions of water and wastewater services for Options subject to the high emissions climate change scenario

Figure 7.12 reveals that the alternative Options provide considerable reductions in cumulative greenhouse gas emissions over the planning horizon. The ULT and ULT1 Options reduce cumulative greenhouse emissions by 30% (34,170 kTonnes) and 19% (21,470 kTonnes) respectively. Reductions in the cumulative greenhouse gas emissions ranging from 16% (18,330 ktonnes) to 11% (12,400 kTonnes) are generated by the BASIX and BASIX1 Options. These reductions in greenhouse gas emissions are driven by minimising requirement for desalination, transport of water and sewage across long distances; and use of water efficient buildings.

The greenhouse gas emissions and the cost of carbon for each of the Options are compared to the BAU Option for 2050 in Table 7.28.

Table 7.28: Summary of greenhouse gas emissions for water and wastewater services for the Options

Criteria	Option				
	BAU	BASIX	ULT	BASIX_1	ULT_1
Greenhouse Gas Emissions 2050 (kT CO2e/yr)	1,920	1,121	821	1,167	927
Change (%)		**-42**	**-57**	**-39**	**-52**
Cost of Carbon 2050 ($M)	$48	$28	$21	$29	$23
Change (%)		**-42**	**-57**	**-39**	**-52**

Table 7.28 demonstrates that the alternative Options will generate considerable reductions in greenhouse gas emissions by 2050. The majority of these reductions are generated by reduced requirement for desalination, by the use of local water sources and water efficiency.

The magnitude of these reductions in greenhouse gas emissions will overwhelm any conjecture about the energy consumption of various water management strategies. Nevertheless, innovation is expected to improve energy efficiency into the future as a result of the adoption of alternative water strategies.

Greenhouse gas emissions from scenarios

The greenhouse gas emissions from the BAU scenarios are summarised in Table 7.29.

Table 7.29: Summary of greenhouse gas emissions for water and wastewater services for scenarios – BAU

Criteria	Scenario							
	BAU	0	2	LE	HE	IF	GF	EC
Greenhouse Gas Emissions 2050 (kT CO2e/yr)	1,928	1,079	2,247	2,427	3,185	1,991	1,851	1,344
Change (%)		**-44**	**17**	**26**	**65**	**3**	**-4**	**-30**
Cost of Carbon 2050 ($M)	$48.2	$27.0	$56.2	$60.7	$79.6	$49.8	$46.3	$33.6
Change (%)		**-44**	**17**	**26**	**65**	**3**	**-4**	**-30**

Table 7.29 reveals that the different scenarios create large variations in greenhouse gas emissions from the BAU Option. The highest greenhouse gas emissions are generated by dependence on desalination in the high emissions climate change scenario and the lowest emissions were created by avoidance of desalination and long distance transfers in the low population growth scenario.

The impact of different scenarios on the BASIX Option for greenhouse gas emissions is presented in Table 7.30.

Table 7.30: Summary of greenhouse gas emissions for water and wastewater services for scenarios – BASIX

Criteria	Scenario								
	BAU	BASIX	0	2	LE	HE	IF	GF	EC
Greenhouse Gas Emissions 2050 (kT CO2e/yr)	1,928	1,153	916	1,863	1,529	2,569	1,224	1,084	1,119
Change (%)		**-40**	**-52**	**-3**	**-21**	**33**	**-37**	**-44**	**-42**
Cost of Carbon 2050 ($M)	$48.2	$28.8	$22.9	$46.6	$38.2	$64.2	$30.6	$27.1	$28.0
Change (%)		**-40**	**-52**	**-3**	**-21**	**33**	**-37**	**-44**	**-42**

Table 7.30 reveals that the BASIX Option mitigates the impacts of the scenarios on greenhouse emissions and generates reductions in emissions for all scenarios in comparison to the BAU Option.

The impact of different scenarios on the BASIX1 Option for greenhouse gas emissions is shown in Table 7.31.

Table 7.31: Summary of greenhouse gas emissions for water and wastewater services for scenarios – BASIX1

Criteria	Scenario								
	BAU	BASIX	0	2	LE	HE	IF	GF	EC
Greenhouse Gas Emissions 2050 (kT CO2e/yr)	1,928	1,215	943	2,161	1,651	2,606	1,318	1,128	1,145
Change (%)		**-37**	**-51**	**12**	**-14**	**35**	**-32**	**-41**	**-41**
Cost of Carbon 2050 ($M)	$48.2	$30.4	$23.6	$54.0	$41.3	$65.2	$33.0	$28.2	$28.6
Change (%)		**-37**	**-51**	**12**	**-14**	**35**	**-32**	**-41**	**-41**

Table 7.31 shows that the BASIX1 Option produces similar, albeit slightly less significant, results as the BASIX Option for all scenarios. A strategy to implement building scale measures in accordance with the BASIX Options outlined in this investigation will be produce consistent reductions in greenhouse gas emissions.

The impact of different scenarios on the ULT Option for greenhouse gas emissions is presented in Table 7.32.

Table 7.32: Summary of greenhouse gas emissions for water and wastewater services for scenarios – ULT

Criteria	Scenario								
	BAU	ULT	0	2	LE	HE	IF	GF	EC
Greenhouse Gas Emissions 2050 (kT CO2e/yr)	1,928	1,036	920	1,053	1,085	1,770	1,013	1,055	1,018
Change (%)		**-46**	**-52**	**-45**	**-44**	**-8**	**-47**	**-45**	**-47**
Cost of Carbon 2050 ($M)	$48.2	$25.9	$23.0	$26.3	$27.1	$44.3	$25.3	$26.4	$25.4
Change (%)		**-46**	**-52**	**-45**	**-44**	**-8**	**-47**	**-45**	**-47**

Table 7.32 reveals that the ULT Option generates large reductions in greenhouse gas emissions and associated carbon costs across all scenarios. These benefits result from reduced water demands, transport of water and wastewater, and diminished reliance on desalination.

The impact of different scenarios on the BASIX Option for greenhouse gas emissions is presented in Table 7.33.

Table 7.33: Summary of greenhouse gas emissions for water and wastewater services for scenarios – ULT1

Criteria	Scenario								
	BAU	BASIX	0	2	LE	HE	IF	GF	EC
Greenhouse Gas Emissions 2050 (kT CO2e/yr)	1,928	1,095	901	1,187	1,269	2,302	1,100	1,089	1,774
Change (%)		**-43**	**-53**	**-38**	**-34**	**19**	**-43**	**-44**	**-8**
Cost of Carbon 2050 ($M)	$48.2	$27.4	$22.5	$29.7	$31.7	$57.6	$27.5	$27.2	$44.4
Change (%)		**-43**	**-53**	**-38**	**-34**	**19**	**-43**	**-44**	**-8**

Table 7.33 shows that the ULT1 Option also produces significant reductions in greenhouse gas emissions for all scenarios. Nevertheless, the reductions in the greenhouse emissions generated by the ULT1 Option are less than the reductions created by the ULT Option. All of the alternative Options generate considerable reductions in greenhouse gas emissions that are resilient to different potential futures represented by the scenarios.

7.7 Spatial capacity and performance of local strategies – towards lot and precinct scale policies

This section discusses the differences in the capacity of each Option in the "districts" described as combinations of locations across Greater Melbourne with similar characteristics. These "maps of opportunity" refer to capacity of building scale (BASIX and BASIX1) and precinct scale (ULT and ULT1) Options. The spatial capacity of each Option was paired with the potential spatial performance of each Option during the planning horizon that was derived from the systems analysis.

Capacity is the definition of the potential of each Option at each building or household or precinct throughout Greater Melbourne. This is the actual behaviour of the Option at the local scale.

Performance is the definition of the behaviour of each Option within the planning horizon that is modified by population growth, renovation rates, demographic processes and the legacy of existing infrastructure and policies. This is the actual impact of each Option throughout a district.

The Greater Melbourne region includes a wide range of spatially diverse influences that ensures that the performance of water cycle management strategies cannot be generalised across the region. This insight is highlighted by the differences in climate and socio-economic behaviours for the selected "districts", the transport distances associated with delivering centralised services and various infrastructure legacies throughout the region. This investigation utilised these parameters to define districts for presentation of results:

- Greenfield East – areas in the east of Greater Melbourne subject to new growth
- Greenfield Low Growth – areas subject to low rates of new growth
- Outer Metro – outer areas of existing Greater Melbourne mostly subject to infill development
- Inner Metro – inner areas of exisitng Greater Melbourne mostly subject to infill development
- Greenfield West – areas in the west of Greater Melbourne subject to new growth

BASIX

The capacity of each allotment or building in the BASIX Option for the different water cycle management districts is presented in Figure 7.13.

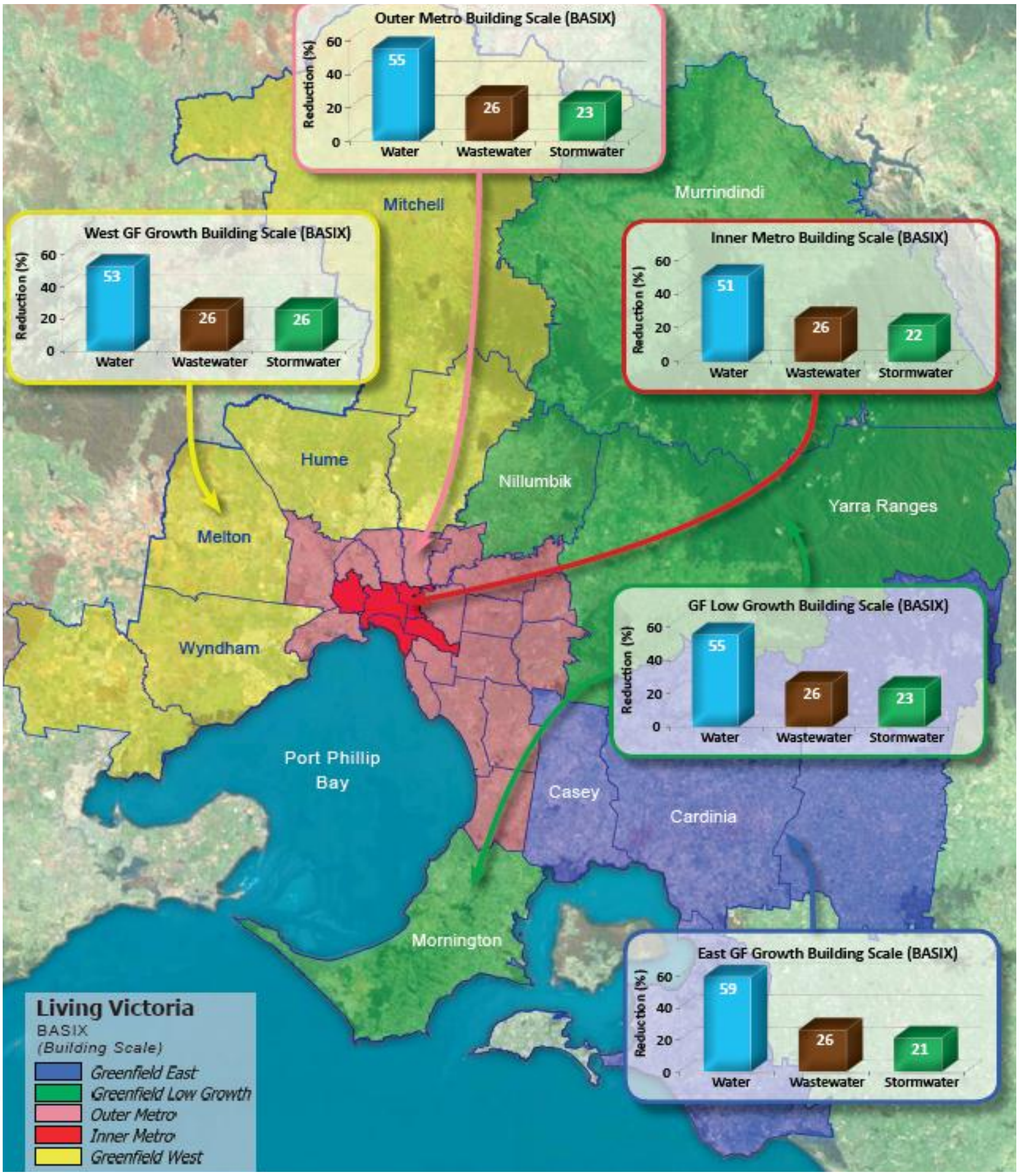

Figure 7.13: Spatial capacity of building scale measures - BASIX

Figure 7.13 demonstrates that the BASIX Option generates consistent reductions in water demands, wastewater discharges and stormwater runoff throughout Greater Melbourne. It is noteworthy that greater reductions in water demands and lower reductions in stormwater runoff are generated in the higher rainfall areas (such as East GF Growth district).

The performance of BASIX Option within the planning horizon (2010 to 2050) for each water cycle management district is presented in Figure 7.14.

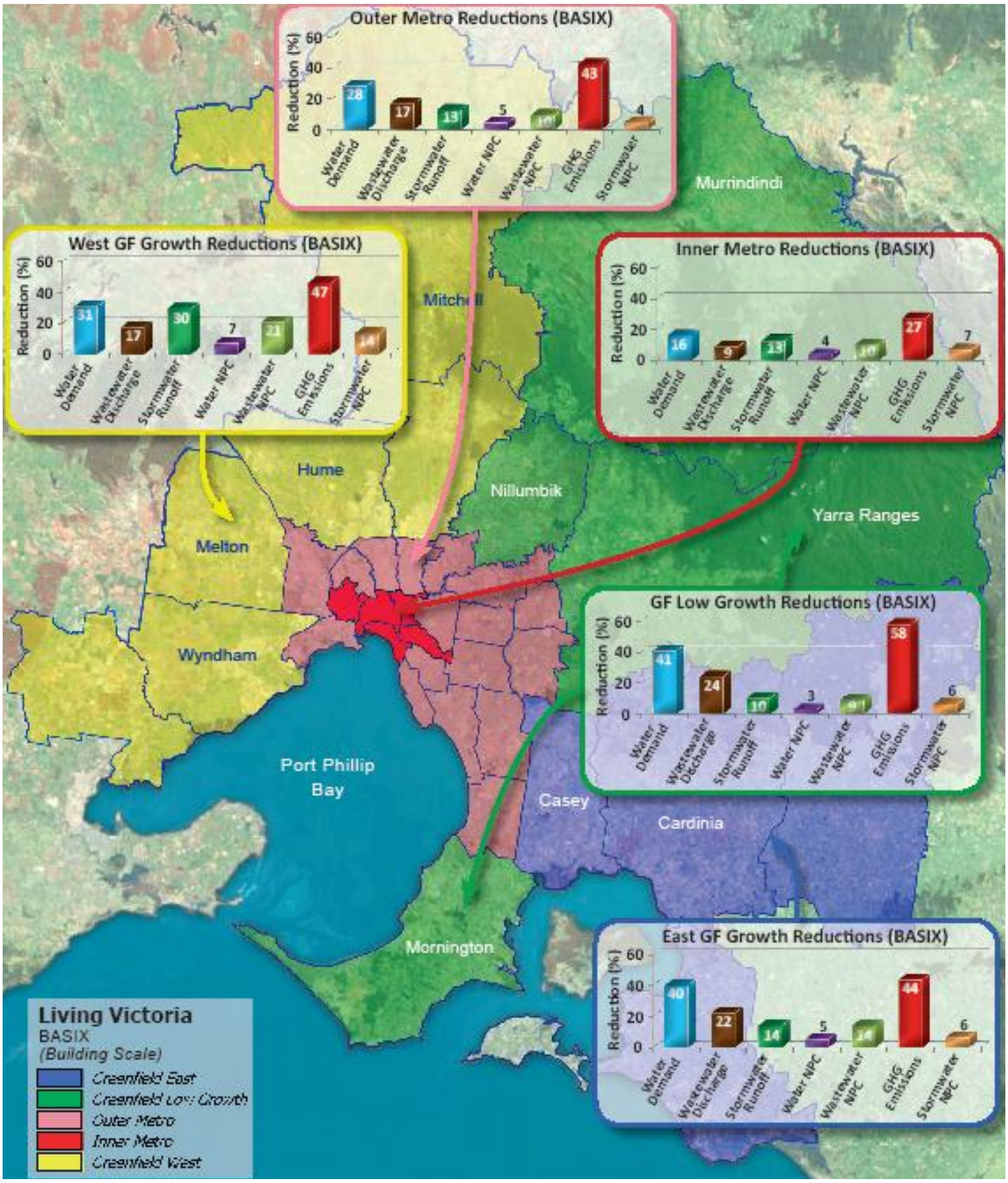

Figure 7.14: Spatial performance of building scale measures – BASIX

Figure 7.14 highlights that the variable performance of the BASIX Options in each of the spatial Districts that is dependent on the different growth and renovation rates, transport distances for water cycle services, infrastructure legacies and the distribution of water demands. All Districts are subject to significant reductions in water demands, wastewater discharges, stormwater runoff, greenhouse gas emissions and net present costs (NPC).

The Inner Metro District that includes a greater proportion of non-residential demands for water cycle services generates lower reductions in water cycle demands and net present costs. This area is subject to high growth and renovation rates. Housing stock is dominated by units and, to a lesser extent, detached housing which generates higher indoor water demands and insignificant outdoor water use. This area experiences higher rainfall than the western and north western areas. Rainwater harvesting in this area is mostly provided by cluster scale facilities – for example; a single rainwater tank is used to supply a building containing multiple units.

Rainwater harvesting and water efficient appliances provide similar reductions in water demands that are modified by growth and renovation rates. Nevertheless, water efficient appliances and rainwater harvesting to partially supply a higher water demand generated a significant reduction in mains water demands for building scale measures. All districts experience similar proportional reductions in wastewater discharges because water efficient appliances impact on the same proportion of indoor water demands at each location. The rainfall in the Inner Metro District combines with lower indoor water use and a higher proportion of outdoor water use to limit the effectiveness of rainwater harvesting to a moderate yield.

Rainwater harvesting generates higher reductions in stormwater runoff and associated costs in lower rainfall areas such as the West GF Growth District. Nevertheless, water efficient appliances and rainwater harvesting provide similar reductions in mains water demands. This results in significant reductions in demands for mains water.

Use of water efficient appliances also provides reductions in wastewater discharges. A combination of already lower water demands and wastewater discharges with reductions generated by water efficient appliances and rainwater harvesting provides higher reductions in water and wastewater costs.

Higher and more frequent rainfall in the GF Low Growth and East GF Growth Districts acts to generate the highest water savings and to diminish reductions in stormwater runoff. Larger reductions in water demands produce greater reductions in greenhouse gas emissions.

The impacts of the economic costs (NPC) generated by the BASIX Option in all Districts are modified by the following issues across Greater Melbourne:

- differences in extension, renewal and operating costs of infrastructure,
- distances from bulk water supply and wastewater disposal points, and
- variable growth and renovation rates

BASIX1

The capacity of each allotment or building in the BASIX1 Option for the different water cycle management districts is presented in Figure 7.15.

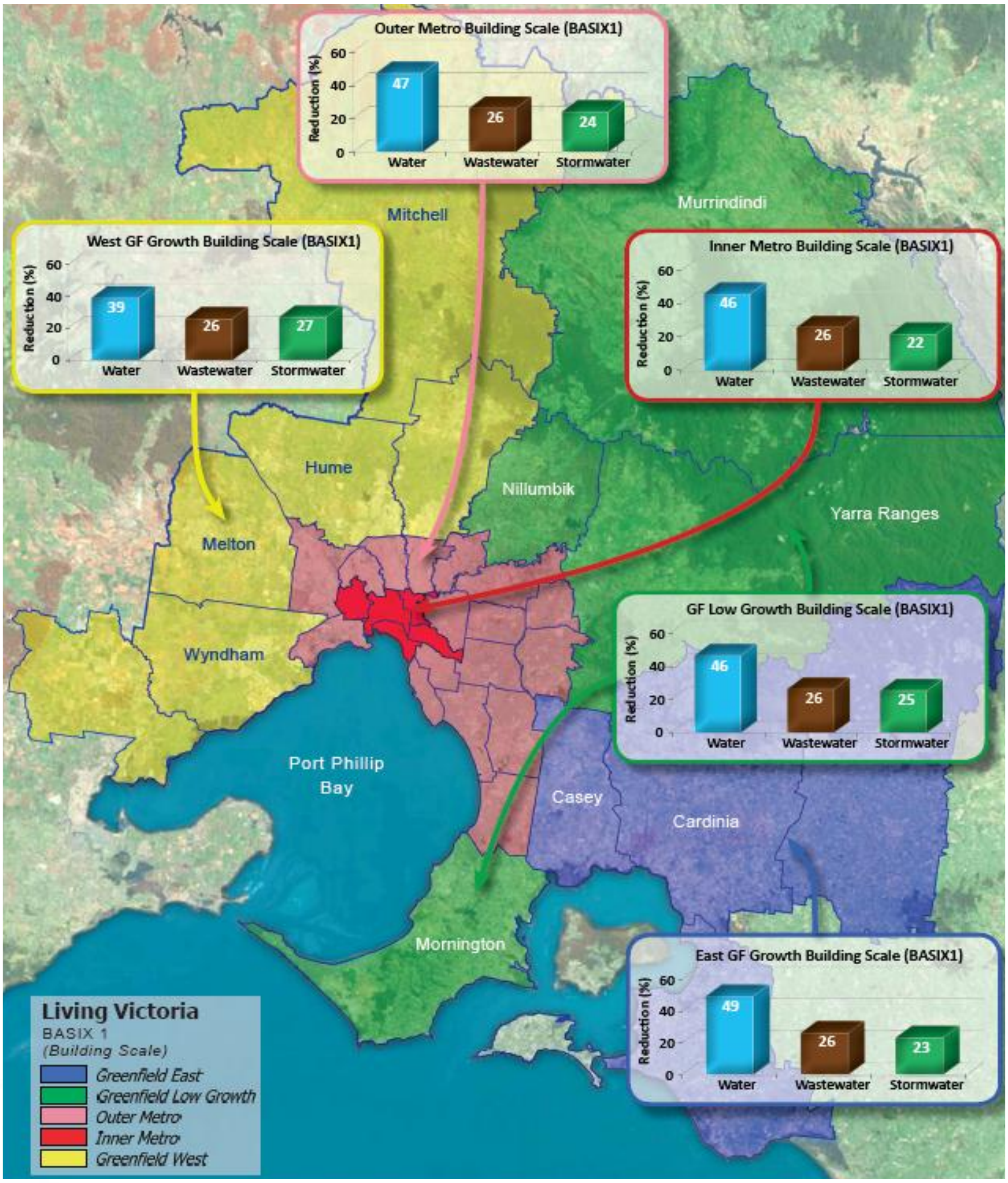

Figure 7.15: Spatial capacity of building scale measures – BASIX1

Figure 7.15 reveals that the capacity of the BASIX1 Option is consistent throughout Greater Melbourne and provides similar variation, albeit slightly reduced, in capacity to the BASIX Option. Water savings from water efficiency is slightly reduced in comparison to the BASIX Option by the exclusion of water efficient gardens from the strategy.

Lower water saving and higher reductions in stormwater runoff are generated in West GF District whilst higher water savings and lower reductions in stormwater runoff are created in the East GF Growth District. The building scale solution does not include water efficient gardens resulting in a reduction in water savings generated by water efficiency and an increase in water savings provided by rainwater harvesting. In any event, the capacity of the BASIX1 "building scale" Option is significant throughout Greater Melbourne.

The performance of BASIX1 Option within the planning horizon (2010 to 2050) for each water cycle management district is presented in Figure 7.16.

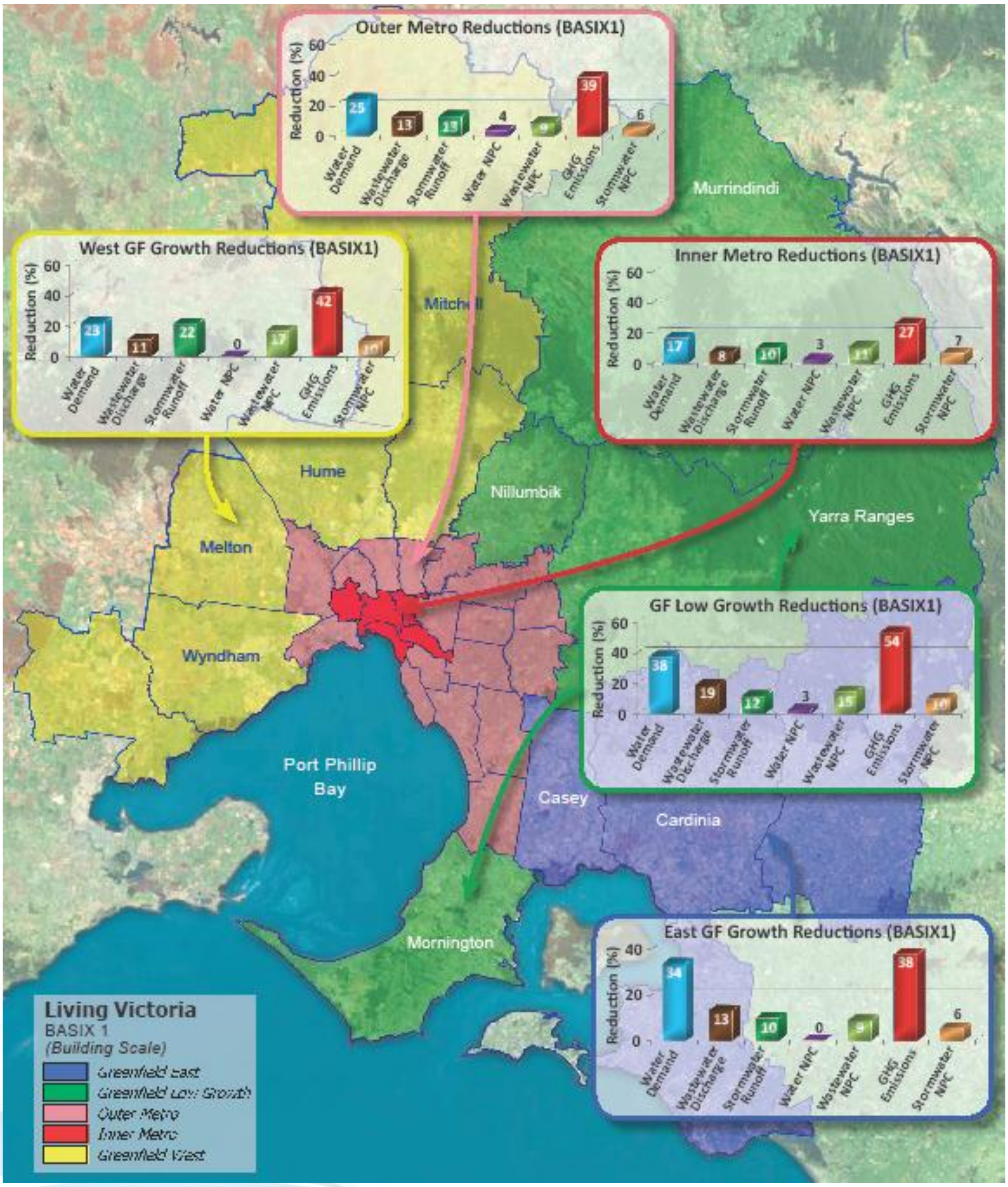

Figure 7.16: Spatial performance of building scale measures – BASIX1

Figure 7.16 reveals that BASIX1 Option produces relatively consistent performance across the Greater Melbourne region that is consistent with the variation displayed in the BASIX Option. Consistent small reductions in performance in comparison to the BASIX1 Option are experienced that are attributed to the absence of water efficient gardens.

ULT

The capacity of precinct scale strategies in the ULT Option for the different water cycle management districts is presented in Figure 7.17.

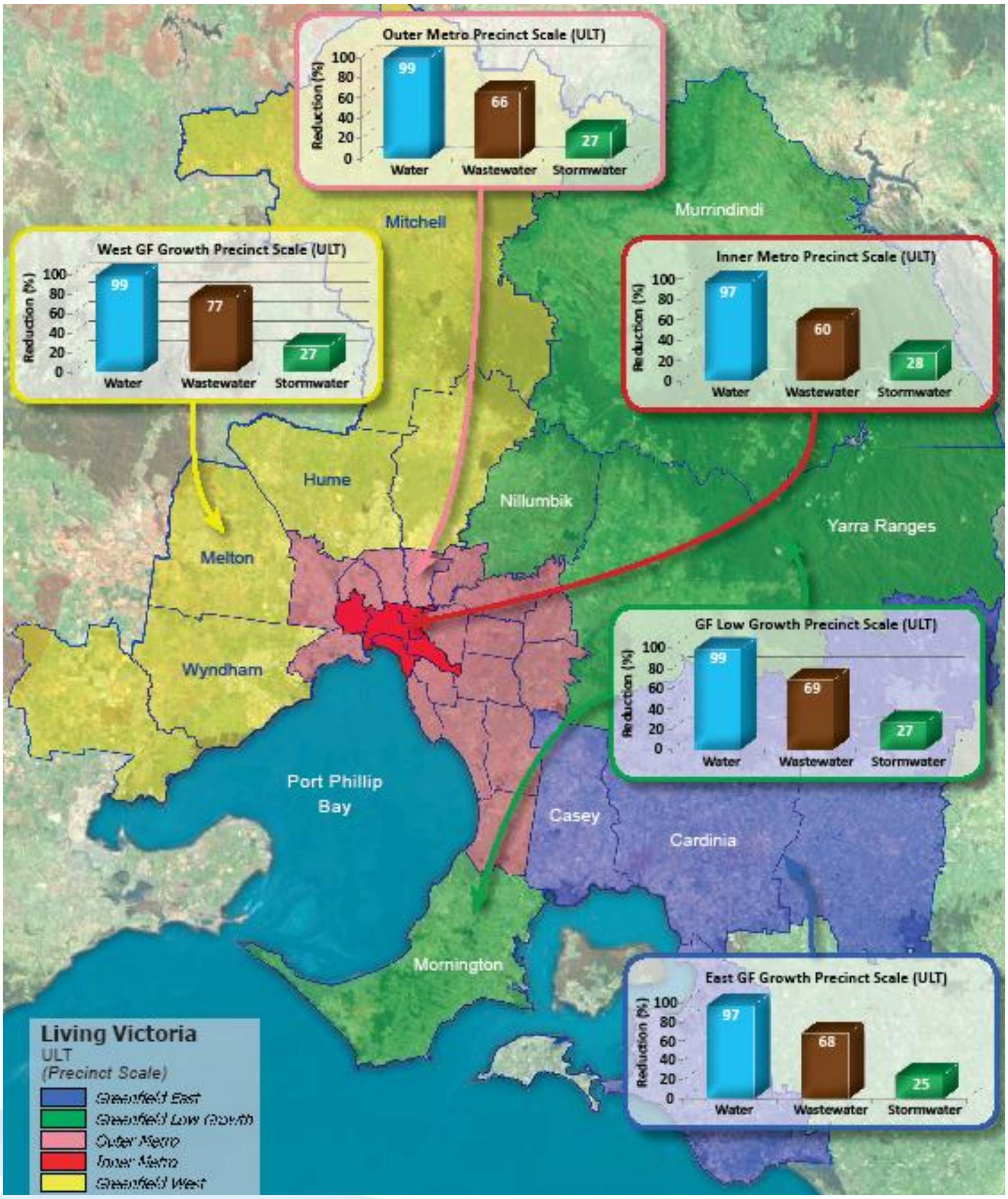

Figure 7.17: Spatial capacity of precinct scale measures – ULT

Figure 7.17 demonstrates that the ULT Option generates highly consistent and substantial capacity for precinct scale reductions in water demands and stormwater runoff across Greater Melbourne. Importantly, the integrated water cycle management (IWCM) can almost eliminate demands for mains water throughout Greater Melbourne. The precinct scale reductions in wastewater discharges are also substantial with more variation throughout Greater Melbourne. The variations in reductions in wastewater discharges are dependent on the magnitudes of demands of outdoor use within each District.

The performance of ULT Option within the planning horizon (2010 to 2050) for each water cycle management District is presented in Figure 7.18.

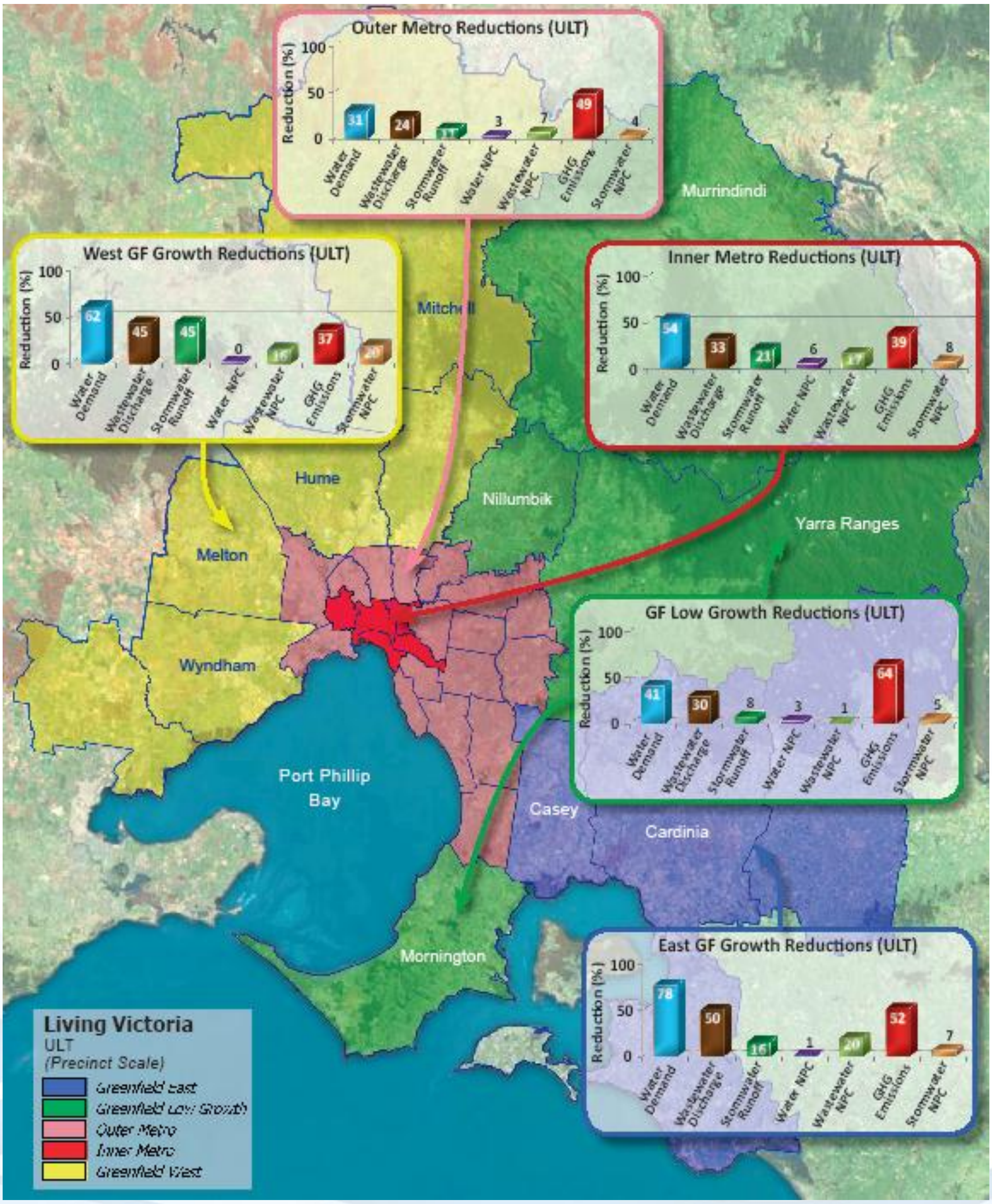

Figure 7.18: Spatial performance of precinct scale measures – ULT

Figure 7.18 reveals a high level of variability of water cycle, greenhouse gas and economic benefits throughout the Greater Melbourne region that was dependent on spatial factors including growth and renovation rates, transport distances for water and wastewater, demographics and the legacy of the costs of existing infrastructure.

The ULT Option generates the lowest reductions in demands for mains water and wastewater discharges in the Outer Metro District whilst the East GF Growth District provides the highest reductions in water demands and wastewater discharges. In contrast, the ULT Option creates consistently high reductions in water demands, wastewater discharges and stormwater runoff in the West GF Growth District.

Significant variation in the reductions in stormwater runoff is created by the ULT Option throughout Greater Melbourne that is dependent on climate and demographic factors. The highest reductions experienced in the West GF District and the lowest reduction provided in the GF Low Growth District.

Similarly, considerable variation in greenhouse gas emissions are generated by the ULT Option throughout Greater Melbourne that are dependent on transport distances for water and wastewater services, a legacy of existing infrastructure and policies, and requirement for regional augmentation for water security. The highest reductions in greenhouse gas emissions are generated for the GF Low Growth District and the lowest reductions are experienced in the West GF Growth District.

The most significant reduction in mains water demands are provided by water efficient appliances and gardens in the Inner Metro District. A small outdoor water use is balanced by higher indoor uses at this location to allow similar water efficiency as other locations. However, demand for treated wastewater is limited by the smaller outdoor water use in the Inner Metro District. This results in the lowest reductions in wastewater discharges and a slightly smaller reduction in water demands in comparison to the other districts for the precinct scale.

In addition, rainwater and stormwater harvesting provides greater reductions in water demands that result from supplying a higher indoor water demand. Greater yields from rainwater and stormwater harvesting at this location generate increased reductions in stormwater runoff and significant reductions in the costs of stormwater management.

Water efficient appliances and gardens provide similar reductions in water demands to rainwater and stormwater harvesting. The higher reduced costs for water and wastewater services are attributed to the reductions in water demands and wastewater discharges, and the higher costs in the Inner Metro District.

The most significant reductions in demands for mains water in the West are provided by water efficient appliances and gardens. The higher proportion of outdoor water use allows larger savings for water efficiency. Reductions in water demands created by reuse of wastewater and rainwater harvesting are similar. Higher outdoor use generates demands for treated wastewater and use of rainwater for constant indoor uses balances the impact of lower rainfall in the area.

Rainwater and stormwater harvesting in a lower rainfall area provides greater reductions in stormwater runoff with associated decreases in stormwater costs. Similarly, the combination of water efficient appliances and reuse of wastewater drives reductions in wastewater discharges.

ULT1

The capacity of each precinct in the ULT1 Option for the different water cycle management districts is presented in Figure 7.19.

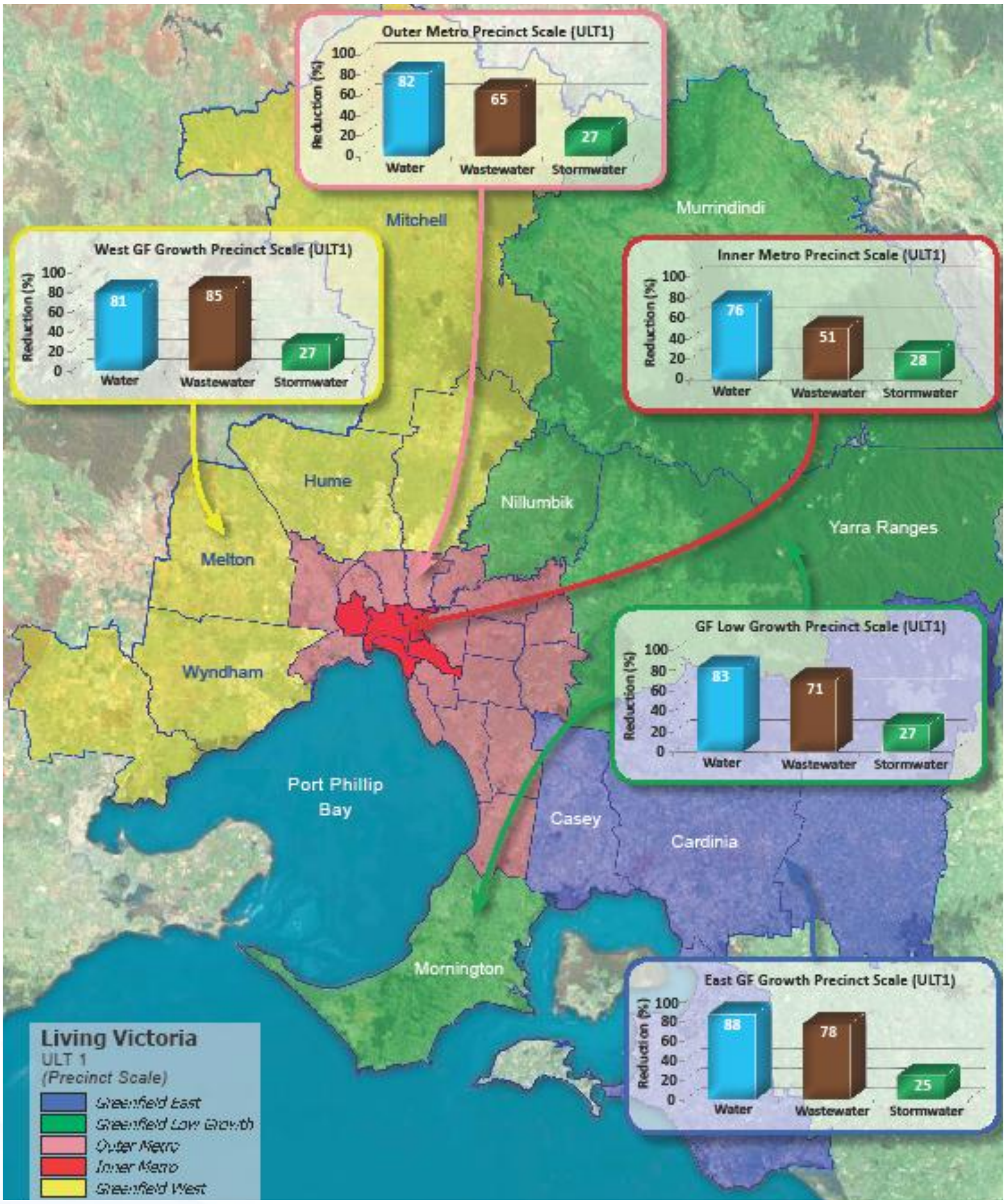

Figure 7.19: Spatial capacity of precinct scale measures – ULT1

Figure 7.19 demonstrates that the ULT1 Option creates relatively consistent reductions in demands for mains water and stormwater runoff throughout Greater Melbourne. The ULT1 Option produces similar variations in water demands, wastewater discharges and stormwater runoff to the ULT Option. However, the ULT1 Option generates diminished reductions in demands for mains water in comparison to the ULT Option because alternative water sources are not used to supply kitchen demands (including drinking water).

The performance of ULT1 Option within the planning horizon (2010 to 2050) for each water cycle management District is presented in Figure 7.20.

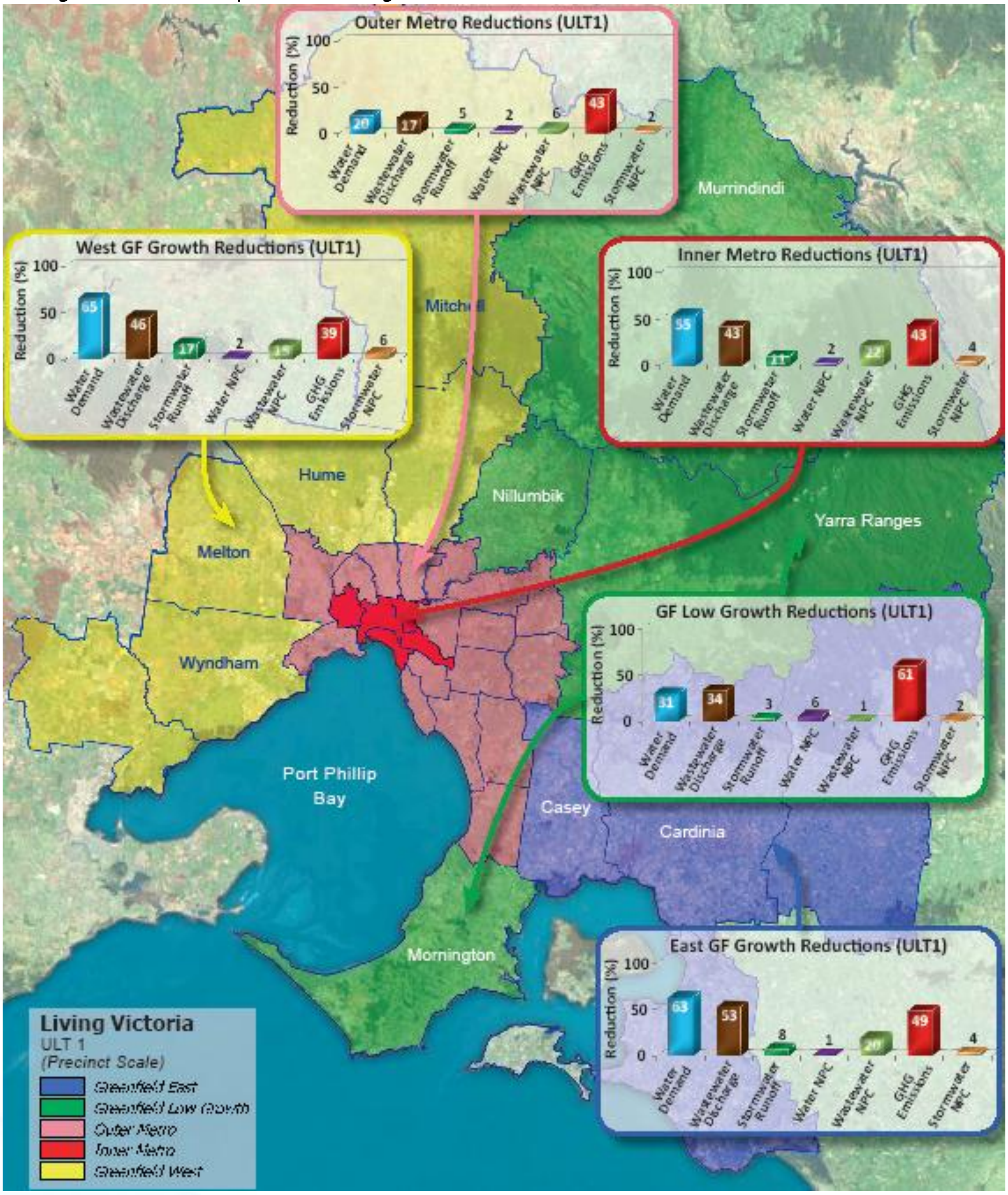

Figure 7.20: Spatial performance of precinct scale measures – ULT1

Figure 7.20 show that the ULT1 Option produces similar spatial variation of water cycle, greenhouse gas and economic benefits as the ULT Option. The differences between the ULT and ULT1 Options are generated by different demands for alternative water sources:

- wastewater reuse only supplies toilet and outdoor demands, and
- rainwater harvesting only supplies laundry and hot water demands.

Nevertheless, the ULT1 Option provides significant reductions in water cycle demands, greenhouse gas emissions and costs during the period to 2050.

7.8 Land savings, holding costs and the time value of money

The expected net present value of new and infill urban development was estimated to be $274 billion during the period 2010 to 2050. This value of potential land development throughout Greater Melbourne is substantially greater than the net present costs of providing trunk water and sewage services ($36.9 billion), stormwater management ($7.35 billion) and street scale infrastructure ($3.19 billion). It is essential that water cycle management strategies evolve to adequately service expanding urban areas.

Ongoing delays of one year throughout Greater Melbourne during the period 2010 to 2050 have the potential to create substantial increases in the costs of housing that are motivated by holdings costs that have a net present cost of $24.7 billion (9% of the NPV of the urban development industry). The annualised value of holding costs was $2.74 billion. It is important that more flexible and competitive solutions for water, sewage and stormwater services are available for the optimum future settlement of the Greater Melbourne region.

The use of the alternative Options reduces the area of land required for centralised stormwater management infrastructure (such as large constructed wetlands and retarding basins). Combining the alternative Options with WSUD streetscape measures including rain gardens, bio-retention facilities, landscaping measures that maximize infiltration and evapotranspiration, and roof gardens further reduces the land required for centralised infrastructure. The value of land savings is presented in Table 7.34.

Table 7.34: Summary of the value of land savings available from alternative management of stormwater

Criteria	Option				
	BAU	BASIX	BASIX1	ULT	ULT1
NPC of land for stormwater management ($B)	13.9	12.2	11.3	9.7	12.1
Saving in NPC (%)		**12.2**	**18.7**	**30.2**	**12.9**
NPC of land for stormwater management ($B) with WSUD	13.9	11.3	10.4	7.4	10.8
Saving in NPC (%)		**18.7**	**25.2**	**46.7**	**22.3**

Table 7.34 highlights the synergistic benefits of local measures such as rainwater and stormwater harvesting, and linear street scale WSUD measures for reducing the overall requirement for land to accommodate centralised infrastructure and flooding. Note that magnitude of these benefits range from a net present value of $1.7 billion to $6.5 billion.

Whilst these measures provide considerable economic value derived from land savings, it is also expected that these combinations will produce significant amenity value for greater Melbourne.

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Please note that these values are in addition to the stormwater infrastructure, nutrient and flooding values that were previously derived.

It is indeed significant that the land costs associated with stormwater management are considerably higher than the infrastructure costs – thus the net present costs of stormwater management for Greater Melbourne are $21.3 billion which is similar to the net present costs of providing water and sewage services. End of line stormwater management facilities such as detention basins and constructed wetlands with consequent requirement of flood ways results in a considerable demand for land.

7.9 Summary of results

The potential variability of population growth and climate are key drivers of future water demands, wastewater discharges and stormwater runoff throughout Greater Melbourne. A change in the structure of the Victorian economy could also present a significant impact on water demands, security of water supplies and the spatial needs within the system.

Alternative water cycle management Options deliver consistent and significant reductions in water demands, wastewater discharges and stormwater runoff. Alternative Options also deliver the greatest resilience and flexibility when subject to future variability. This results in substantial financial and environmental benefits to the State of Victoria.

The omission of water efficient gardens, and stormwater harvesting injected into the mains system for potable use "leaves significant value on the table".

Alternative water cycle management in buildings, households and precincts throughout Greater Melbourne has the capacity to achieve significant reductions in water demand, wastewater discharges and stormwater runoff throughout Greater Melbourne. The spatial performance of these alternative strategies during the planning horizon is modified by population growth, renovation rates, demographic processes and the legacy of existing infrastructure and policies.

Importantly, the Greater Melbourne region is subject to highly variable spatial and temporal processes that indicate that the performance of water cycle management cannot be described by averages, assumptions or generalisations. Some of these variable parameters include climate, demographics, performance of infrastructure, proximity to services and system constraints. Inclusion of this variability in analysis enables the understanding of the previously hidden opportunities for Greater Melbourne.

Climate

The Greater Melbourne region is subject to considerable spatial variation of average annual rainfall depths ranging from 486 mm to 1,337 mm. Annual rainfall is highly variable over time and throughout the Greater Melbourne region.

The rainfall regime for the region can best be described as cyclic patterns of wet and dry periods throughout recorded history. The region has not experienced a "step change" in rainfall regime. Nevertheless, the average response to the recent drought was a 13.2% decrease in rainfall. It is noteworthy that daily maximum temperatures observed at the Melbourne RO gauge increased by 6% during the recent drought.

There was a trend to increased rainfall throughout the region in comparison to pre 1950 rainfall. In contrast, daily maximum temperatures were observed to increase by 3% in comparison to pre 1950 temperatures.

The average response to the recent drought in the water supply catchments was a 15.8% decrease in annual rainfall depths. There was no evidence that rainfall would cease at any location throughout water supply catchments. There was no evidence of a significant step change to reduced rainfall throughout the water supply catchments. Indeed, there was a trend to increased rainfall throughout the water supply catchments in comparison to pre 1950 rainfall regimes.

The seasonal distribution of rainfall varies throughout the region. Many locations within Metropolitan Melbourne are subject to even seasonal distribution of rainfall. The dominance of Winter and Spring rainfall in the seasonal distribution is more significant in areas with higher rainfall and elevations or near the ocean.

Greater Melbourne experiences considerable variation in the seasonal distributions of rainfall which highlights the importance of using local data in analysis of water resources. A majority of the region is subject to relatively high number of average annual rain days that range from rainfall occurring every 3 to 5 days. The region is subject to higher frequencies of rainfall during the Winter and Spring seasons.

Residential water demand

Metered quarterly water use from households, distribution of household sizes and dwelling types, average weekly income, average age and a range of climate parameters from each location were utilised to derive the lot scale water demands employed in this study.

Importantly, household water use was found to be dependent on climate and demographic parameters that vary widely across the Greater Melbourne region. The spatial variation of household water use across Greater Melbourne is influenced by income, minimum and maximum temperatures, rainfall depths and frequency of rainfall.

The strongest influence on domestic water use was annual average maximum daily temperatures and annual average number of rain days. The average age parameter was observed to have a limited impact on water use. Higher values of average annual rainfall, average annual minimum temperature, annual average number of rain days and average age correlate with lower water demands. Greater values for average annual temperatures and average incomes correlate with higher water demands.

The spatial variation of parameters influencing water use indicates that use of global averages to represent water demands for the Greater Melbourne region will produce a misleading understanding of water planning, analysis of alternative water sources and water conservation strategies. Importantly, household sizes and dwelling types are not normally distributed or spatially consistent throughout the region which renders the use of averages unreliable.

This study has revealed a paucity of knowledge about household water use behaviour throughout Greater Melbourne. Current and historical metering programs do not provide sufficient information to allow a robust understanding of the highly variable water use behaviour throughout Greater Melbourne. There is only limited information available to understand the drivers for indoor and outdoor water use.

Regional water supply

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 ULT1 and the BASIX Options provide similar cumulative reductions in demands for mains water of 20% and the BASIX1 Option generates a 17% reduction in demands for mains water.

Regional wastewater management

The ULT Option produced a 21% reduction in the cumulative discharge of wastewater. The ULT1 Option uses less treated wastewater than the ULT Option and generates a 17.5% reduction in cumulative wastewater discharges. The BASIX and BASIX1 Options provide reductions in cumulative wastewater discharges of 11% and 8% respectively.

Regional stormwater management

The ULT and ULT1 Options reduce cumulative stormwater runoff by 20.5% and 19.4% respectively. Reductions in the cumulative volumes of stormwater runoff ranging from 14.3% to 11.8% are generated by the BASIX and BASIX1 Options.

Water balance

The alternative Options for water cycle management include a range of water sources that are components of each water balance in 2050. The BAU Option includes mains water (81%), wastewater reuse (1.5%), rainwater harvesting (7.5%) and water savings from efficient buildings (9.6%).

In contrast, the BASIX Option includes 59% mains water, 16.5% rainwater and 23.1% savings from water efficient gardens and buildings. The BASIX1 Option includes 61.8% mains water, 18.5% rainwater and 18.2% savings from water efficient buildings.

The ULT Option includes 44.6% mains water, 16.5% wastewater reuse, 7.5% rainwater, 8.4% stormwater harvesting and 23.1% savings from water efficient buildings and gardens.

Components of the ULT1 Option are mains water (50%), wastewater reuse (14.5%), rainwater (12.3%) and water efficient buildings and gardens (23.1%). Multiple water sources combine to produce substantial reductions in demands for mains water – this is typical of an IWCM strategy.

The response of each Option to the scenarios in 2050 is presented in Table 7.34 for mains water supply, wastewater discharges and stormwater runoff from the Greater Melbourne region.

Table 7.34: Summary of water balances for the Options

Option	Change (%)		
	Water	Wastewater	Stormwater
BAU	-19 to +7	-2 to +6	-22 to +9
BASIX	-36 to -24	-25 to -11	-29 to -7
BASIX1	-34 to -20	-23 to -6	-30 to -8
ULT	-52 to -40	-36 to -30	-26 to -11
ULT1	-40 to -30	-32 to -25	-24 to -2

Table 7.34 demonstrates that the alternative Options for water cycle management provide consistent reductions in water demands, wastewater discharges and stormwater runoff that were resilient to the impacts of the scenarios.

Water security

A summary of the results from each scenario for security of water supplies is presented in Table 7.35.

Table 7.35: Summary of water security for scenarios

Scenario	Year of augmentation versus Option				
	BAU	BASIX	BASIX1	ULT	ULT1
BAU	No	No	NO	No	No
HE	2014, 2026, 2045	2023, 2039	2015, 2023, 2047	No	2045
LE	2015, 2032	2034, 2045	2031, 2045	No	2038
GF	No	No	No	No	No
IF	No	No	No	No	No
Zero	No	No	No	No	No
Two	2042	No	2042	No	No
EC	No	No	No	No	No

Table 7.35 reveals that alternative Options for water cycle management provide significant improvements in the security of Greater Melbourne's water supply. The ULT Option that includes multiple sources of water eliminate requirement to augment regional water supply under any likely future scenario.

This investigation has utilised systems analysis using 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 use of increasingly generalised 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.

Although each of the water demand Options includes the same total water demands, different levels of generalisation about water demands creates uncertainty about the security of water supplies for Greater Melbourne. Clearly, increasing generalisation and averaging produces:

- Increasingly optimistic understanding of the security of water supplies
- Dramatic reductions in certainty about system behaviour – leading to incorrect understanding of the performance of the system.

Regional economics

The cumulative costs of water and wastewater services are significantly reduced by the alternative Options over the planning horizon. 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 and wastewater across Greater Melbourne reduces the costs of augmentation, renewal and operation of infrastructure. In addition, the requirement for regional augmentation of water supplies creates long run economic benefits. The changes in the net present costs of water and wastewater infrastructure are summarised in Table 7.36.

Table 7.36: Summary of the changes in net present costs of water and wastewater services provided by the Options and Scenarios

Option	Change (%)		
	Water	Wastewater	Total
BAU	-10 to +16	-9 to +4	-9 to +10
BASIX	-10 to +6	-15 to -8	-12 to 0
BASIX1	-9 to +13	-14 to -6	-11 to +5
ULT	-10 to +1	-13 to -10	-11 to -3
ULT1	-11 to +4	-14 to -9	-12 to -1

Table 7.36 highlights that the net present costs of providing water and wastewater services are subject to considerable variation. However, the alternative Options reduce the potential variability of the costs of providing water and wastewater services, and produce consistent reductions in costs.

Flooding and health of waterways

Additional benefits created by the alternative Options include management of stormwater runoff volumes from urban areas which can assist with reducing risks associated with flooding, environmental damage created by low frequency events and nutrient loads impacting on waterways.

Management of the cumulative loads of nitrogen discharging from urban development will assist in managing the health of urban waterways. The changes in the net present costs of trunk stormwater infrastructure, flooding and management of nutrients are summarised in Table 7.37.

Table 7.37: Summary of the changes in net present costs of stormwater trunk infrastructure, flooding and management of nutrients provided by the Options and Scenarios

Option	Change (%)		
	Infrastructure	Flooding	Nutrients
BAU	-59 to +20	-8 to +3	-22 to +4
BASIX	-61 to +8	-10 to -3	-30 to -8
BASIX1	-61 to +9	-11 to -3	-30 to -6
ULT	-60 to +4	-14 to -3	-41 to -11
ULT1	-59 to +14	-8 to -1	-24 to -1

Table 7.37 reveals that the net present costs of trunk stormwater infrastructure, flooding and managing nutrients are subject to substantial variation. The alternative Options reduce the potential variability of the costs and produce consistent reductions in costs.

Greenhouse Gas Emissions

The cumulative greenhouse gas emissions of each Option were derived as a function of sourcing, treating and transporting water and sewage throughout the entire Greater Melbourne system. The alternative Options provide considerable reductions in cumulative greenhouse gas emissions over the planning horizon. These reductions in greenhouse gas emissions are driven by minimising requirement for desalination, transport of water and sewage across long distances; and use of water efficient buildings. The changes in the greenhouse gas emissions for each Option in response to the Scenarios are summarised in Table 7.38.

Table 7.38: Summary of the changes in greenhouse gas emissions provided by the Options and Scenarios

Option	Change (%)
BAU	-44 to +65
BASIX	-52 to +33
BASIX1	-51 to +35
ULT	-52 to -8
ULT1	-53 to +19

Table 7.38 reveals potential substantial variation in greenhouse gas emissions. The alternative

Options reduce the potential variability in greenhouse gas emissions and produce consistent reductions in emissions.

Spatial Results

The Greater Melbourne region includes a wide range of spatially diverse influences that ensures that the performance of water cycle management strategies cannot be generalised across the region. This insight is highlighted by the differences in climate and socio-economic behaviours for the selected "districts", the transport distances associated with delivering centralised services and various infrastructure legacies. This investigation utilised these parameters to define districts for presentation of results:

- Greenfield East – areas in the east of Greater Melbourne subject to new growth
- Greenfield Low Growth – areas subject to low rates of new growth
- Outer Metro – outer areas of existing Greater Melbourne mostly subject to infill development
- Inner Metro – inner areas of exisitng Greater Melbourne mostly subject to infill development
- Greenfield West – areas in the west of Greater Melbourne subject to new growth

The alternative Options generate consistent and substantial capacity for building and precinct scale reductions in water demands and stormwater runoff across Greater Melbourne. The performance of the alternative Options in all Districts is dependent by the following issues across Greater Melbourne:

- differences in extension, renewal and operating costs of infrastructure,
- distances from bulk water supply and wastewater disposal points, and
- variable growth and renovation rates

8 Conclusions and recommendations

The purpose of this investigation was the provision of systems analysis of the water cycle for Greater Melbourne and advice in support of the Ministerial Advisory Council (MAC). This process aimed to generate discussion and deeper understanding of the detailed transactions that drive water cycle management throughout the region.

This alternative view was used as a basis for the implementation of the *Living Melbourne, Living Victoria* policy and this report supports the investigations and recommendations in the MAC's final report.

An integrated systems approach was employed by this study 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 unique analysis was dependent on detailed local inputs throughout the system, such as demographic profiles and human behaviour, and linked systems that accounts for water supply, sewage, stormwater and environmental considerations. The systems analysis was built on local scale (the people) impacts (a "bottom up" process) rather than traditional analysis of metropolitan water resources that commences with regional scale assumptions (a "top down" process).

This project has utilised the powerful framework for detailed systems analysis of the Melbourne region that has been developed over a long period of continuous investigation. Three decades of research, two separate investigations (the previous investigation commenced in 2006) and a year of dedicated analysis have enabled a robust analysis.

The process of refining and undertaking the systems analysis has generated a considerable volume of information and capability for additional analysis of the Greater Melbourne region. It was only possible to present some of the outcomes of a very detailed analysis in this report.

It is clear that the considerable ongoing growth of Greater Melbourne presents a range of substantial challenges to traditional water planning and servicing paradigms. However, the challenge of growth also presents compelling opportunities to change the approach to planning and providing water services for the region. It is also likely that Melbourne will not evolve as a uniform spatial or temporal process which creates considerable uncertainty about the provision of traditional centralised strategies for management of water and sewage.

The increasing movement and accumulation of water, wastewater and stormwater in expanding and aging networks of infrastructure is the greatest challenge facing Melbourne. In addition, the increasing age, declining capacity and condition of assets is expected to escalate the cost of managing these assets. Incremental extension, renewal and amplification of the infrastructure networks to meet these challenges are likely to generate significant diseconomies of scale into the future.

It is commonly perceived that the distribution of water and sewage throughout Greater Melbourne is solely reliant on gravity. However, water cycle networks throughout Greater Melbourne are reliant on significant amounts of energy to transfer water and sewage to locations where gravity can be utilised for distribution or disposal. Treatment of water and wastewater to acceptable standards is also dependent on substantial consumption of energy. In addition, reliance on desalination, large scale pipelines and large centralised wastewater reuse strategies will dramatically increase the energy profile of water and sewage services. Melbourne is being transformed from a city with lower energy water resources to a far higher energy profile.

The historical contribution of men and women employed in the Melbourne water sector is responsible for creating an international benchmark in provision of water services. Their knowledge, skills and approach have been critical in overcoming the many challenges involved in delivering the highest possible quality water services to Melbourne.

Melbourne is now faced with a new challenge. A change in the paradigm and approach to provision of water services will require new skills and methods. It is essential to harness the knowledge, skills and experience of the past and incorporate the new skills required to achieve a more diverse sector.

Melbourne's water authorities and government agencies occupy a powerful position within the Australian water industry and the Greater Melbourne region. This dominant position in the market has created institutional and economic co-dependence with a wide range of entities including consulting companies, research institutions and government agencies. Whilst this market position does have benefits, there are also negative outcomes such as a difficulty in seeking different independent advice, development of innovative solutions and approval of strategies.

There are encouraging and ongoing programs throughout the water sector in Greater Melbourne that are addressing the modernisation of water cycle management to meet future challenges. Nevertheless there is compelling evidence of the existence of pathway dependence on the provision of centralised services and a regulatory structure that limits interaction and inter-disciplinary collaboration. Moreover, a dominance of traditional engineering assumptions and processes that focus on provision of large scale centralised infrastructure excludes viable alternatives. Codified design guidelines based on centralised assumptions are also limiting innovation and adoption of alternatives.

Significant spatial variation exists throughout the Greater Melbourne region that cannot be described by the "whole of region" averages and generalisations commonly employed in the water industry. Indeed, use of averages prevents accurate understanding of the system and associated economics. It is our contention that the global responses of the Greater Melbourne system are driven by a range of decentralised behaviours – there is a need for greater understanding of the regimes of water use behaviours throughout the region.

This study has evaluated the efficacy of alternative water management strategies to supplement the existing centralised infrastructure that delivers services to Greater Melbourne. These alternative systems are not necessarily "stand alone" systems. In many situations these systems will be connected to the existing mains water and wastewater systems. They represent smaller systems within a larger regional system that may have infrequent and diminished dependence on the existing system. Alternative water cycle management solutions provide a lower cost and greater community value approach to ensuring water security throughout Melbourne. This study has established that alternative water cycle management is technically, commercially and environmentally viable strategy.

However, a holistic decision making framework for provision of services and investment decisions is required to recognise the value of alternatives. The smaller scale and timely nature of alternative water cycle management strategies allows adoption of more advanced modern technology as it becomes available. In addition, the associated deferral of investment in large scale traditional infrastructure presents significant option value. We should also be mindful that the holding and societal costs of urban development outweigh the cost of water cycle infrastructure – lengthy delays and the spatial dependence associated with the provision of large scale centralised infrastructure can have substantial impacts on the affordability of urban settlements.

The society of Greater Melbourne has come to an important junction in the approach to planning and providing water services. Behaviour and attitudes over the past decade provide a stark contrast of alternatives. The first involves government dominated centralised water cycle services reliant on "just in time" large scale augmentations. This will result in rising bills, escalating environmental damage, and community discontent.

The second alternative is to harness the community action which saved Melbourne from running out of water during the recent drought. The community has demonstrated they are responsible water managers and deserve a seat at the table in deciding how water services are provided.

8.1 Summary of results with key insights

A summary of the systems analysis of the Greater Melbourne region is presented in Table 8.1.

Most parameters relevant to water cycle management are subject to significant spatial variation throughout Greater Melbourne. The water cycle for Melbourne cannot be described by homogenous parameters based on a single location or regional averages.

The regimes of water demands, wastewater generation and stormwater runoff varies substantially across Greater Melbourne. There is also significant variation in the cost of providing water and wastewater services throughout the region. Existing water demands, growth, distance (and differences in elevation) from water sources and wastewater treatment contribute to the variable costs of providing services.

Performance of the system or policy responses cannot be based on single parameters or solutions. The existing system (BAU) is critically dependent on (or sensitive to) variations in climate and population. The expected increases and accumulation of wastewater and stormwater in water cycle networks are significant challenges for Greater Melbourne. Up to three additional augmentations of the regional water supply system may be required in the next 40 years. The alternative Options provide the following key outcomes:

- The building scale Options (BASIX and BASIX1) substantially mitigate the challenges of variable population and climate
- The precinct scale Options (ULT and ULT1) almost eliminate the challenges of variable population and climate
- Generate substantial reductions in water demand, wastewater generation and stormwater runoff
- Provide significant reductions in the cost of providing water and wastewater services
- Reduce transfer costs of providing water and sewage services

Table 8.1: Summary of the systems analysis

Criteria	BAU	BASIX	BASIX1	ULT	ULT1
Water Demand 2050 (GL/annum)	522	378 28% decrease	396 24% decrease	286 45% decrease	321 38% decrease
Cumulative water demand 2010-2050 (GL)	19,210	15,390 20% reduction	15,926 17% reduction	14,010 27% reduction	15,342 20% reduction
Augmentation of water supply	YES – up to 3 (HE) 2014 – 50 GL 2026 – 100 GL 2045 – 50 GL	YES - up to 2 (HE) 2023 – 50 GL 2039 – 100GL	YES - up to 3 (HE) 2015 – 50 GL 2023 – 50 GL 2047 – 50 GL	None required	YES - 1 (HE) 2045 – 50 GL
Reliant on desalination?	YES	YES	YES	NO	NO
Wastewater Discharge 2050 (GL/annum)	552	466 15% decrease	490 11% decrease	378 32% decrease	378 32% decrease
Cumulative wastewater discharges 2010-2050 (GL)	19,625	17,383 11% reduction	17,972 8% reduction	15,477 21% reduction	16,191 17% reduction
Stormwater Runoff 2050 (GL/annum)	527	483 8% decrease	478 9% decrease	306 42% decrease	467 11% decrease
Cumulative stormwater runoff 2010-2050 (GL)	17,487	15,383 12% reduction	15,171 13% reduction	14,919 15% reduction	15,355 12% reduction
Greenhouse Gas emissions 2050 (kT CO^2e/yr)	1,928	1,513 40% decrease	1,215 37% decrease	1,036 46% decrease	1,095 43% decrease
Cost of Carbon 2050 ($M)	48.2	28.8 40% reduction	30.4 37% reduction	25.9 46% reduction	27.4 43% reduction
Water NPC ($B)	23.9	22.7 5% decrease	23.2 3% decrease	23.2 3% decrease	23.5 2% decrease
Wastewater NPC ($B)	13	11.6 11% decrease	11.7 10% decrease	11.6 11% decrease	11.7 10% decrease
Stormwater NPC: Infrastructure, Flooding and Nutrients ($B)	7.35	6.9 6% decrease	6.83 7% decrease	5.37 27% decrease	6.53 11% decrease
Nutrients 2050 (tonnes/annum)	1,110	1,020 8% decrease	1,002 10% decrease	640 42% decrease	882 20% decrease

The alternative Options have the potential to transform the challenges of water cycle management throughout Greater Melbourne into opportunities. Growth is a key driver of future water demands, wastewater generation and stormwater discharges. The costs of incorrectly predicting population growth has critical implications for the State of Victoria.

Future variations in climate regimes will create substantial variations in water demands and availability of water. Higher temperatures drive greater water demands, and reduced rainfall and streamflow. The debate as to whether future urban growth should occur as Greenfield or Infill development does not appear to be significant. These Options do not have significantly different impacts on the behaviour of the entire system.

A change in the structure of the Victorian economy could have a significant impact on water demands, security of water supplies and the spatial response of the system.

Mistaken predictions of water cycle impacts and associated requirement for large scale infrastructure may result in stranded assets – large infrastructure without the demand to pay for it. Alternative Options consistently deliver significant reductions in water demands, wastewater generation and stormwater discharges.

The ULT Option generates the greatest reductions in water cycle impacts in comparison to BaU. The other alternative Options generate significant (but diminished compared to ULT) reductions in demands on the water cycle for Greater Melbourne.

Alternative Options also deliver the greatest resilience and flexibility when subject to future variability. The ULT Option delivers the greatest resilience and flexibility in comparison to BAU that is derived from the use of multiple water sources in combination with water efficiency. The other alternative Options also generate significant (but diminished compared to ULT) resilience and flexibility.

Water efficient gardens and public open space areas are an important component of overall water efficiency for Greater Melbourne. This initiative delivers tangible benefits including reduced water demands and avoided augmentation of infrastructure. Water efficient gardens should form part of future water policies.

The omission of stormwater harvesting for injection into the mains system for potable use from the ULT Option "leaves significant value on the table". This includes substantial reduction in mains potable demands, improved water security and reduced requirement for augmentation of the regional water system. Perceived problems that originate from concerns about institutional and governance issues need to be challenged and overcome. Failure to resolve these issues stand in the way of substantial benefits to society.

Alternative Options generate significant economic and financial benefits. The ULT Option generates the most significant reductions in costs and the other alternatives generate significant (but slightly reduced) benefits, including a reduction in the cumulative total costs of the system by up to $30 billion over 40 years.

Total water cycle management costs vary significantly in response to different futures. Substantial reductions in total costs are generated by the low growth and economic structural change Scenarios. In contrast, the high growth and climate change Scenarios produce considerable increases in total costs. The ULT Option generates the greatest resilience to variations in costs resulting from alternative future states and the other alternative Options generate diminished but still significant resilience.

The alternative Options generate a range of additional financial, social and environmental benefits, including:

- Up to a 20% (8,246 tonnes) decrease in nitrogen loads entering waterways
- Significant reduction in the costs of stormwater infrastructure (up to a 13% decrease), flooding (up to a 17% decrease) and management of nutrients (up to a 17% decrease)
- Up to a 30% (34,171 kT) reduction in cumulative GHG emissions. This result challenges the perception that alternative Options consume more energy than BAU. It also highlights the importance of holistic and integrated systems analysis.

This study compared the spatial opportunities for each Option with the potential spatial performance of each Option that was derived from the systems analysis.

Capacity is the definition of the potential of each Option at each building or household or precinct throughout Greater Melbourne.

Performance is the definition of the behaviour of each Option within the planning horizon that is modified by population growth, renovation rates, demographic processes and the legacy of existing infrastructure and policies.

Buildings and households across Melbourne have the capacity and ability to achieve significant reductions in water demand, wastewater discharges and stormwater runoff. This capacity varies across Melbourne. All Options provide fairly consistent capacity that results in substantial reductions in water demands, wastewater discharge and stormwater runoff for all locations across Greater Melbourne.

The spatial variation in performance of Options is driven by a multitude of factors including rainfall, proportion of residential and non-residential buildings, the age of suburbs and the condition of existing infrastructure, and the distance to and from water supply sources and wastewater treatment facilities.

- The ULT Option achieves consistently greater capacity and higher performance for all measured indicators for all of Greater Melbourne.
- Other alternative Options generate significant (but slightly diminished) capacity and performance for Greater Melbourne.

8.2 Recommendations

New Objectives

Whole of Melbourne objective based targets supported by spatially relevant local targets

The investigation has demonstrated that Greater Melbourne is subject to significant spatial variation and that specific locations provide differing capacity and deliver varying performance in response to "whole of system" policies. Delivery of discrete local solutions has the potential to generate significant financial, social and environmental benefits.

Objective based targets for "whole of Melbourne" that are underpinned by spatially relevant local targets will provide overarching guidance for appropriate technical and institutional solutions. These minimum objectives can be presented as building scale targets and whole of Melbourne objectives as shown in Table 8.2.

Table 8.2: Summary of minimum local or building scale targets for Greater Melbourne

Criteria	Annual reduction (%)		
	Water demand	Wastewater discharges	Stormwater runoff
Building scale targets	50	30	20
Whole of Melbourne Objectives	80	50	30

These objectives represent a base level of performance that regulators, water authorities, developers and households should be required to meet when building new developments or planning future services. Performance above these targets is feasible at specific locations and should be encouraged.

Eliminating lumpy expenditure

The current system of regulation, planning and provision of services in the water sector encourages authorities to minimise expenditure on assets for as long as possible. This process results in a requirement for infrequent or "lumpy" investment in regional infrastructure in response to the potential of imminent system failure. This investigation has demonstrated significant value in avoiding investment in large scale infrastructure by utilising timely investment in smaller scale distributed local infrastructure as required.

Regulation and objectives for infrastructure decisions should include a requirement to include the costs of finance and the timing of investment in analysis of Options.

Minimising the transfer distance of water and wastewater

It is current practice to only consider the incremental costs of extending infrastructure and transporting water and wastewater throughout Greater Melbourne. This investigation has demonstrated that the cost of moving water and wastewater across long distances becomes prohibitively expensive when all direct costs and benefits are included in decision making (without including unpriced elements such as environmental values, flooding and public amenity).

A holistic decision making framework must be utilised to account for these costs and benefits. The qualitative objective should be an aspiration to minimise the transfer distance of water and wastewater from their source of collection or generation.

Improved planning and analysis

Detailed holistic systems analysis underpinning planning and decision making

A key insight of this investigation is the value of holistic and integrated systems analysis for water cycle planning and decision making. The systems analysis considers all the costs and benefits of alternatives and presents the decision making process in an open and transparent manner.

It is recommended that the systems analysis methods utilised for this investigation be incorporated in decision making to provide better understanding of the spatial variance and complexity of the water cycle throughout Greater Melbourne. The use of open, transparent and holistic analysis that includes all costs and benefits will ensure that clear understanding of alternatives and tradeoffs are generated.

This process combines many of the recommendations from this investigation (holistic decision making, minimising lumpy investment and transfer distance of water and wastewater) and will generate outputs provided by this study (whole of system objectives supported by sub regional objectives).

A new set of design guidelines incorporating the latest knowledge and understanding

This investigation has demonstrated that the current codified design guidelines do not provide the flexibility required to develop an adaptive and resilient water cycle. Furthermore these design rules are likely to impose greater costs than may otherwise be necessary to deliver new infrastructure and providing ongoing services.

A new set of design guidelines that are underpinned by the latest knowledge, understanding and approach to the design of water services infrastructure are essential to assist in the implementation of successful alternative strategies. The new guidelines must consider the impacts of multiple water sources, water efficiency and local variability on the design of infrastructure.

Implementation of a new set of guidelines must be supported by an effective communication and engagement process to ensure relevant stakeholders have a sound understanding of the new process.

Access and contestability

The shortcomings of "Competition by Comparison"

The structure of the monopoly water sector for Metropolitan Melbourne is portrayed as a leading model for urban water governance structures and institutional arrangement. However, this investigation suggests that the "competition by comparison" structure may have actually created a number of perverse outcomes.

Significant gaps in information and understanding of water and sewage networks are evident across jurisdictions throughout Greater Melbourne. This appears to be a consequence of:

- inadequate systems for collection and management of information,
- conflicting and confusing organisation of the system,
- inconsistent organisation of information generated from the system, and
- a lack of common understanding.

This is a critical element of water cycle management that requires resolution. Recommendations relating to the management of data and information are provided later in this document.

The creation of a single bulk water authority and three retail water authorities for Greater Melbourne has resulted in significant duplication of resources, systems, bureaucracies and corporate structures. Many common elements for provision of water and wastewater services are provided by different water authorities with dedicated staff and systems.

The current structure of effectively four water monopolies has divided a naturally linked infrastructure network across four separate entities. This structure also results in each geographic area being "cordoned off" to competition from the other authorities and third parties. This has not produced incentives for water authorities to compete to deliver optimum or innovative infrastructure strategies or services.

Creation of a competitive environment that forces the incumbent water authority to prove that its preferred solution is the socially optimal outcome and that the incumbent authority is best placed to deliver these services is critical. Enabling other organisations, such as existing water authorities or third parties to propose alternative solutions and services will ensure delivery of the best value for money and greatest benefit to society as a whole.

The development of a competitive structure is the subject of significant consternation and conjecture. One approach is to create a set of rules and processes to enable third parties access to delivery and provision of services. Whilst this process may work in theory, establishment of the rules of engagement and entry are only part of the problem.

The co-location and operation of planning, approval and operational functions for delivery of infrastructure and the provision of services creates an inherent conflict and uncompetitive situation. An external competitor will always struggle to compete with the incumbent than controls planning and operation. This situation has been well demonstrated by the processes relating to the Telstra and Optus "battle" in the Australian telecommunications sector.

Measures can be taken to separate the planning, approval, infrastructure development and operational functions of water authorities. Accounting separation between divisions to generate accountability, transparency of costs and "competition between divisions" enables the costs of geographic authorities to be compared. Physical separation of divisions (different buildings and different suburbs) can also work but experience has shown that this simply increases the telephone and travel costs within the organisations.

An optimum solution is to ensure that water authorities are not responsible for planning, approval and infrastructure development processes. These processes should be the jurisdiction of an independent authority. Water authorities should be responsible for operational processes.

Data and information

Improved data gathering and management across the system

This investigation identified significant gaps and failures in the approach to data gathering and management. There were many situations where information does not exist, is difficult to access, or has inadequate quality.

Water authorities are reliant on aging information collection (SCADA) systems that provide inadequate coverage and inconsistent information throughout the networks servicing Greater Melbourne. In particular, these information systems provide conflicting and inconsistent data at the boundaries of the jurisdiction each water authorities. Elements of these problems include insufficient meters and faulty meters that provide incomplete and incorrect information. Some authorities appeared to have a better knowledge on their information management systems or have recently implemented new SCADA systems and meters.

In addition there is a paucity of knowledge about water demands at the building scale (individual households and businesses). Observations from most properties were limited to observations made for billing purposes that are based on a three month rolling average process of meter reading.

This investigation has demonstrated the importance of the water demands and wastewater generation of individuals. Small variations between individuals can result in significant variation across geographic areas and all of Melbourne. An accurate understanding of the spatial and temporal patterns of household water use is fundamental to sound planning and investment.

It is not possible to accurately and efficiently manage a system that is not understood or adequately monitored. There is a clear need for a high quality, robust, consistent and reliable information collection system for the entire network. This system should be implemented and managed independently and in partnership with all water authorities to ensure consistency.

This investigation revealed a scarcity of trained and knowledgeable individuals for collection and management of information about water cycle systems throughout Greater Melbourne. It is unacceptable that there are insufficient appropriately skilled, qualified and accessible individuals who can access information as required.

It is critical that there are sufficient people within water authorities that have the requisite skills, knowledge and understanding to manage information collection and management systems.

Open and transparent information freely available to all

The LV MAC process and the interactions that have occurred during this investigation have demonstrated that there is significant information asymmetry between various stakeholders throughout the sector. In particular, the water authorities have significantly greater access to information than other players in the market. Further, an unwillingness to share this information and provide an equal understanding to external parties was evident throughout the process.

This asymmetry has had a significant impact on the sector and resulted in many of the sub-optimal outcomes outlined in this investigation. To assist in overcoming this asymmetry, it is crucial to provide open, transparent, and freely accessible information for all stakeholders and the community.

It is important to foster equal access to information about historic and current water cycle, infrastructure, demands, climate, streamflows, dam levels, water security, system constraints and operating rules. Plans for future system management including capital plans, strategic assessments, asset condition and infrastructure assessments, planned augmentations, and demand projections should also be made available.

This information should be available in a common location and format. Technical explanation of information should also be provided to stakeholders. Affording this right to all stakeholders will provide the basis of a common understanding of opportunities throughout society.

9 Question and answers

A forensic investigation and systems analysis of the entire water cycle for a metropolis is a significant task. Open and transparent engagement with stakeholders via wide ranging consultation and explanation resulted in a comprehensive and robust process.

The authors of this report questioned themselves throughout the entire process to ensure the highest quality analysis was conducted. Hundreds of questions were also fielded from many different organisations and individuals that assisted with understanding of "what is it that we were doing, how it worked and why we got the answers that we did".

This Chapter provides an overview of some of these questions with the aspiration to enlighten the reader, share part of the journey of the investigation and provide a taste of the rich and robust discussion that is generated by a policy development process.

What is wrong with the current approach to the provision of water services? What is wrong with the status quo? Why do we need to change?

Melbourne is not homogenous. Global system responses are driven by local behaviours. For example, demands for water, wastewater discharges and the physical constraints of providing services vary substantially and are not suited to single uniform assumptions or responses. Greater understanding of water use behaviours throughout the region will assist in defining solutions.

The future reliability of centralised urban water systems is uncertain. The recent drought demonstrated that traditional water supply systems and planning processes do not have the necessary resilience and flexibility to handle future shocks.

Increasing movement and accumulation of water, wastewater and stormwater throughout expanding and aging infrastructure networks is an ongoing economic problem for Victoria. Greater Melbourne's water demands are expected to increase by 76% to 540 GL/annum in the status quo Options within the next forty years. There are realistic scenarios that indicate the need to augment regional water supply supplies three times over the next 40 years.

By 2050, wastewater discharges throughout Greater Melbourne are predicted to increase by 43% to 550 GL/annum. Likewise stormwater runoff from urban areas is expected to increase by 23% to at least 478 GL/annum. As a consequence, significant increases in stormwater peak discharges, flooding and sewer overflows in urban areas are anticipated.

The increasing age, declining capacity and condition of water cycle network infrastructure will escalate the cost of managing assets and providing services. A significant proportion of this network infrastructure has already exceeded its design life. A combination of aging infrastructure and incremental extension, renewal and amplification of infrastructure networks is likely to result in significant diseconomies of scale across the system.

The water cycle system for Greater Melbourne consumes significant amounts of energy to treat and transfer water and sewage through the centralised network. By 2050, 1,920 kT of GHG emissions are expected to be produced every year. At a price of $25/tonne this equates to an annual debt of $48 million.

Victorian Government agencies and water authorities responsible for water cycle services occupy a powerful position within Melbourne and the Australian water industry. This dominance has created institutional and economic co-dependence across consulting services, research and development, and the development of government policy. Pathway dependence has emerged that limits external interaction, inter-disciplinary collaboration and alternative solutions. This process is dominated by detailed engineering and a focus on provision of large scale centralised infrastructure based on codified design guidelines that also limits innovation and the adoption of alternatives.

Population growth is a key driver for the performance of the system and sustainability outcomes. Areas subject to new development or redevelopment will present the greatest challenge to the provision of traditional infrastructure and services. This population growth will not occur uniformly across temporal and spatial scales. This presents a significant challenge to the planning and delivery of traditional centralised water, wastewater and stormwater strategies.

What are the purpose of Options and Scenarios? How do they differ and how have they been used in the analysis?

Options were created to analyse the performance of alternative water management strategies. The purpose of establishing Options is 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, comparison and understanding of the water cycle throughout Greater Melbourne.

Four alternative Options were examined for water cycle management within Greater Melbourne and compared to the BAU Option:

1. **Business as Usual (BAU)** – The current approach water cycle management. The Base Case.
2. **BASIX** – Integrated water cycle management at the building scale that includes water efficient gardens.
3. **BASIX1** - Integrated water cycle management at the building scale that does not include water efficient gardens.
4. **Ultimate (ULT)** – Integrated water cycle management at the precinct scale that includes stormwater harvesting for potable use.
5. **Ultimate1 (ULT1)** - Integrated water cycle management at the precinct scale that does not includes stormwater harvesting for potable use.

The performance of each alternative Option was compared to the performance of the Business as Usual (BAU) Option.

Scenarios were established to test the performance of each Option with realistic potential opportunities and threats. The Scenarios developed for this investigation included:

1. **Low Emissions Climate Change (LE)** – Annual incremental increases in maximum temperatures that are consistent with the lower bounds of the IPCC's high emissions scenario. Tests the impacts of temperature increases on the each Option.
2. **High Emissions Climate Change (HE)** – Annual incremental increases in maximum temperatures that are consistent with the upper bounds of the IPCC's high emissions scenario. Tests the impacts of temperature increases on the each Option.
3. **All Greenfield Growth (GF)** – A situation where all of Melbourne's growth occurs at the urban fringes in undeveloped "Greenfield" areas.
4. **All Infill Growth (IF)** – A situation where all of Melbourne's growth occurs within existing developed areas as densification of urban form.
5. **Low Population Growth (0%)** – No change in Melbourne's population to 2050.
6. **High Population Growth (2%)** – A 2% annual growth in Melbourne's population to 2050.
7. **Economic Structural Change (EC)** – Restructure of Melbourne's economy from (water intensive) manufacturing and industry into other sectors.

Use of Options and Scenarios ensured the investigation did not pick an endpoint or a certain outcome. Instead the systems analysis provides useful insights about the performance of the system in response to a range of stressors that can subsequently inform future decision making.

What is Integrated Water Cycle Management? Why is it proposed as an alternative to the status quo?

Integrated Water Cycle Management (IWCM) is a multi-disciplinary, multi-objective approach to planning for the sustainable use of available resources. The principles of IWCM have been applied in the development of the BASIX, BASIX1, ULT and ULT1 Options.

The key processes of environmental protection, water supply, wastewater disposal and stormwater management are integrated at the start of the planning process. These objectives are evaluated across a whole-of-life-cycle using multiple criteria that include environmental, social, technical, economic, financial, health and biodiversity factors.

Importantly, an IWCM strategy presents solutions at multiple scales. The principles of IWCM are applicable to the development of strategic overarching Government policy (National, State or Local Government) or the development (or redesign) of a single dwelling, high density development, precinct or city. Specific attributes may vary slightly but the guiding principles and philosophy remain.

An IWCM strategy should consider the availability of all water resources including water extracted from river systems, groundwater, roof water, grey water, treated wastewater, stormwater and water conservation. The quality of water from these sources should be matched with the desired water quality of the end uses thereby minimising the requirement for treatment. This is also known as a "fit-for-purpose" approach. Water efficiency (water efficient appliances and practices) are an important element of an IWCM strategy.

Importantly, IWCM strategies combine best practice stormwater management or Water Sensitive Urban Design (WSUD) approaches with reductions in mains water use and reduced sewage loads to improve the security and sustainability of regional water supplies. The philosophy addresses multiple objectives including reductions in greenhouse gas emissions, costs and benefits, and timing of development.

This strategy has been proposed as an alternative to the status quo for this investigation as IWCM demonstrates how many of the key limitations of centralised water cycle management can be rectified. When implemented correctly, IWCM can achieve a paradigm shift away from current practices.

How does IWCM differ from traditional water cycle planning? What are the key benefits of IWCM?

The first and most important difference between the traditional water cycle management and IWCM is the philosophy and approach to planning.

Traditional strategies base solutions on relatively simplistic analysis and seek to apply existing solutions. IWCM strategies integrate analysis of all aspects of the water cycle to identify the most sustainable use of all water sources - even if the system is more complex. This enables co-dependencies and tradeoffs to be recognised and assessed.

This investigation has demonstrated that IWCM solutions represent a lower cost and greater community value approach to water cycle services throughout Greater Melbourne in comparison to the business as usual approach. The flexibility of IWCM allows adoption of newer technology as it becomes available and delivery of infrastructure as it is required.

An important difference is the focus on resilience, flexibility, the time value of money and benefits of deferred traditional infrastructure. This investigation has demonstrated IWCM strategies defer investment in large scale traditional infrastructure which generates significant option value.

Another important difference of IWCM is the consideration of holding and societal costs of urban development. The flow-on impacts of delayed centralised infrastructure (such as the financing costs of delayed land development) dwarf the cost of water cycle infrastructure. Delay and spatial dependence of large scale centralised infrastructure impact on the affordability of urban settlements.

How does Integrated Water Cycle Management differ to Water Sensitive Urban Design?

Water Sensitive Urban Design (WSUD) are design principles that aim to reduce the impact of interactions between the urban built form and the urban water cycle as defined by the three urban water streams of potable water, wastewater and stormwater.

The concept of IWCM developed from a number of sources including WSUD. IWCM is seen as a way of combining multiple objectives in an integrated systems framework to help ensure ecosystem health is maintained. IWCM often includes WSUD strategies as components for management of stormwater.

Are there any existing cases of IWCM?

There are many examples of successful WSUD and IWCM strategies throughout Australia. These philosophies are now emerging as accepted practice. Most new policies and projects will include elements of these strategies. However, strong elements of resistance remain within water authorities, local government and government departments, largely due to institutional inertia. It remains a difficult task to implement a WSUD or IWCM project within Greater Melbourne.

Do decentralised solutions necessarily mean they are disconnected to the regional system?

No. Decentralised systems are not necessarily "stand alone" systems. In many cases these systems are connected to existing centralised systems - representing a "multi-scaled" smaller system within a larger system. Decentralised systems simply have diminished dependence on the centralised system. This reduces aggregate system demand and wastewater discharges. This reduces the size of trunk infrastructure required to provide a given level of services. This approach has strong impacts on the performance of infrastructure that connects to the regional network.

During the last drought, it was stated that it would never rain again. Is this true? If water supply is decentralised, won't urban storages run out of water during periods of drought?

This investigation has found that considerable spatial variation in average annual rainfall depths was observed across the Greater Melbourne region that ranged from 486 mm to 1,337 mm. This has varied impacts on the system.

Rainfall sequences display cycles of higher and lower rainfall that do not demonstrate a "step change" in rainfall regimes. In addition, the Greater Melbourne region has not experienced a year without rainfall. The majority of rainfall records across Greater Melbourne show a trend to increasing annual rainfall depths since 1950.

The Greater Melbourne region experienced an average decrease in annual rainfall depths of 13.2% during the recent drought. However, even during low rainfall years, sufficient depths of rainfall occur at all locations for effective rainwater and stormwater harvesting. Water supply catchments over the same period recorded a greater average reduction in annual rainfall depths of 15.8% that generated 30% reductions in average annual streamflows into Thomson Dam. Storages in urban catchments demonstrate a greater resilience to reduced rainfall than traditional water supply catchments due to the impacts of greater impervious areas in urban catchments.

Another important consideration is that IWCM strategies include the diversification of water sources. Use of treated wastewater for non-potable purposes becomes a valuable resource and significantly reduces overall demand for mains potable water and reduces wastewater discharges to the environment.

Does alternative water management mean people will be forced to drink wastewater?

Alternative water management strategies (such as IWCM) are not reliant (or focused) on drinking recycled wastewater. These strategies encourage the sustainable use of all available water sources. Wastewater it is a valuable source of water which should be used. Wastewater can be treated to Class A standards and used for non-potable purposes such as public space irrigation and outdoor use, toilet and potentially laundry uses.

What is the cost of implementing an IWCM scheme in relation to traditional water solutions? Will an alternative water strategy mean water will cost more?

This investigation has demonstrated that alternative water strategies (IWCM) can be implemented across Greater Melbourne for less than the whole of system costs of delivering traditional water cycle services.

In addition, alternative water (IWCM) strategies generate additional benefits that traditional approaches do not consider. These benefits include reduction in pollution, urban flooding, environmental benefits, and improved urban amenity and community choice. Alternative (IWCM) strategies are less expensive than traditional water services when all of the benefits are considered.

How does the alternative strategy relate back to the emerging community needs and attitudes?

There has been an evolution of community attitudes to water management over time. Greater Melbourne is not a homogenous entity and cannot be labelled by a single unit or value. In reality there are a range of views, beliefs and desires which drive a range of attitudes to water cycle management throughout the community.

Some members of the community seek cheap and secure services. Others seek greater choice and options for provision of water services.

Centralised water services provide a homogenous product (potable water and wastewater management). Alternatively, decentralised and multi-scaled (IWCM) solutions enable provision of services based on local desires, choices and preference of smaller clusters of decision makers. An individual household, street, precinct, or suburb can decide how services are provided.

Does the alternative approach to provision of water services equate to the privatisation of water?

No. Alternative approaches to water management represent a change in philosophy rather than the outsourcing or privatisation of water services. Third parties may be contracted to deliver an IWCM strategy but this is not the privatisation of water.

Similar to this investigation, alternative solutions often uncover opportunities to improve the governance arrangements underpinning water services. All of the opportunities identified in this analysis could be implemented today provided there was support from Government agencies. Changes in policy are recommended to change legislation from preventing and restricting alternative strategies to a more enabling and encouraging legislative environment.

What makes this analysis and report different to other reports presented on this topic

This study employed an integrated systems approach to analysing the performance of the water cycle for Greater Melbourne. The philosophy of the study is a first principles forensic investigation.

This unique analysis starts with the base elements of a city (demographics, climate, building form and behaviour) and integrates water supply, sewage, stormwater and environmental considerations. A range of alternative versions of the system were simulated over a long planning horizon (40 years) using multiple replicates of expected climate and water use behaviours at daily time steps.

An integrated spatial and temporal analysis of the entire system has been employed at an unprecedented level of detail. All processes were integrated in a single system that allows understanding of "trade off's" and benefits throughout Greater Melbourne. This approach has demonstrated that the use of global average water demands in analysis produces a misleading understanding of water planning, analysis of alternative water sources and water conservation strategies. A traditional pipes and pumps analysis does not uncover the spatial variation and detail of the system.

The analysis clearly identifies significant spatial variation across Greater Melbourne for a wide range of parameters. It is not possible to generalise the parameters or performance at any location to describe the behaviour of another area of Greater Melbourne.

How is the uptake of water efficient appliances handled in the BASIX and ULT scenarios? Do the Options assume complete take up from day 1 or a gradual process?

Households and businesses across Greater Melbourne have an existing level of water efficient buildings and behaviours. This has occurred over time throughout the existing system as the community and government became more aware of the need for water conservation. This existing water efficiency was spatially incorporated into the base case "Business as Usual" Option. The Business as Usual Option incorporates a continuation of current patterns, trends and behaviours in relation to water use and the installation of water efficient appliances.

The Alternative Options (BASIX, BASIX1, ULT and ULT1) include the same base level of water efficiency incorporated at the beginning of the analysis period. In addition, the alternative Options include progressive implementation of an alternative policy approach to water efficiency. All new and renovated buildings (above a certain value) must have a mandated level of water efficiency (toilets, shower and tap fittings, and appliances). This process drives a greater adoption of water efficiency over time throughout Greater Melbourne.

The adoption of this alternative water efficiency approach is driven by the growth and redevelopment of buildings throughout Greater Melbourne over time. The systems analysis captures this spatial and temporal process. Scenarios were also tested that altered rate of population growth (low and high growth scenarios) throughout Greater Melbourne. This analysis demonstrated that investment in infrastructure only occurs as required by the growth of the city.

Scenarios were also used to test the spatial implications of population growth (densification of existing areas or development of new areas). The analysis also revealed that infrastructure investment only occurred where it was required and was triggered by development.

This process highlighted the profound spatial and temporal benefits of water efficiency, in stark contrast to investment in centralised infrastructure that requires the "picking of winners" many years ahead of demand eventuating and estimates of where and when growth will occur.

It is also important to note that some aspects of water efficiency were considered to be "hard wired" into the system. Installation of water efficient appliances such as dishwashers and washing machines are an example. These appliances are unlikely to be replaced until the end of their working life.

Other aspects of water efficiency are more dynamic and can change over time. For example the length of showers and frequency of washing is variable. Households are likely to be more aware of water use behaviours during periods of water scarcity and conversely households are likely to be more relaxed about water consumption in period of abundant water supplies. These patterns have been incorporated into the analysis of all Options and Scenarios.

How does the energy consumption of decentralised systems compare to centralised systems?

A common argument is that centralised water cycle infrastructure consumes less energy than decentralised or alternative strategies. This assumption is rarely correct and often results from partial analysis of a system. It is important to consider the energy impacts of a strategy throughout an entire system.

The energy consumption per unit of supply (kWh/ML) of a large scale water treatment plant may be less than a smaller local water treatment plant but this is only one part of the story.

A holistic assessment of the supply of water and management of wastewater and stormwater is required. Energy consumption is not limited to treatment processes. The transfer of water and wastewater across Melbourne consumes significant amounts of energy. This energy is used to supplement gravity for the movement of water and wastewater

Alternative water strategies such as IWCM reduces the energy required to move water and wastewater across the city by locally sourcing a greater proportion of water supply and using wastewater at source. This investigation found that the BASIX Option reduced system wide energy consumption by 42%, BASIX1 by 39%, ULT by 57% and ULT1 by 52%. These results represent significant savings to society. Energy savings of this magnitude also have important implications for cities such as Melbourne that face energy capacity constraints in the future.

Greater use of decentralised systems will encourage improved understanding of the design and operation of alternative technology. Many small scale MBR wastewater treatment plants are already reported as having comparable or better energy consumption for unit of water than larger centralised plants. The efficiency of these systems will only improve as adoption of decentralised systems increases.

Does the stormwater runoff in the analysis include all stormwater and all urban surfaces and catchments?

The investigation considered stormwater runoff from properties and the adjoining public surfaces (footpaths and roadways). Limited information provided by relevant authorities and project time constraints meant that stormwater runoff from main roads and public open space not associated with properties was not included in the analysis.

As a consequence, the stormwater volumes outlined in the report are considered to be conservative and the actual volumes will be greater. Importantly, the analysis provides an indication of the magnitude and scope of stormwater management across Greater Melbourne and the relative benefits of the Options.

What is the difference between BASIX and BASIX1? Is it a realistic assumption for water efficient gardens to be removed from some Options?

The BASIX Option includes water efficient gardens as part of a mandated water efficiency policy. BASIX1 did not include water efficient gardens. A decision was made by the MAC that the community may remove water efficient gardens (and replace them with more water intensive gardens) during periods of higher rainfall and greater water security.

It is our view that research and experience does not support an assumption that water efficient gardens would be removed from properties during periods of higher rainfall periods or greater water security. Establishing a garden is a significant investment - it would be unusual (and expensive) to replace an established garden, simply because of higher rainfall.

What is the difference between ULT and ULT 1? Is it a realistic assumption that stormwater should not be injected into mains water systems?

The ULT Option represented precinct based IWCM whereby water supply was sourced locally using rainfall collected from roofs (roof water) and impervious surfaces (stormwater). This harvested stormwater was collected, treated and injected into the mains water system for potable use.

The ULT1 Option was altered to remove collection, treatment and injection of stormwater into the mains water system. This Option uses roof water for laundry and hot water use. Mains water is e supplied for kitchen and drinking purposes. The MAC decided it was not feasible for treated stormwater to be injected in the mains water system.

In our view, research and experience does not support the MAC's decision. Numerous cases exist where stormwater is collected, treated and used for potable purposes – including the current mains water system that harvests stormwater from rivers. There are currently a number of large precincts in Greater Melbourne that are planning to use stormwater as their primary water supply.

Understanding and acceptance of the use of stormwater has evolved significantly in recent times. Stormwater use for potable purposes was considered, and still is, a valid proposition for an investigation that assessed options up to 2050.

Do the population projections incorporate the latest forecasts and projections? How sensitive is the analysis to variations in population projections?

Bonacci Water was provided the latest population projections (2011) for Greater Melbourne by the Department of Planning and Community Development (DPCD). This information was incorporated to replace the previous population projections by the Victorian Government and the Australian Bureau of Statistics.

Victoria's population projections have been increased in the latest projections in response to higher than expected population growth over recent years. To ensure the revised projections did not distort the analysis, high population growth (2% annual growth) and low population growth (0% annual growth) scenarios were tested to understand the impact of population growth on the system.

Do alternative water sources include the full CAPEX and OPEX costs?

All capital expenditure and operating costs for all Options have been included in the systems analysis. Bonacci Water has developed a detailed spatial economic model which includes these costs in the analysis.

Who owns Victoria's water authorities? Are they publically owned?

It is commonly claimed that the public own water authorities. However this is not the case.

Water authorities are officially Government Business Enterprises or GBE's. In practical terms this means these authorities are not part of the public service nor are they private organisations. The Treasurer is the single shareholder of water authorities and the Water Minister has approval of some operational processes.

In practice water authorities are in fact owned and run by the bureaucracies and engineers that work within the water authorities and operate the system. This issue is simply confused and clouded by large amounts of regulation and legislation.

How have transfer and distribution costs been determined without the use of a "pipes and pumps model"?

The economic impact of the delivery of water and wastewater services was defined as extension, renewal and operation costs that were derived from the historical expenditure patterns of the water authorities. These expenses and revenues were embedded in the dynamic analysis as a function of the daily transfer volumes of water or wastewater at different locations throughout Greater Melbourne.

Transfer of water from one location to another requires the use of infrastructure and a range of associated resources that are included using this methodology. The major distribution pathways within the water and wastewater networks were extracted from GIS databases of existing infrastructure and included in the systems model. This allows a realistic understanding of the magnitudes of water and sewage in transfer pathways (trunk infrastructure) throughout the existing system.

Note that the costs associated with the transfer of additional flows in the sewage networks generated by infiltration of stormwater are also included in this method. Moreover, the financial impacts of alternative water strategies that may have some reliance on the existing centralised network are also counted in this method – failure to supply sufficient water from (say) a stormwater harvesting system at a given spatial location will require additional water supply from the centralised system which may generate a requirement to augment the central systems and incur extension costs.

Water demands have varied substantially over the past 10 years? How has this variation been accounted for?

The highest water demands were experienced prior to 1997 during a period of higher water use behaviour and the systems model was previously calibrated to water demands in 2006 that represented a period of relatively lower water use. Ongoing drought and high levels water restrictions during the period 2006 to 2010 also significantly modified total water demands.

A hindcasting process was utilised to calibrate water demand models to past behaviours. A gradual adoption of significant water efficiency was assumed to commence in 1997. Water efficient appliances and rainwater harvesting were adopted for half of all new and redeveloped dwellings during the period 1997 to 2010.

In addition, the analysis also included parameters that accounted for the regional impacts of dryness, higher temperatures, wet weather and smoothing effect of the distribution system on daily water demands.

How has gaps in data and information been dealt with across Melbourne - not all locations have the same quality of information?

The available data utilised in this investigation was of variable quality and completeness. However, data was utilised from multiple temporal and spatial (for example from lot, pressure zones and reservoirs) scales throughout the Greater Melbourne system which included a significant redundancy of information.

The systems framework utilised for this investigation can be described as analysis of systems within systems across multiple scales. The biophysical and scale transition framework used in this study links the dynamics of system with inputs across multiple scales and time periods. This allowed the use of hierarchical calibration techniques that utilise all available data in the systems to derive the most likely sequences of information.

For example, continuous simulation of water demands in all dwellings was conducted at sub-daily time steps. These demand models were calibrated to observations of quarterly water use derived from billing records. However, the daily temporal pattern of these sequences of water demands were also calibrated to long sequences of water supplies from pressure reservoirs and regional storages.

Gaps in any of these observations are accounted for by the use of models that utilise first principles processes that were calibrated to available data.

How do the alternative options account for partial update of the elements in the Options – for example water efficient appliances and partial roof catchment supplying rainwater tanks?

The framework for the systems analysis used in this investigation included continuous simulation of the actual physics of each strategy at 6 minute time steps using long sequences of climate data. This includes roof areas connected to rainwater tanks and the proportions of indoor water use connected to water efficient appliances. This ensures that the systems analysis accounts for the temporal and spatial performance of each strategy.

All strategies are simulated for all dwellings at each location in the alternative Options. The sequences of behaviour for each strategy are combined at each location based on the number of dwellings or buildings that include a particular strategy. This process facilitates the partial adoption of different strategies within each Option – for example all new and redeveloped buildings include water efficient appliances, and the remaining buildings include the current level of water efficiency.

How has climate change been incorporated into the analysis?

This study has utilised the high emissions scenarios for climate change from the recent IPCC summaries of global climate models. Lower and upper bounds from the high emissions scenario were adopted to account for potential continuing growth in global emissions.

Our analysis including multiple replicates of potential climate behaviour that are based on the longest possible climate records and incorporate expected climate change by using temperature as a key statistical driver.

This allows a rate of increase in annual temperatures of 0.025 °C/year and 0.05 °C/year from the expected high emissions scenario to be included as a fundamental driver of emerging changes in rainfall, evaporation, streamflow, water demands and related processes in the systems models.

How have waterways been accounted for in the analysis?

This analysis has included the significant catchments and waterways within Greater Melbourne to allow understanding of the impacts on waterway health and flooding created by the different Options.

This analysis has only included stormwater runoff from urban allotments (residential and non-residential) and adjacent roads to waterways to allow direct understanding of the changes created by different Options. The investigation accounts for all streamflows in rivers that are included in the water supply headworks system.

Are the raw sewage concentrations used in this study employed to understand impacts of sewage overflows to waterways?

No. This study has used the constituents in raw sewage to determine the costs of operating the Eastern and Western Wastewater Treatment Plants in accordance with the determination of prices by the Essential Services Commission. Although waterways throughout Greater Melbourne are subject to overflow of raw sewage during rain events, we have not included this impact in the systems analysis. This decision was taken during the review process of MAC Stage II. Bonacci Water do not agree with this exclusion of a real impact on waterways and Port Phillip Bay. Nevertheless, this decision has ensured that the reported improved impacts on waterways are conservative.

The analysis uses a ratio of demands, transfer distances and cumulative changes in height to disaggregate costs and green house emissions from the jurisdiction of water authorities to local government areas. Does this process impact on the overall results?

No. Costs of stormwater infrastructure for each LGA were provided by MWC that were used in the analysis. However the costs and greenhouse emissions of water and sewage infrastructure within each LGA area were not provided. Thus a ratio of total transfer distance for water supply or sewage disposal, demands and cumulative change in height were used to disaggregate costs and greenhouse gas emissions from the jurisdiction of water authorities to LGAs. These ratios are not used in the systems analysis and are only used to apportion costs and greenhouse gas emissions as inputs to derive local costs and emissions. In addition, these spatial inputs do not change to overall quantum of emissions and costs for each water authority and for Greater Melbourne. Note that the systems analysis determines the sequences of stormwater runoff, water demands, wastewater flows and streamflow throughout Greater Melbourne.