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Water-energy futures for Melbourne: the effect of water strategies, water use and urban form

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Water for a Healthy Country Flagship Report
October 2008

www.csiro.au

Water for a Healthy Country Flagship Report series ISSN: 1835-095X

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The Water for a Healthy Country Flagship aims to achieve a tenfold increase in the economic, social and environmental benefits from water by 2025. This report has been prepared by a team from CSIRO including Steve Cook (Scenario formulation, urban hydrology analysis, report compilation), Graham Turner (Systems modelling, scenario design and outputs, virtual water analysis), Steven Kenway (Project concept, focus, leadership and report structure and finalisation), Tim Baynes (Energy and water analysis, water account establishment) and Jim West (energy account establishment and modelling). The work builds on a substantial body of work involved in developing the Australian Stocks and Flows Framework (ASFF) and the Victorian Regional Stocks and Flows Framework (VRSFF).

For more information about Water for a Healthy Country Flagship or the National Research Flagship Initiative visit www.csiro.au/org/HealthyCountry.html

Citation: Kenway, S.J. et al. 2008. Water-energy futures for Melbourne: the effect of water strategies, water use and urban form. CSIRO: Water for a Healthy Country National Research Flagship.

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ISBN 978 0 643 09566 3

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ACKNOWLEDGEMENTS

The authors would like to thank a range of reviewers for comments at various stages of the report preparation.

ABBREVIATIONS AND NOTATION

a	annum (year)
ABARE	Australian Bureau of Agricultural Resource Economics
ABS	Australian Bureau of Statistics
ASFF	Australian Stocks and Flows Framework
BAU	Business as usual
CO2-e	carbon dioxide equivalent – An index that integrates various greenhouse gases associated with a system by using the global warming potential of each to weight the contributions. Note that approximately 300 kg $C0_2$-e/GJ (approximately 1 kg $C0_2$-e/kWh) is the recommended conversion factor for indirect emissions factors (Full Fuel Cycle including Scope 2 and 3) for consumption of purchased electricity in most Australian States (Department of Climate Change 2008). Consequently use of 100 GWh (0.36 PJ) is factored to contribute approximately 100,000 t of CO_2-e.
CSIRO	Commonwealth Scientific and Industrial Research Organisation
GHG	Greenhouse Gases (GHGs common to the water industry include Carbon Dioxide ($C0_2$), Methane (CH_4) and Nitrous Oxide (N_2O).
GJ	Giga Joule (10^9 Joules)
GL	Giga Litre (10^9 Litres)
HWS	Hot water system
J	joule (one watt second)
kWh	kilowatt hour (3.6 MJ or 3.6 x 10^6J)
LGA	Local Government Area
ML	megalitre
PJ	Peta Joule (10^{15} Joules)
TJ	Tera Joule (10^{12} Joules)
Virtual Water	Refers to the quantity of water required to manufacture, and supply to the point of use, a product, material or service. Also referred to as embodied water, embedded water or hidden water.
VRSFF	Victorian Regional Stocks and Flows Framework
WWTP	wastewater treatment plant

EXECUTIVE SUMMARY

This report presents an analysis of water and energy futures for Melbourne. The backdrop to the work is regional and national water stress, which increasingly attributes to climate change, a shift towards more energy-intensive future water sources and a struggle to constrain growth in energy consumption. The work has been undertaken to initiate dialogue regarding the substantial, complex and often ignored relationships between water and energy policy and management.

An important sub-theme of the work is the desire to describe the influence of relevant policy levers in context with the total energy and water throughput of Melbourne. The report aims to create a more quantitative and sustainability-oriented context for decision-making including the "virtual" water consumption by Melbourne in electricity and food.

Six scenarios were designed to identify the potential influence of three key policy considerations on future water and associated energy needs: urban form, residential end-use and the type of water supplies provided. The scenarios were analysed through to the year 2045 using the Victorian Regional Stocks and Flows Framework (VRSFF) model. VRSFF is comprised of linked calculators that account for many dynamics of the "physical" economy such as land use, demographics and water and energy accounts. The model has been calibrated to replicate trends from the 1970s through to 2001.

The study has demonstrated that by 2045:

- A compact urban form over a sprawling Melbourne could reduce growth in residential water consumption by approximately 100 GL/year, primarily through reduced outdoor water use. If Melbourne's urban growth and operation progresses without efforts to conserve energy, water or land, residential water use increases by about 50% relative to 2001 and residential energy use increases by 200% over the same time period.
- Compared to "business as usual", adopting water demand management strategies could directly save 45 GL/year of water. Using solar hot water systems (HWS) could indirectly offset an additional 10 GL/year due to reduced water demand for electricity generation.
- Using increased solar hot water systems, (80% on new dwellings and 20% of existing) could save 0.14 PJ/year in the water system. It could also save around 30 PJ/year through reduced residential energy use.
- Compared to conventional water supply services, desalination increases energy consumption for water services by approximately 3 PJ/year which leads to a tripling of current energy use for water service provision. However, this increase is marginal in the context of the anticipated growth in Melbourne's residential and total urban energy use (approximately 200 and 2000 PJ/year respectively).

The report does not attempt to provide a definitive analysis of all links between water and energy use or to rank or judge any particular solution. However, it does demonstrate how the application of whole of system analytical techniques such as the stocks and flows framework can provide new insights to inform the development of effective integrated resource management policies.

Recommendations are made to progress the understanding and management of water-energy interactions including:

- Improved characterisation of energy use through the water cycle;
- Analysis of regional plans and strategies;
- Collaborative development of more detailed scenarios; and
- Development of reporting indicators and requirements to help widen the knowledge sets.

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1. INTRODUCTION

1.1 Background

There is increasing urgency in Victoria for the development of policy that offers solutions to the long-term security of Melbourne's water supply. Policy decisions are being formed against a backdrop of current water stress due to lower than average inflows, predicted future water shortages due to increased demand driven by population growth and a shift to a drier climate due to projected impacts of human-induced climate change.

In the haste to provide solutions to the challenges of water supply shortages, there remains the need to consider the future implications of policy options and interactions with other sectors such as energy services, greenhouse gas emissions and demographics. In moving forward with resolution of water supply issues, it is important to ensure that inter-linked problems are not exacerbated.

Based on current water supplies and projected demand, it has been forecast that Melbourne will face a shortfall in supply of 205 GL/year by 2055 (Department of Sustainability and Environment 2005). This is driving the need to consider alternative sources such as desalination and reuse which have implications for energy demand and greenhouse gas emissions. This has been a sticking point for their policy support, particularly desalination, because the solution contributes to the problem.

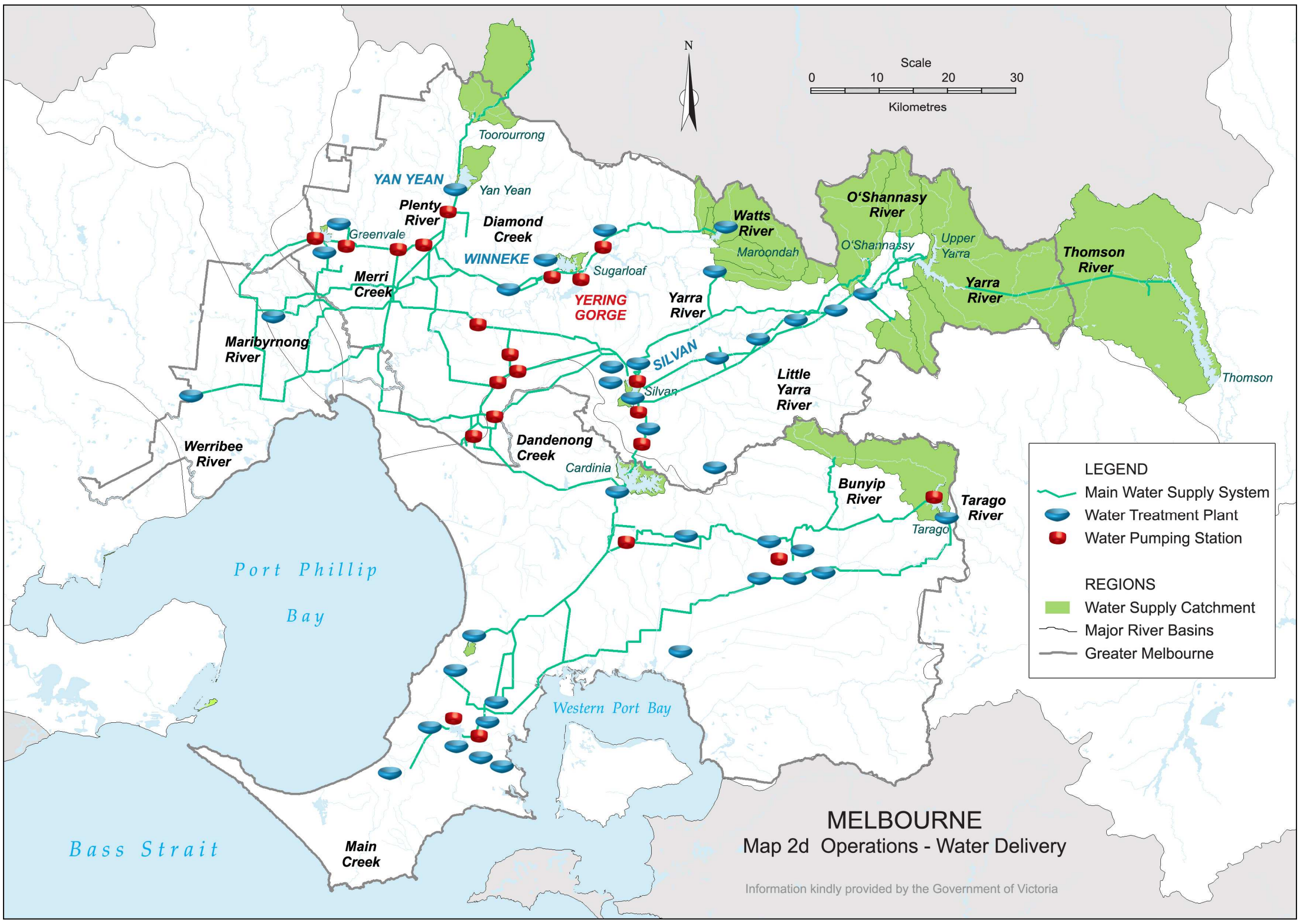
While the energy use and greenhouse emissions of water supply options are often discussed, there has been relatively little discussion regarding the significance of these increases or the wider implications of their adoption. The approach adopted for this study aimed to investigate these implications as well as to consider related drivers of water use and urban form.

The Victorian government has released the *Central Region Sustainable Water Strategy: Action to 2055* (Department of Sustainability and Environment 2006) which proposes a number of solutions for the projected Greater Melbourne water shortages. Solutions floated include wastewater recycling, seawater desalination and end-use demand management strategies. The Victorian government has recently released the water strategy for Melbourne, *Our Water Our Future*, which identifies desalination and transfers from the Goulburn catchment as the preferred options in securing Melbourne's water supply. Desalination would increase the energy required to deliver water services because Melbourne's potable water supply is largely supplied by gravity from ranges to the east of Melbourne (Figure 1) and the system uses more passive treatment processes because its catchments are largely protected and deliver relatively clean water.

This report specifically aims to inform and promote discussion regarding the links between urban water and energy policy. As such it sets out to explore existing trends and potential shifts affecting water and energy services and the implications of these factors over the next 40 years for a limited scenario set. The report does not attempt to provide a definitive analysis of the many links between water, energy and greenhouse emissions. This would be a difficult task given the current state of knowledge and the limited scope of this exploratory study. However, it does attempt to provide an example of the type of approach that may elucidate these linkages and identify areas necessary for knowledge development. The report focuses on energy specifically because current knowledge regarding greenhouse gas emissions throughout the water cycle is less well developed. In Victoria, most electric energy is sourced from brown coal-fired power plants. This produces around 387 kg of carbon dioxide equivalents ($C0_2$-e) per GJ of power generation (WSAA 2005) or 1.444 kg of $C0_2$-e per kWhr of generation (Sustainability

Victoria 2004). In the Latrobe Valley around 1 GL of water is consumed for every 2 PJ of power produced.

A particular focus of the report is the interactions between water services and energy demand. Water utilities use large amounts of energy to treat and deliver water to residential and industry end-users which then consume more energy in heating, pumping and using the water. Wolff (2004) makes the point that there is the need to better understand the energy implications of water policy decisions. There has been recent analysis and discussion of national-level linkages between climate, energy and water (Proust et al. 2007). This report aims to contribute to this debate with a focus on urban systems.



Source: Kenway et al. (2008)

Figure 1 Greater Melbourne Region water delivery system

An additional focus of the report is that of “virtual water” movement. There is strong current debate regarding urban and rural water sharing including the use of water for power generation. The water necessary to sustain cities can be sourced from well outside city boundaries and includes water to produce agricultural food and fibre, energy and other products. Preliminary analysis of this virtual or embedded water was undertaken to characterise the total dependence of Melbourne on water as well as to describe the flows and again commence an exploration of the interrelationships that exist in this area.

This report does not consider the implications of alternative population and energy supply policy, although the modelling framework is designed for such analysis. However, all scenarios do include the projected implications of climate change for Victoria (e.g. Howe et al. 2005). Given the dynamic nature of water and energy policy and knowledge at present, the scenarios developed by the research team can be expected to date, possibly rapidly. The important point though is that improved understanding is needed regarding the implications of water management on energy as well as energy management on water.

This work aims to act as a preliminary demonstration of this analysis. Further liaison with industry and government is recommended to test in more detail a wider or more characterised scenario set.

1.2 Driving Forces

In order to explore the likely implication of different policy options a range of scenarios have been defined. This section briefly outlines the driving forces that the scenarios have been constructed around. Numerous drivers are providing the stimulus for exploring options for the provision of urban water supply and implications for energy demand. Drivers include projected climate change impacts, such as decreasing inflows to water catchments, the need to stabilise and decrease emission of greenhouse gases, population growth and land use change.

There is also emerging tension nationally between the provision of water and power provision. Because most power provision requires water (e.g. for boiler steam and cooling), in the ongoing drought there is a strategic need to reserve some water supplies to ensure continued power production. These drivers create a significant challenge in developing policy for water and energy security while at the same time responding to the local need for environmental protection and the global need to reduce greenhouse emissions.

The following paragraphs describe the scenario drivers within the current political and social setting and the trajectories of these drivers as explored within scenarios. The driving forces used have a high degree of uncertainty around future trajectory and in many cases are politically dynamic. Therefore, the scenarios described don’t have the purpose of simulating what is most likely to happen in the future, but instead explore alternative directions that highlight trade-offs, physical limitations and interactions between different sectors.

Population

Population in the Melbourne Statistical Division is projected to grow from 3.47 million people recorded in the 2001 census to 4.8 million in 2031 (Department of Sustainability and Environment 2005). There are projected to be a number of fundamental shifts in Victoria’s demographics over this period, which include a rapidly ageing population, declining fertility rates and decreasing household size. The population scenario used in this report is consistent with the projections of *Victoria in Future 2004* (Department of Sustainability and Environment 2005). Population growth will further pressure the supply of water resources from natural catchments, which will drive the need to explore alternative options for urban water supply. The projected population for Melbourne is consistent across all scenarios.

Climate change

Human-induced climate change, which is linked to the burning of fossil fuels that emit greenhouse gases, is likely to impact on inflows to Victoria’s water catchments. Howe et al. (2005) show that under the assumptions of most climate change scenarios Victoria is likely to receive less rainfall and display higher evaporation rates. This decreased rainfall will drive the demand for alternative water sources.

Urban form

The Melbourne population is currently predominately accommodated in low density separate dwellings, which has resulted in considerable sprawl of the city. This urban form impacts on end-use water demand, with the majority of these dwellings having gardens that require irrigation. The land use pattern also has implications for infrastructure provision. In response to some of the issues associated with urban sprawl the Victorian government has released *Melbourne 2030* (Department of Infrastructure 2002), which sets a strategy for the growth of the metropolitan area to accommodate an expanded population. A key direction of this strategy is the setting of urban growth boundaries to limit the sprawl of the urban area, with future growth increasingly directed away from the urban fringe towards higher density development. This study aims to inform similar decisions.

The proposed move to increased density in Melbourne's urban form has been a very contentious political issue due to perceived effect on land prices and suburb character. There have been a number of adjustments to the urban growth boundary since it was enacted five years ago. The last census revealed that population growth was still occurring most rapidly at the rural urban fringe; while in a number of older inner city suburbs the population was stable or actually had declined. The complete realisation of the *Melbourne 2030* vision for urban growth remains a significant challenge. Scenarios used for this report compared increased urban density and continued sprawl.

Water end-use

Demand management strategies, such as low-flow showerheads and water efficient washing machines, have the potential to not only significantly reduce overall water demand, but also reduce the energy associated with the end-use of water. Water end-uses, in particular water heating, are a significant part of overall residential energy consumption and therefore greenhouse gas emissions. In Melbourne, the majority of households (77%) use gas as the primary energy source for water heating, while 19% use grid electricity for water heating and less than 1% have system primarily fuelled by solar power (ABS 2005). The energy source for water heating has significant implications for greenhouse gas emissions, with electric storage systems releasing 4 tonnes of C02-e per year compared to gas systems of 1 tonnes of C02-e per year and gas boosted solar systems 0.1 tonnes of C02-e per year (based on 140 litre hot water consumption per day) (Australian Greenhouse Office 2001).

In Victoria, water heating accounts for 27% of total residential energy demand (ABS 2005). Other significant household demands for energy are heating and cooling (39%) and appliance use, including lighting (30%). Therefore, a demand management strategy that focuses on a shift to cleaner energy sources for water heating, such as solar and increased efficiency of hot water appliances could be expected to significantly reduce residential energy use. As the majority of Melbourne households use gas as an energy source for water and space heating, a focus on appliances and hot water would also address the majority of household greenhouse gas emissions (Australian Greenhouse Office 2005).

Scenarios explored in the report compare an increased uptake of solar hot water systems (HWS) and demand management strategies, especially in new dwellings, with a baseline that assumes continuation of current mix of energy sources for water heating and no increased uptake of water efficient appliances. At the time of writing new homes in Victoria are required to have either a rainwater tank or a solar HWS installed. The increased uptake of many demand management strategies, such as more efficient washing machines, may largely depend on government incentives or statutory requirements, as in many cases the economic payback period does not justify the investment at current water and energy prices.

Water services

Current water stress in Melbourne has led to the consideration of alternative water sources. Scenarios used for this report propose two alternatives for comparison with conventional water supply for Melbourne, where water is captured in protected catchments remote from the urban area. The first alternative simulates increased uptake of rainwater tanks and local industrial or irrigation wastewater recycling using limited or no additional treatment of Melbourne's wastewater flows.

This scenario assumes 20% of low density houses have rainwater tanks used for toilet flushing installed to ensure negligible energy use. Currently rainwater tank uptake in Melbourne is estimated at 6% of households (Marsden Jacob Associates 2007). The second alternative assumes that new potable demand will be satisfied by desalination plants. Desalination has been identified as a preferred option in Victorian government's *Our Water Our Future* for securing Melbourne's potable water supply.

1.3 Report Objectives, Focus and Outline

A key objective of this work was to improve the understanding of the complex interrelationships between urban water and energy and improve debate on this topic which is often focussed on very specific options. An important sub-objective was the desire to describe the influence of relevant policy levers (particularly water policy) in context with the total energy and water throughput of Melbourne: or Melbourne's metabolism. Metabolic analysis also typically includes all material (including water and nutrients) and energy flows (refer for example, to Sahely et al. 2003; Newman 1999, Pamminger et al. 2008 and Kenway et al. 2008); however this report is focused specifically on water and energy. In so doing the report aims to create a more quantitative and sustainability-oriented context and methodology for decision-making. A final objective was to evaluate the efficacy of the Stocks and Flows Framework and the VRSFF model in undertaking such analysis.

The concepts and issues explored in this work included the water and energy use implications of:

- city-scale water management options focused on major alternative water supply options as well as decentralised options including rainwater tanks
- water end-use characteristics including demand management and use of solar hot water systems
- future configurations of Melbourne or options relating to urban form
- the total flows of water to Melbourne including virtual or embedded/embodied water.

The structure of this report is as follows.

Section 1 (this section) provides brief background context to the project and outlines some of the driving forces that scenarios have been constructed around.

Section 2 provides an overview of the Stocks and Flows Framework approach and gives a more detailed description of VRSFF model as applied in this project.

Section 3 describes the scenarios that were applied within VRSFF, which includes the technical assumptions behind the scenarios.

Section 4 presents the results of the scenarios implemented in VRSFF. It also draws out the implications of the scenario outputs, with particular focus on the interactions between sectors and the trade-offs or synergies that might be involved in implementing different water policy options.

Section 5 offers some conclusions together with research needs in this area.

2. MODELLING APPROACH

2.1 Victorian Regional Stocks and Flows Framework

The Victorian Regional Stocks and Flows Framework (VRSFF) was developed to comprehensively cover the physical economy of Victoria. The VRSFF defines key stocks and flows of materials (including water) and energy and the interconnections between them in physical units (e.g. kilograms, litres, joules) rather than dollar values. It can be used for exploring the physical implications of pursuing different future development pathways or policy options.

The VRSFF is based on systems theory that focuses on the interconnections and interdependence between different parts of the system, with the system in this case being defined as the Victorian physical economy. This means the model is equipped to explore interactions between different parts of the system, such as water, energy, land use and climate.

The VRSFF is a set of linked calculators that account for many of the important dynamics in the physical economy, such as land use change, demographics and water and energy accounts. The model is implemented as a dynamic simulation that enables a future pathway for a physical stock (e.g. land, water) to be set and then evaluated for physical feasibility. This allows for cross-checking by mass balance the future trajectory of a variable according to physical laws and relationships. This enables the VRSFF to identify tensions or feedbacks in the system; for example, under a projected climate change scenario and assumed population projection it could be explored at what point current water supply services would not be able to meet demand. This approach can highlight the implications of different futures over the long term that can be used to improve policy decisions in the present.

The Stocks and Flows approach has previously been applied in Australia to analyse, at a 5-years time step, the Australian physical economy, such as the *Future Dilemmas* report that explored implications of different population scenarios for Australia and interactions with technology, resources and the environment (see Foran and Poldy 2002). A key point of difference between VRSFF and some earlier Stocks and Flows frameworks is that VRSFF has a higher degree of spatial resolution which enables more detailed tracking of variables such as dwelling types.

The coverage and level of detail of the VRSFF water account closely matches that of the physical account of the System of Environmental-Economic Accounting for Water (SEEAW) framework developed by the United Nations Statistics Division [2007]. Appendix A contains an overview of the VRSF model. Historical data sources for the VRSFF are many and include, for example, decades of information on population from ABS Censuses; time series on energy consumption from ABARE; land use zoning and GIS data from the Department of Sustainability and the Environment and water data from multiple locations such as the ABS Water Accounts, State Water Reports, Murray Darling Basin Commission Reports, State of the Environment Reports and the Victorian Water Review. For a full account refer to Baynes et al. (2007). Relevant data from outside the direct water arena include, *Victoria in Future 2004* population projections; *Melbourne 2030* policies; Victorian Greenhouse Strategy; *Our Water Our Future* and the Victorian Regional Scenarios draft report. Except for the variables that we have described in the report to do with specific scenario settings, the remainder of the controls variables were set in keeping with the historical trend established by the calibration. Climate variables were established using output from CSIRO and Department of Sustainability and Environment modelling and analysis.

The current version of the water account framework covers, in annual time-step:

- water requirements across all sectors of the Victorian economy and society (informed by other components of the VRSFF) at Local Government Area (LGA) level, including water recycling by centralised treatment plants and re-use of water (within industry or sector)
- water availability by 29 water basins, influenced by many factors, including climate variables and land-use (informed by other components of the VRSFF)
- water stocks or flows including surface (rivers, wetlands) and major storage (dams)
- soil (groundwater/aquifers) water discharge from all water uses, tracking water quality as unpolluted, blackwater, greywater, stormwater
- water transfers between water regions and inter-state
- additions to and extractions from all water stocks, by centralised systems; or self-extracted means
- energy required to treat and move water for potable treatment and pumping sewage treatment and pumping; desalination; and inter-region transfers.

The spatial coverage of the framework is the state of Victoria, with the accounts maintained in each of the 29 water regions of Victoria at yearly time-steps. Appropriate geographical connections such as transfers between states are also included. The water regions are major catchment basins and are linked in the framework according to the river networks.

The VRSFF analytical system has features in common with system dynamics which is an approach to understanding the behaviour of complex systems over time. System dynamics is different from other approaches in the use of stocks, flows and feedback loops. These elements help describe how even seemingly simple systems can display baffling non-linearity and cyclical patterns. The common features in VRSFF includes the evolution of stocks (with age profiles), linking of stock and flow variables in causal chains of influence and the use of a diagrammatic interface and time series output (see also Appendix A).

An innovative difference of the work with VRSFF is the deliberate removal of automated feedback loops within the model code related to the social or economic domain. This has particular importance for exploring the many behavioural, technological and engineering options that influence the physical world (e.g. water, energy). For example, a strength of VRSFF is that storage (dam) volumes can, under some circumstances, exceed their capacity or become negative depending on the various settings that ultimately determine the inputs and outputs to the storage. Clearly this is physically impossible; however, the tension forces the analysis to investigate the drivers of the tension rather than automating this process. This sort of tension can be solved by a wide range of options, such as changing the proportion of river flow that is stored, modifying the storage capacity, changing abstractions, employing inter-basin water transfers, or simulating alternative population growth, economic structure or climate change. Keeping the feedback loops associated with these dynamics non-automated greatly enhances the ability to identify key factors resulting in the tension. It is then possible to design and explore (manually or through auxiliary feedback code) a wide range of responses that alleviate the tension.

The model is grounded with several decades of historical data (Baynes et al. 2007; Turner et al. 2007a; Turner et al. 2007b) that are used to calibrate the model for simulation over the next 50 to 100 years. This provides confidence in the simulation due to the wide range of data inputs, the multiple “cause and effect” chains influencing output variables, and the fact that independently sourced data corresponding to output variables (e.g. storage levels and energy used in the water sector) are simultaneously reproduced. It also means that all variables have historical data which provide context for understanding past changes and the foundation for creating meaningful scenarios.

3. SCENARIO DESCRIPTIONS

3.1 Scenario Overview

Six scenarios were developed to explore the impact of potential policy choices (Table 1). The key objective was to investigate a set of factors that influence the water system and its interaction with the energy system. The scenarios were created to examine the implications of potential and plausible options. Therefore, driving factors were set in different ways according to the scenarios – rather than, for example, all changed by the same percentage. Consequently, judgements made about the calculated outcomes of the scenarios, or comparisons between them, should take into account the specific differences between various settings, such as the degree of change in urban form compared with that in recycling, for example. Each scenario was created from a combination of changes to urban form, water end-use and water services (see Table 1), with the combinations designed to facilitate broad comparisons (see Table 2).

There are two main scenario sets. Scenario Set 1 explores a shift away from urban sprawl to higher density development. The Scenario Set 2 models a future population which continues to be accommodated in low density housing that perpetuates Melbourne's urban sprawl.

Variations within sub-scenarios focus on changes to end-use demand and water services. End-use scenarios address a more rapid uptake of water demand management measures and solar HWS or a baseline approach with minimal additional demand management or uptake of solar hot water beyond the current mandatory installation of a rainwater tank or solar hot water system on all new dwellings. Water services scenarios considered include continued use of conventional systems to meet demand (1a, 2a and 2c), or a shift to increased use of rainwater tanks and wastewater recycling (1b) or meeting new demand through desalination (2b, 2d). The reuse scenarios assumed local (on-site) recycling requiring marginal additional energy that is typically used, for example, in industry and mining and not treated to high standards. In effect, these scenarios represent policy levers at three very different levels. Urban form depicts the potential influence that our choices around future cities could have. In contrast water end-use and water-services represent the potential influences at household and water strategy or utility levels.

Table 1 Scenario summary

Population	Scenario set	Urban Form	Water end-use	Water services	Sub No.
Victoria in Future 2004 Projections	1	Melbourne 2030 guidelines – Limit to urban sprawl and focus on high density development	Increased uptake and retrofitting of demand management options and solar hot water systems	Conventional – Potable water supplied from protected catchments	1a
				Alternative sources- rainwater tanks and wastewater reuse	1b
	2	Urban Sprawl – low density housing continues in Greenfield sites without constraint	Baseline – no adoption of demand management or solar HWS	Conventional – Potable water supplied from protected catchments	2a
				New demand met by desalination	2b
			Increased uptake and retrofitting of demand management options and solar hot water systems	Conventional – Potable water supplied from protected catchments	2c
				New demand met by desalination	2d

3.2 Common Assumptions

All scenarios have the following base assumptions:

- By 2050 Victoria's population grows to approximately 6.7 million of which 4.9 million live in the Melbourne statistical division (*Victoria in Future2004* population projections).
- There is 2% per capita growth in material and energy consumption.
- The present methods of electricity generation continue into the future.
- A "medium" climate change scenario (Howe et al. 2005; Jones 2005) corresponding to an average global temperature increase of 1.5°C by 2050, involving decreased rainfall, increased evapo-transpiration and increased dam evaporation.
- Agricultural water use is initially capped at approximately 2001 levels though ultimately increases in water use are allowed in response to climate change impacts.
- Residential outdoor water use increases due to climate change impacts (Moran 2005).
- Dam levels are maintained at 2001 levels through a 50/50 combination of diversions from rivers and inter-region transfers where possible, otherwise solely from river diversions.

3.3 Scenario Descriptions

3.3.1 Scenario Set 1 (Compact Urban Form)

This scenario set sees future urban growth in Melbourne increasingly accommodated within high and medium density residential dwellings. There is some brownfield development, which sees existing low density dwellings demolished for higher density redevelopment. The Urban Growth Boundary as defined in *Melbourne 2030* restricts the spread of urban development.

Scenario 1a (water demand management and solar hot water systems, conventional water supply)

This scenario explores a shift to solar HWS, with 20% of existing dwellings and 80% of new residential dwellings moving to solar (gas boosted) HWS. Existing dwellings are assumed to move proportionally from the current energy source mix for HWS, which shows 77.5% of Melbourne households have gas HWS and 19.1% electric (ABS 2005).

Scenario 1a also explores a number of demand management strategies that have the purpose of reducing end-use demand from residential dwellings. In this case the demand management strategies explored are low-flow showerheads and water efficient washing machines. The uptake is consistent with solar HWS as 80% of new dwellings and 20% of existing dwellings implementing the demand management options. It is assumed that low-flow showerheads reduce water consumption by 40% over conventional systems and that water efficient washing machines use 30% less water.

In VRSFF these assumptions were incorporated as assuming low-, medium- and high density residential development use of water at 413, 354 and 358 L/year/m^2 respectively. With demand management measures in place these were assumed to drop to 379, 325 and 329 L/year/m^2 respectively. For more detail on these assumptions refer to Appendix C.

This scenario is based on a "Business As Usual" (BAU) approach for potable water supply, with drinking water sourced from protected catchments remote from the urban area.

Scenario 1b (water demand management and solar hot water systems and alternative water supplies)

This scenario is consistent with 1a and assumes the same urban growth pattern, shift to solar HWS and demand management strategies. However, there are the following exceptions in the area of water supply services where a number of alternatives are explored to augment supply:

- 20% of wastewater collected at centralised treatment plants is treated and used locally by industry with minimal energy investment for treatment or pumping.
- 20% of wastewater generated in heavy industry, such as mining and manufacturing, is treated to a standard required for non-potable applications with minimal energy investment for treatment or pumping. The wastewater treatment occurs proximal to where treated wastewater is used for non-potable applications.
- Residential rainwater tanks are used. This option simulates 20% of separate dwellings installing an onsite rainwater tank that is used for toilet flushing with mains back-up and for minimal energy cost (i.e. designed to flow gravitationally). Appendix B contains more detailed information on the assumptions and data used to model the reliability of supply from onsite rainwater tanks. More recent data suggest that rainwater tank pumps can use substantial energy per volume of water (Gardner et al. 2006).

Figure 2 shows the spatial extent of Melbourne's urban area analysed for this project. In the map, darker shading indicates a higher proportion of land area used for residential dwellings within a growth boundary for *Melbourne 2030*. The urban form of Melbourne and extent of different density residential areas analysed for Scenario Set 1 is in Appendix A.

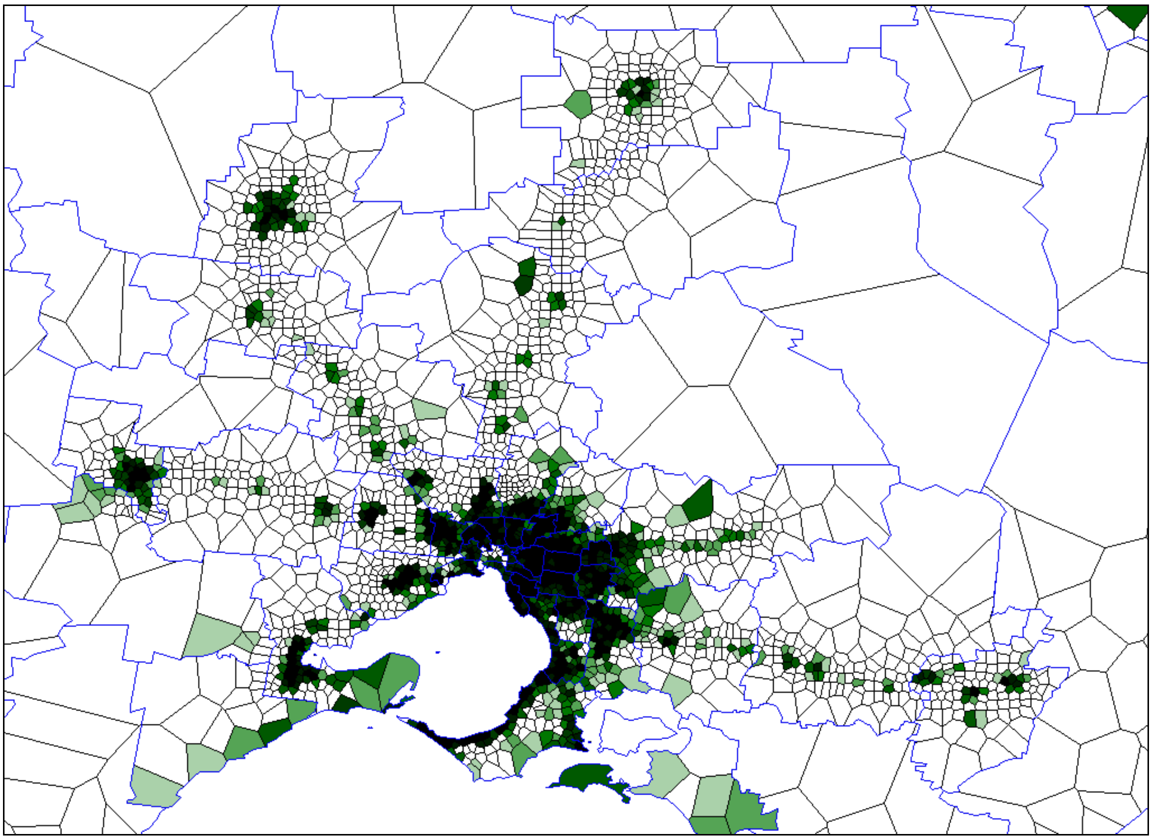


Figure 2 VRSFF spatial representation of settlement pattern

3.3.2 Scenario Set 2 (Urban Sprawl)

This set of scenarios differs from Scenario Set 1 in that it assumes that urban growth in Melbourne continues to occur at the urban fringe with low density dwellings. This pattern of growth results in the continued sprawl of Melbourne's urban area. This pattern of urban growth is consistent for all of the sub-scenarios.

Scenario 2a (no adoption of demand management or solar hot water systems, conventional water supplies)

This scenario is very much a passive scenario in that there are no real changes implemented to address potential shortfalls in Melbourne's water supply. It is BAU for water services and there are no demand management strategies or shift to solar HWS.

Scenario 2b (no adoption of demand management or solar hot water systems, desalination for new water demand)

This scenario explores the use of desalination plants to meet all new demand. At the time of analysis, desalination has been identified by the Victorian government as a preferred option to augment water supplies. An issue that is consistently raised regarding desalination is the energy required to remove salt from seawater and the resultant greenhouse gas emissions. This analysis assumed 17,753 J/L for the production of water by desalination and negligible energy for provision of water via rainwater tanks (refer to Appendix B). This scenario assumes no limit to low density urban growth and no adoption of end-use demand management strategies.

Scenario 2c (water demand management and solar hot water systems and conventional water supplies)

The key element of this scenario is the implementation of a number of end-use demand management strategies. In other regards there is very little shift from the current situation with Melbourne's urban sprawl continuing unchecked and water services supplied as usual.

This scenario explores a shift to solar HWS, with 20% of existing dwellings and 80% of new residential dwellings moving to solar (gas boosted) HWS. Existing dwellings are assumed to move proportionally from the current energy source mix for HWS, which shows 77.5% of Melbourne households have gas HWS and 19.1% electric (ABS 2005).

Scenario 2c also explores a number of demand management strategies that have the purpose of reducing end-use demand from residential dwellings. In this case the demand management strategies explored are low-flow showerheads and water efficient washing machines. The uptake is consistent with solar HWS as 80% of new dwellings and 20% of existing dwellings implementing the demand management options as clarified in scenario 1a.

Scenario 2d (water demand management and solar hot water systems, desalination for new water demand)

Scenario 2d incorporates the same elements as scenario 2c in regards to urban form and end-use demand management strategies. The differentiation between the scenarios is water services. In this scenario all new demand is met through desalination plants.

4. SCENARIO ANALYSIS AND DISCUSSION

This section presents the results of scenarios analysed with the VRSFF model. The results are structured in thematic sections that focus on comparison of scenarios to elucidate the impacts in different areas.

Table 2 and Table 3 summarise key outputs for each of the scenarios mapped against the key drivers. Other outputs, such as effects on river flow or water quality are discussed in more detail later. The base case for comparison purposes is taken as 2001, as this is the starting point for the simulation with years prior to 2002 populated with historical data.

Table 2 Scenario results (water and energy overview)

Scenario	Water service options			Water end-use options		Urban form		Melbourne in 2001, (VRSFF Base Case) population = 3.47 million)				Melbourne in 2045, (population = 4.80 million)			
	Conventional water services	Rainwater tanks & wastewater reuse	Desalination	Demand management and solar HWS	Business as usual	Increasing density in selected LGAs	Continued low density development at urban fringe	Residential water demand (GL/year)	Energy demand for water services (PJ/year)	Total residential energy demand (PJ/year)	Total Melbourne energy (PJ/year)	Residential water demand (GL/year)[1]	Energy[2] demand for water services (PJ/year)	Total residential energy demand (PJ/year)	Total Melbourne energy[3] demand (PJ/year)
1a	✓			✓		✓		330	1.1	95	1100	380	1.3	260	3200
1b		✓		✓		✓						350	1.3	260	
2a	✓				✓		✓					510	1.7	290	
2b			✓		✓		✓					510	4.8	290	
2c	✓			✓			✓					470	1.6	260	
2d			✓	✓			✓					470	4.2	260	

[1]Refer to Table 3 for a breakdown of the water demand and supply, [2]Excludes additional new transport (pumping) energy for desalination or reuse which could be in the order of 0.3 PJ/year by 2045 assuming lifting 150GL water to 200m elevation. [3]Includes energy from coal-fired electricity, gas, and petroleum and is approximately Melbourne's pro-rata share of total state energy use on a population basis.

Table 3 Water supply breakdown

Scenario	Water Requirement (GL/year)			Water Supply Sources (GL/year)				
	Residential	Commercial, Industrial and Other water use[1]	Total	Conventional Centralised	Reuse	Raintanks	Desal	Total[1]
2001	330	200	530	520	10	1	0	530
1a	375	200	575	555	20	1	0	575
1b	375	200	575	535	30	8	0	575
2a	510	200	710	690	20	2	0	710
2b	510	200	710	510	20	2	176	710
2c	470	200	670	650	20	2	0	670
2d	470	200	670	500	20	2	150	670

[1]Non-residential water use was not a focus of this study: 2001 data are cited from public reports (WSAA 2005) and no estimate of future growth was made, for consistency 200 GL non-residential use has been included in the "Total" but this excludes any growth in non-residential water use. Rows may not total due to rounding.

The study has demonstrated that by 2045:

- The influence of a compact urban form over a sprawling Melbourne (scenario 1a versus scenario 2c) could impact water consumption by approximately 100 GL/year.
- Water demand management and solar hot water system installation (scenario 2a versus scenario 2c) could save directly around 45 GL/year of water (due to water demand management, while solar HWS could indirectly save around 10 GL/year in reduced water use due to lower electricity generation). Additionally, the alternative water end-use in scenario 2c results in energy savings of 0.14 PJ/year for water services as well as about 36 PJ/year in residential energy use due primarily to solar HWS. Demand management is expected to contribute to reduced energy associated with in-house water heating; however, it was not able to be separated in this analysis. Note that apart from energy use associated with the water system, implications of scenarios on Melbourne's total energy consumption were not assessed.
- The worst case scenario results if Melbourne's urban growth and operation progresses without efforts to conserve energy, water or land. For example, scenario 2a results in residential water use in 2045 increasing by about 50% relative to 2001. This is mostly due to population growth (about 95% of the effect) while the remainder is due to household outdoor watering increasing in response to medium level climate change. Similarly, residential energy use increases by 200% over the same period.
- Desalination (scenarios 2b & 2d) results in approximately tripling the current energy used for water services to a total of around 4.5 PJ/year. However when viewed in context of total energy use for Melbourne this growth is marginal. The relatively large amount of energy used for residential purposes including water heating suggests that water conservation strategies which address end-use

of water will have more chance of significantly influencing total urban energy use than focussing on water strategy options alone.

- Rainwater tanks and wastewater reuse for low quality local applications (scenario 1b versus 1a) in a compact urban form could yield a small (~1%) benefit on river flow; however, the energy influence was not able to be separated in this study. Treatment to higher levels and significant transport would require substantial additional energy investments; however, this would be expected to be less energy than desalination as treatment of wastewater to a standard suitable for non-consumptive urban uses requires approximately half the treatment energy of desalination. Similarly, some reuse options may offset energy needs for pumping treated wastewater (e.g. from Melbourne's Eastern Treatment to Boags' Rocks) or to irrigation sites, and some may not.

These results are further explained in the more detailed analysis that follows. The results highlight the role that policy levers in the areas of water services, residential dwelling mix and urban form have on shaping water and energy futures generally. The analysis is not intended to rank or judge any approach because the settings were chosen for creating plausible scenarios only. This means that driving forces of the water system performance cannot be directly compared; however, other scenario settings could be made to provide appropriate consistency to aid comparison, for example, a common volume of water supplied by the various means.

In the subsequent graphical outputs the black lines (to 2001) relate to historical data that are either observed or calibrated in the VRSFF model, while the coloured lines track the projected future pathway under different scenario assumptions. The scenarios have been modelled out to the year 2045.

4.1 Water Use, Energy Use and Overview of Impacts

Figure 3 compares the total residential water demand across all scenarios. This shows scenarios with a compact urban form (1a & 1b) have the lowest overall water demand. Scenarios simulating a continuation of low density urban sprawl and no demand management (2a & 2b) have relatively high levels of end-use demand. This figure also demonstrates that urban form has a greater impact on reducing demand than end-use demand management strategies alone. The scenarios incorporating enhanced end-use demand management, but no change in urban form (2c & 2d) show a relative reduction in residential demand of approximately 50 GL while scenarios with compact urban form and demand management strategies (1a & 1b) have reduced demand by approximately 150 GL (compared with 2a & 2b).

The influence of urban form in these scenarios is predominantly associated with reduced outdoor watering due to the loss of backyards through infill and multi-storey dwellings. Substantial high-rise development (significantly lower per capita land-footprint than for separate dwellings) was required to accommodate population growth within the *Melbourne 2030* urban growth boundary. An additional factor in the impact of urban form is the slightly lower water intensity (per unit floor area) of high-rise residential dwellings.

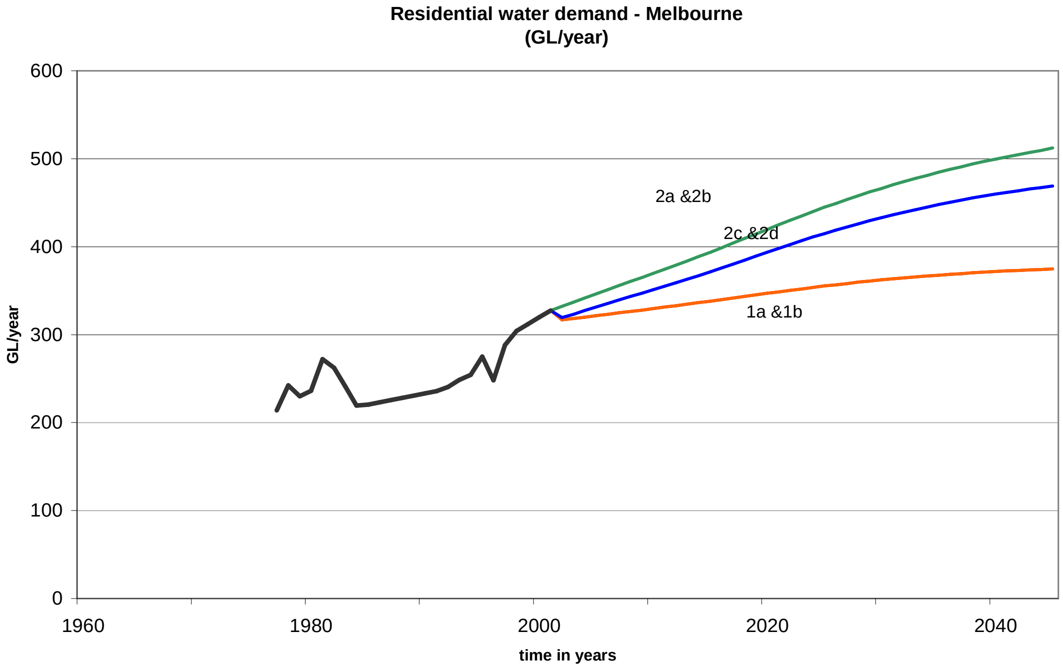


Figure 3 Residential water demand for Melbourne

Figure 4 provides an overview of all scenarios regarding the total energy required for the water services in Melbourne. This takes into account existing treatment and pumping of potable water, treatment and pumping of discharged water, energy for local wastewater reuse, pumping of inter-regional transfers and desalination. Energy for transfers of new reuse water, desalinated water or rainwater tank pumping are not included in this. The figure clearly shows that in scenarios where new demand is met by desalination (2b & 2d) there is a significant increase in energy required with demand management and solar hot water systems (2d) reducing energy use by around 0.7 PJ if desalination is implemented. Shifts to solar HWS and demand management strategies are consistently less energy intensive than their comparable BAU scenarios. For example, the difference between scenario 2a & 2c at 2045 is around 0.2 PJ.

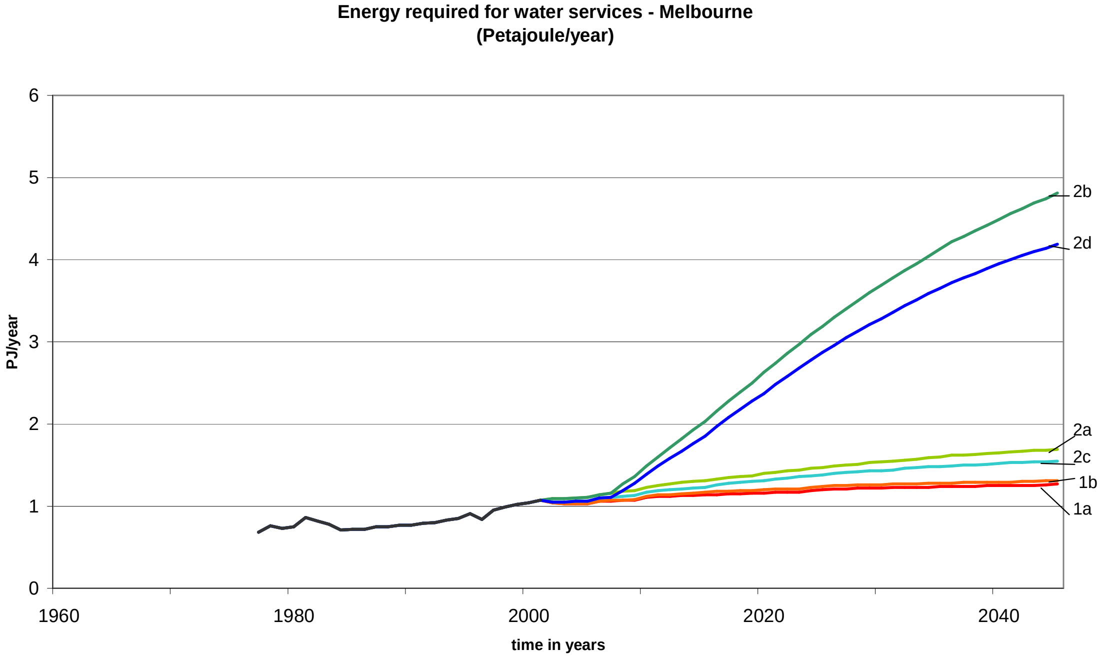


Figure 4 Energy required for water services

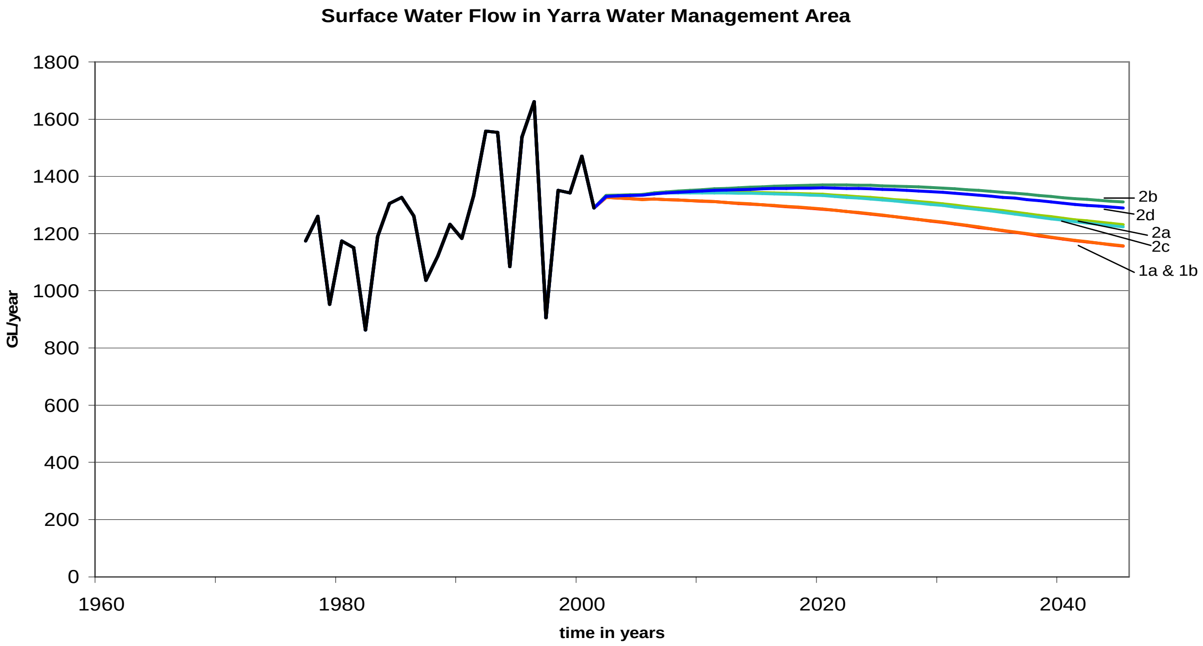


Figure 5 Surface water flow in Yarra Water Management Area

Figure 5 illustrates the change over time of surface water flows in the Yarra River Water Management Area under the different scenario assumptions (note, the flows incorporate all surface water within the Management Area, not solely the Yarra River in this example). Urban form has implications for surface water quality and flow, with scenarios simulating a shift to a more compact city (1a & 1b) resulting in lower surface water flows (exiting the water management area, see Figure 5) than for a city with sprawling fringe development. There is a comparatively lower ratio of impervious surfaces in a compact city than for low density urban sprawl, and consequently stormwater discharge is greater for the expanded city. This discharge may enter the river system.

In addition to the influence of urban form, the impact of a shift to a drier climate for Victoria is evident with many rivers, including the Yarra, projected to have decreased average annual flows. This is most evident in Figure 5 for the compact city scenarios (1a & 1b) where there is little growth in the area of Melbourne; consequently the continual reduction in surface flows is largely associated with climate change factors. For the urban sprawl scenarios, the flows increase for about 2 decades since the additional stormwater discharge and wastewater flows from the expanding built area counteract the effects of climate change for some years.

Scenarios simulating new urban water demand being met by desalination plants (2b & 2d) result in less reduction in river flows for the Yarra due to less demand to divert flow to urban water storage. This is because water provided by desalination substitutes for a fraction of water that would otherwise be drawn from surface water bodies throughout the water management area. This effect is not large in the Yarra water management area because the majority of water is sourced from the Thomson Reservoir and transferred to the Melbourne region. A shift to decentralised water supply alternatives, such as rainwater tanks and wastewater recycling, has only a minor impact on river flow in the Thompson River, which is diverted to the Thomson Reservoir (Melbourne's major storage).

In addition to information on flow volumes, the ratio of stormwater and wastewater discharges to natural river flow provides a potential high-level indicator of river water quality. This is because urban runoff discharged directly to receiving water generally contains relatively high levels of contaminants, such as suspended solids. Scenarios characterised by a low density urban form and conventional water services (2a & 2c) had the highest levels of discharge to the Yarra River.

4.1.1 Urban Form

The majority of Victoria's population is accommodated in low density suburban developments in greater Melbourne. At the time of the 2001 ABS census 78% of Melbournians were accommodated in separate dwellings. *Melbourne 2030* identifies the shift towards a more compact urban form as a primary objective. This section considers the implications of urban form on energy and water demand as well as stormwater flows.

Figure 6 depicts residential water demand by dwelling type projected through to 2045. Compact urban form (Scenarios 1a and 1b) lead to reduction of around 150 GL/year water in water use in low density residential uses with around 75GL/year growth in high density use of water. This pattern leads to the reduction in total water use (refer to Figure 3) and is driven primarily by reduced garden irrigation due to higher urban density. In Victoria 35% of all residential demand is for outdoor uses (ABS 2004). The assumptions related to water consumption and urban density can be seen in Appendix C.

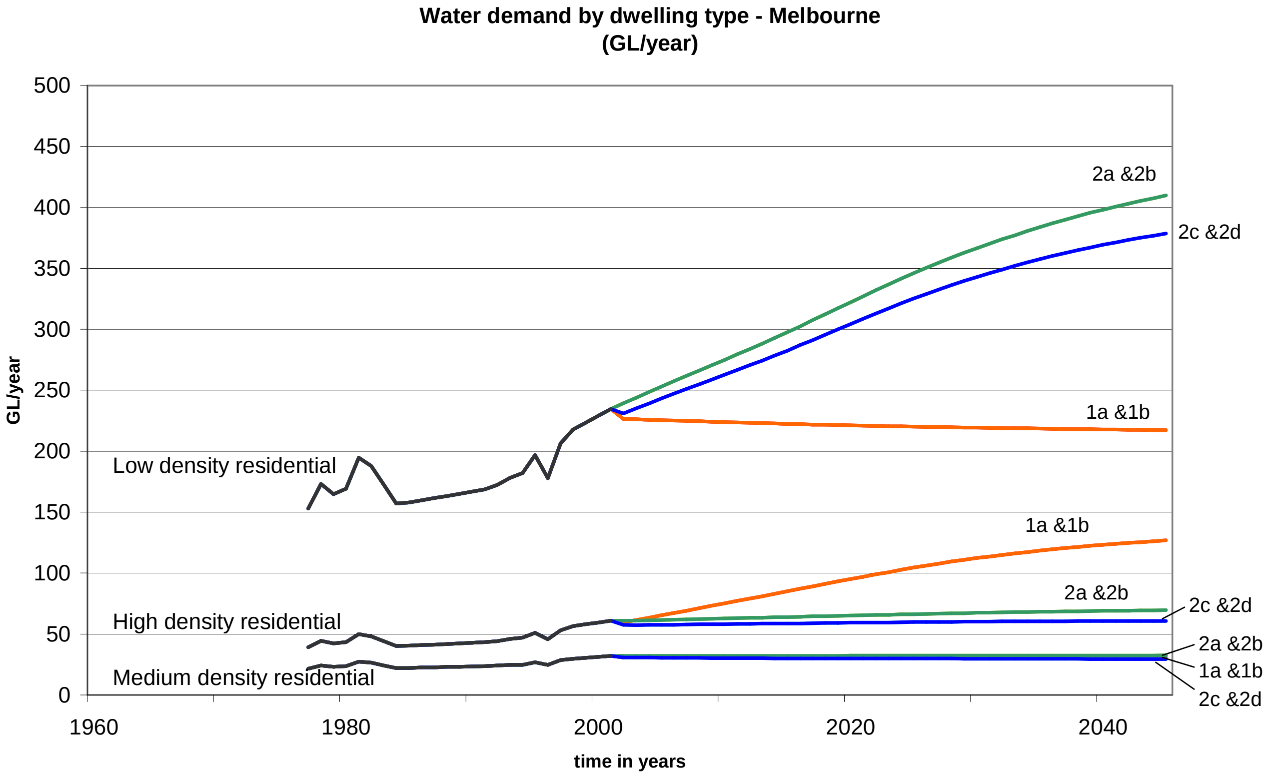


Figure 6 Water required by dwelling type

The *Yarra Valley Water Appliance and Usage Patterns Survey, 2003* demonstrated that per capita indoor consumption decreases with increasing household size (in Birrell et al. 2005). In Melbourne it is projected that households will increase at a greater rate than population due to demographic shifts, such as an ageing population and lower fertility, which will lead to an increased proportion of single person and two person households. The projected impact of urban consolidation and demographic change on Melbourne has been explored by Birrell et al. (2005). The Birrell report suggests that if Melbourne achieves a shift to medium and high density dwellings consistent with the goals of Melbourne 2030 there would be a 37% increase in domestic water consumption by 2031 when compared to 2001 levels, while a continuation of the current urban form would see a 40% increase over the same period. This report demonstrates that future domestic water demand for Melbourne will primarily be shaped by population growth, but also highlights the likely consequences of shifts in household structure and urban form.

A comparison of scenarios 1a (compact form) and 2a (urban sprawl) demonstrates the influence of urban form on end-use water demand, as they have identical water services and end-use. Consequently there is approximately 100 GL reduction in end-use demand that can be attributed to a consolidated urban form. This suggests that by 2045 residential end-use of water could increase from 14%-42% of 2001 levels pending on choices made about urban form and water conservation strategy.

Urbanisation alters the hydrology of catchments leading to the degradation of river ecosystems. The impact of urbanisation can be observed in a river catchment such as the Yarra. The upper reaches are largely undisturbed natural vegetation and have excellent water quality, while the lower reaches which are heavily urbanised have poor to very poor water quality. The degree of impact to receiving waters from urban land use is dependent on the extent of the urban area, the amount of urban runoff generated that drains to the receiving water and whether runoff reaches the receiving waters by sealed drains or more natural flow paths (Walsh et al. 2004) The Victorian government released the *Yarra Action Plan* that identified urban stormwater as the most significant contributor to poor water quality in the Yarra.

Urban form can also impact on stormwater runoff as it can influence both the area and density of impervious surfaces to generate runoff. Predicted climate change impacts will alter stormwater flows as even if the urban area grows (e.g. in the sprawl scenario) stormwater runoff could decline due to decreased rainfall and increased evaporation. Reduction in stormwater generated will also impact on inflows to urban waterways. Results showed that outflows from the Yarra Management Area may decrease by approximately 15% (see Figure 5) under the assumptions of high density urban form when compared to continued sprawl.

4.1.2 Water End-use and Solar Hot Water Systems

The scenarios 2a and 2c are discussed in this section in order to elucidate the impact of strategies at the household level including demand management and hot water systems. Both scenarios involve conventional water services and continued urban sprawl, but 2a simulates BAU in terms of end-use demand management while 2c simulates a shift to solar HWS and increased uptake of end-use demand strategies (see Section 3.3).

Figure 7 illustrates the influence of residential end-use demand management strategies on reducing residential energy demand for Melbourne. Demand management strategies implemented in scenarios are focused on reducing water heating requirements through low-flow shower heads and more efficient washing machines. These strategies are focussed on new dwellings, so it can be seen that the impact on energy demand increases over the simulation time period as population growth is accommodated in new dwellings. The results show that by the end of the simulation a shift to solar HWS coupled with the demand strategy reduces electricity demand by around 35 PJ/year This represents approximately a 12% difference in residential energy demand between scenarios 2a and 2c.

The other end-use strategy explored within the scenarios is a shift to solar HWS. The effects are marginal when considered in the context of overall growth of energy demand due in part to the shift to solar HWS predominantly occurring for new dwellings constructed, with only 20% of existing dwelling stock upgrading to a solar HWS.

Figure 4 shows there is a significant decrease in energy demand for water services under the assumptions of the demand management scenario compared to BAU water services. End-use demand management strategies reduce the electricity required by water services by approximately 8% in 2045 relative to BAU. The reduction in electricity demand is most significant for discharge, as the demand management strategies reduce the amount of residential wastewater generated for treatment and discharge.

There is only a marginal decrease in the energy required for water supply for the demand management strategy relative to the BAU scenario. This is due in part to Melbourne's water supply catchments being situated in the upper reaches of the Yarra Ranges meaning the system is largely gravity fed reducing reliance on energy for pumping of urban water supplies.

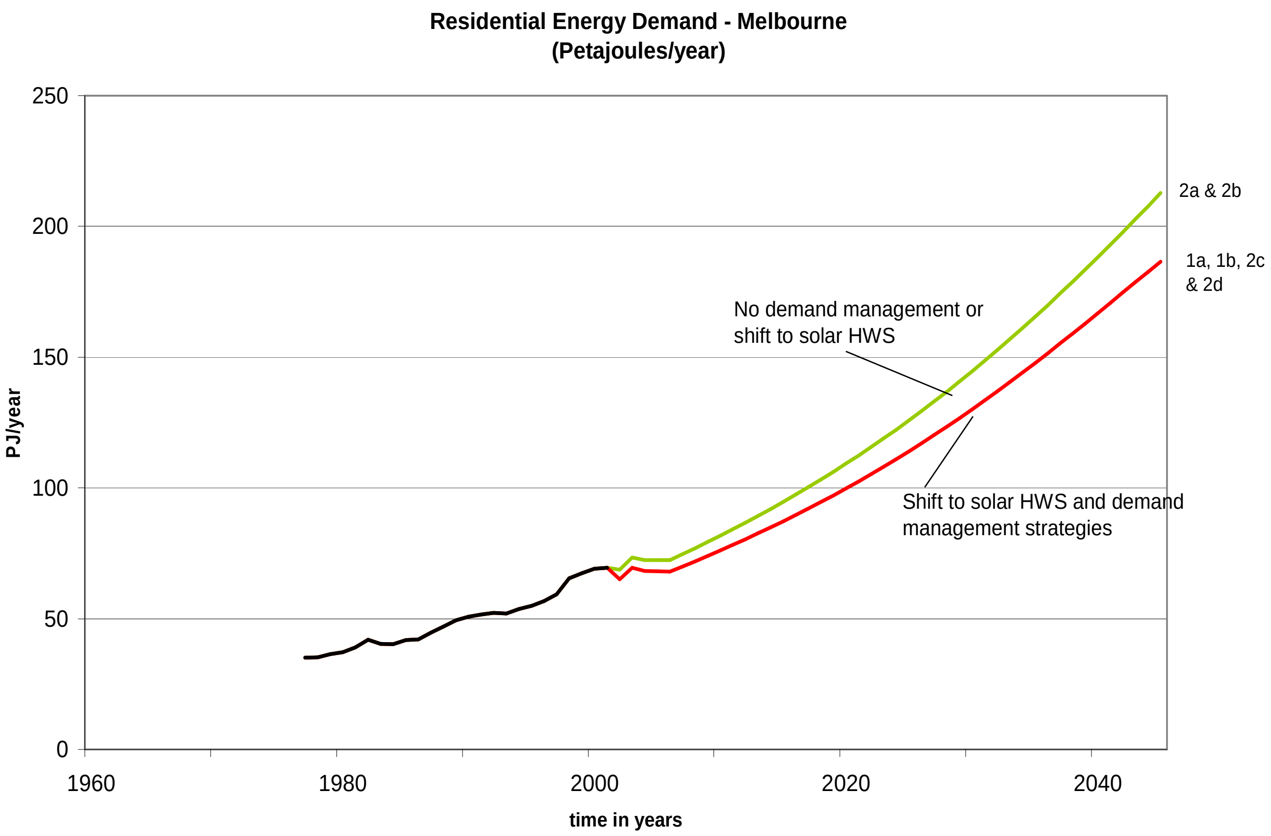


Figure 7 Residential energy demand – Melbourne

4.1.3 Water Services

A comparison of scenarios with conventional water servicing (scenario 2c) and those where all new demand is met through desalination plants (2d) demonstrates that a shift to desalination would substantially increase the energy required for water services (see Figure 4). However, when placed in the context of the overall Victorian economy and the energy use of Melbourne the increase in energy associated with desalination is very marginal, with VRSFF modelling showing an initial 1% increase in overall consumption due to desalination by 2045. In this analysis the additional energy for transporting desalination or treated reuse water was not able to be calculated as the energy demand would be highly site-specific. However, lifting 100 GL to a height of approximately 200m (e.g. Cardina Reservoir) could require around 0.2 PJ energy excluding pipe resistance.

Water required for electricity generation increases sharply during the simulation. The assumption driving this growth in VRSFF is the growth of the Victorian economy at the rate of 2% per annum. National primary energy consumption has grown by around 2% per annum over the past several decades. Projections by the Australian Bureau of Agricultural Resource Economics (ABARE) for the average over 2005-2030 in Victoria based on recent trends are around 1.3% per annum (Akmal et al. 2005); however, there is limited certainty regarding these projections particularly over longer periods of time.

The effect of demand management strategies on water demand for electricity production can be seen in Figure 8 where there is approximately a 5% difference in water required for electricity production. Note that Latrobe produced around 166 PJ of electrical electricity in 2001 of which a large component was used by Melbourne.

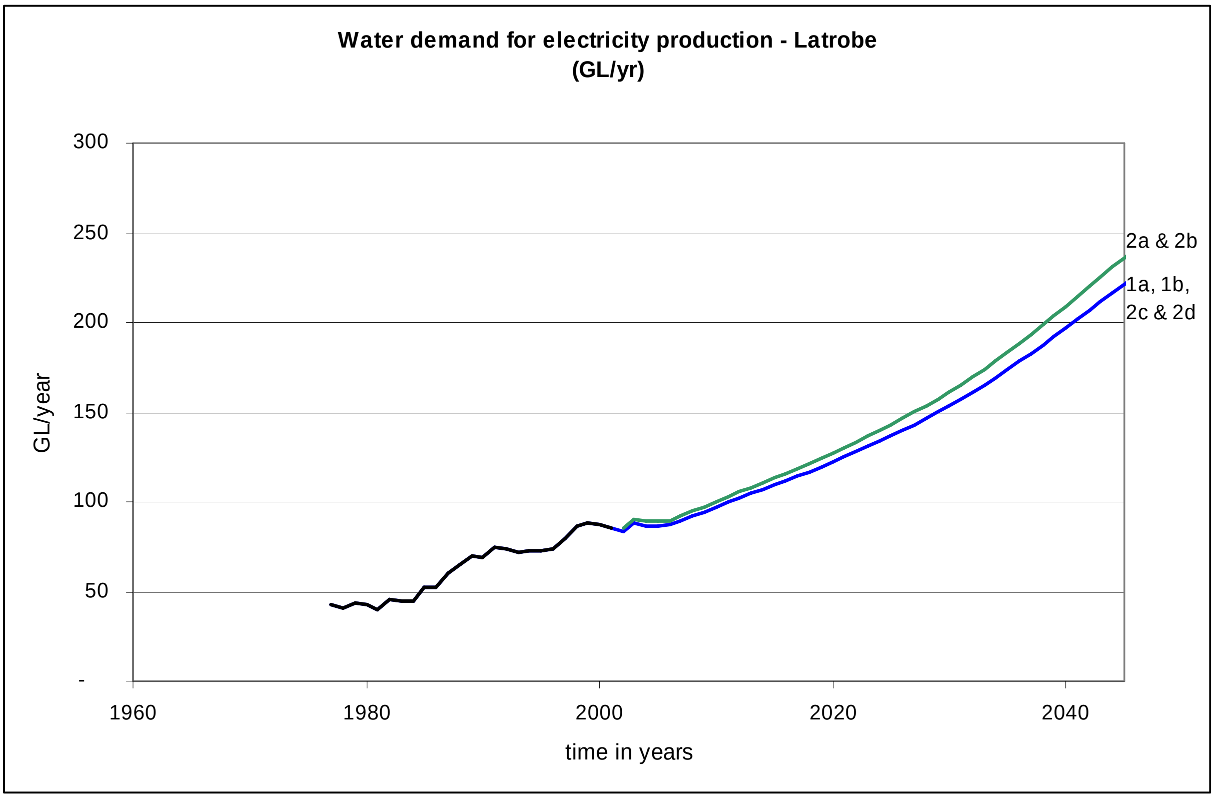


Figure 8 Water demand for electricity production – Latrobe

Desalination will reduce the pressure on river flows that are sourced for urban water supply due to less water being diverted to storage. Figure 9 shows the fraction of river flow that is by-passing dams for the Yarra, Maribyrnong and Werribee rivers under a conventional water service scenario (2c) and a desalination scenario (2d). Climate change impacts decrease overall river flow substantially in both scenarios, which increases the importance of freeing up flow to maintain ecological health of river systems. Wastewater recycling also reduces pressure on river flows; however, the level of wastewater recycling simulated within the scenarios (20% of wastewater flows) is not of the same magnitude as simulated in scenarios where desalination is a feature, as these assume that all new demand for potable water is met by desalination plants.

River flows may be critical in maintaining the ecological health of the river system. Reduced flow has been shown to impact on native fish species by interfering with their breeding cycles. The proposed environmental entitlement for the Yarra River is 17,000 ML per year, which can be stored and released as needed in order to maintain natural flow regimes. Maintaining adequate environmental flows while considering the demands of the population is likely to be a difficult balancing act in the future. Population and economic demand is likely to continue to grow, while impacts of climate change will reduce the inflows to the river system.

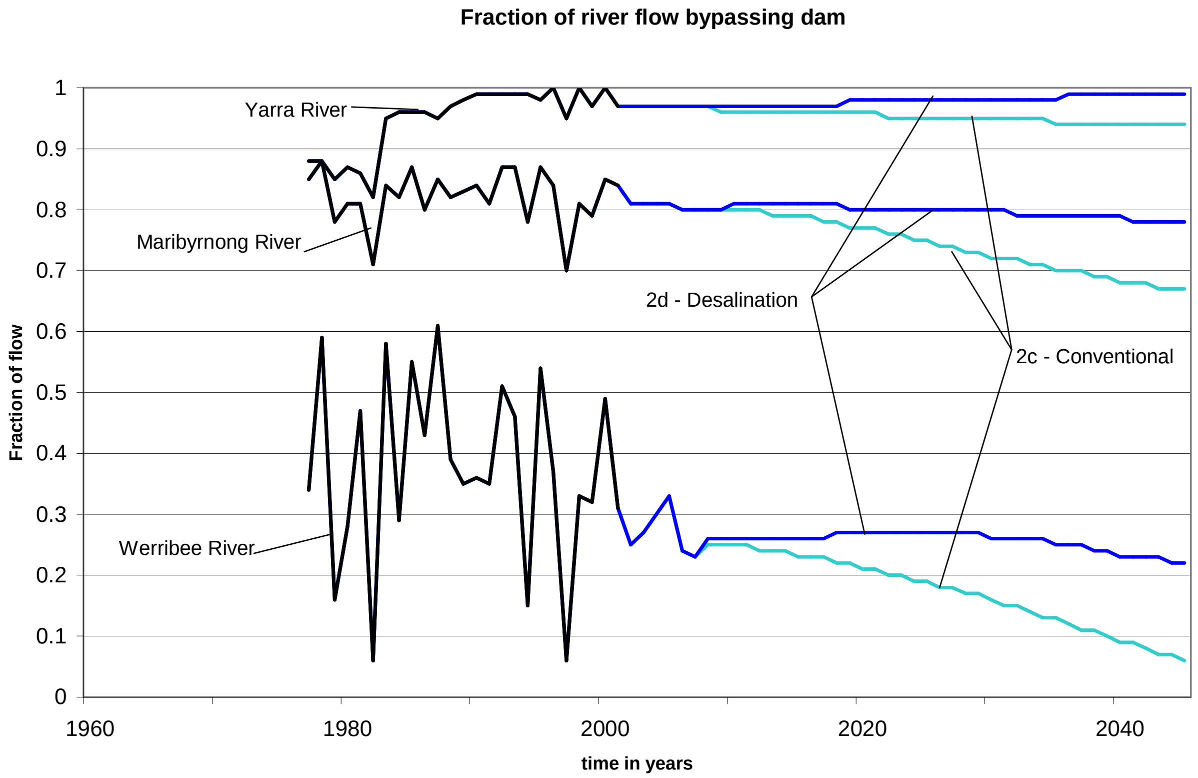


Figure 9 Fraction of river flow by-passing dam – conventional versus desalination

4.2 Virtual Water

Virtual water flows to Melbourne were estimated using the Australian Stocks and Flows Framework (ASFF) and VRSFF, which provide a means of tracking the fate of all abstracted water. This approach allows all direct and indirect water use to be identified and partitioned to the population so that virtual water flows for all cities and regions sum to observed national totals. The flows can be aggregated into six “classes” of product: (1) direct consumption of water in buildings, (2) used in electricity generation, (3) embedded in agricultural goods and processed food consumed domestically, (4) water embedded in non-agricultural goods consumed domestically, (5) water embedded in non-agricultural goods exported and (6) water embedded in agricultural goods and processed food exported.

The total water necessary to sustain Melbourne includes not only around 350 GL/year of direct water use (largely for consumption within residential, commercial and industrial sectors), but also includes approximately 60 GL/year in electricity and 1400 GL/year in food (largely from the Murray Darling Basin)(Figure 10). Around 1600 GL/year is exported as food (the pro-rata share for Melbourne of national production). While the implications of scenarios on virtual water flows have not been assessed as a component of this study, indications are that under all scenarios the growth in electrical energy demand for Melbourne leads to a tripling in the demand for virtual water (in electricity) by 2045. This represents a real growth in water demand of around 100 GL. Note that the curves in Figure 10, unlike others in this report, are cumulative. This means that the top line on the graph represents the summation of all segments mapped in the graph.

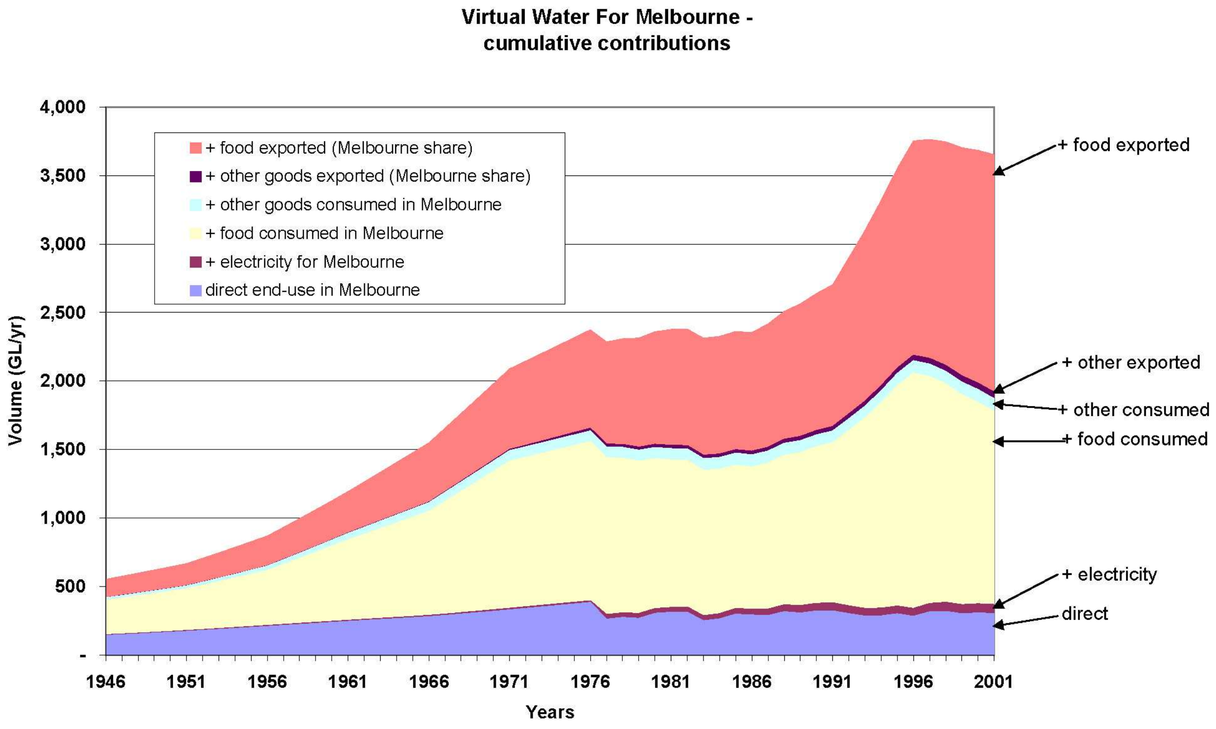


Figure 10 Virtual water flows – Melbourne (Cumulative* Volumes)

** Note that in a cumulative graph the top line represents addition of all the underlying data and that, for example, the volume of water consumed by Melbourne in electricity can be seen by comparing the “+electricity” segment with the “direct water” segment which is underneath it.*

5. CONCLUSIONS, RECOMMENDATIONS AND RESEARCH NEEDS

5.1 Conclusions

Urban form was identified as a major influence on water demand and it also influences stormwater flows. A more compact urban form led to savings of around 100 GL in water compared to continued urban sprawl of Melbourne. This is due primarily to the reduction in outdoor water consumption.

A shift to solar hot water systems coupled with demand management strategies demonstrated significant benefits because both energy and water demand were reduced. Scenarios with more demand management and solar hot water systems (1a, 1b, 2a, 2b) saved around 30 PJ of residential energy use. This amounted to about 10 times more than the anticipated increased energy use by utilities (around 3 PJ/year) from strategies which met new water demand through desalination water.

Water services strategies differed substantially with regard to their total impact on energy use. When all new demand is met by desalination, energy use for water services approximately triples above current levels. This is some 3-4 PJ more energy than if other water options (including demand management) were employed to meet the demand. However, when this increase is placed in context with the total energy consumption for Melbourne the increase is less than 1% of total urban energy use. Desalination provides the obvious benefit of a reliable water source that is not dependant on rainfall. This is especially pertinent given the projected decreases in catchment in flows due to climate change. The increased energy intensity of desalination could potentially be offset through a shift to end-use demand management strategies and solar hot water systems. Wastewater reuse would also demonstrate similar benefits potentially at lower energy intensity; however, a 20% reuse scenario was the maximum level of reuse simulated in this analysis.

In 2001, virtual water use in Melbourne (around 3600 GL) was approximately nine times the water consumed directly within Melbourne (around 400 GL). Virtual flows of water in electricity in 2001 were around 60 GL (15% of current direct use). This flow is projected to increase to over 150 GL by 2045 as energy use increases. Consequently reducing electricity consumption will also help reduce water consumption. Estimation of virtual water flows raised many questions including methods of calculation particularly with regard to consideration of extracted versus rainfed systems, wastewater reuse and international trade. Additional analysis is necessary to answer these questions. Improved spatial tracking of food and fibre would also help with characterising virtual water flows.

This study did not involve analysis of policy or scenarios involving different population growth levels, energy supply, energy use, climate change or their interrelations. Likewise scenario sets around key drivers such as urban form, demographics, lifestyle and technology adoption (e.g. rainwater capture or greywater systems), water demand and more end-use options were limited but sufficient to inform dominant trends.

The influence of scenarios on greenhouse gas emissions was not determined at this point due to limitations in underlying datasets. However, 387,000 tonnes of carbon-dioxide equivalents (CO2-e) are released per PJ of energy generated from Victoria’s brown-coal fired power plants.

In a water and carbon-constrained future it will be necessary to decide on not only the total amount of water and energy that is sustainable to pass through our urban systems, but also agree on the acceptable impacts to the wider regional systems providing these flows to our cities. Understanding these influences will be critical to optimising the performance of our cities and to protecting the environment that sustains them.

The approach enabled by the VRSFF model has provided a high-level “whole of system” view to evaluate policy options around water supply and future trajectories of major drivers of change, such as urban form. This approach makes transparent the interconnections and feedbacks between different parts of the system such as the energy needs of water supply options. A major advantage of the approach is that impacts can be placed in context with the total physical economy of Melbourne (e.g. total energy consumption). It also highlights feedbacks to other parts of the system such as river flow.

A challenge for future analysis of urban water-energy-greenhouse interactions is to bring together information and skill sets which have traditionally been managed separately including water and energy supply, use and conservation. Investigations which integrate across these boundaries will help progress our understanding of these interrelations in our complex urban systems.

5.2 Recommendations and Research Needs

The following recommendations are suggested as necessary to advance our understanding and management of the urban water and energy nexus:

- Characterise energy use through the water system. This should include improved spatial representation in water and wastewater treatment and transport to improve analysis of water strategies including alternative options such as rainwater tanks.
- Evaluate long-term plans which govern the urban form of Melbourne (i.e. Regional Plans or Strategies of 30 year plus time-frames) in detail for their projected flows of water, energy and system-wide influences. Such analysis could help identify solutions which simultaneously reduced water and energy use. Supporting social and economic analysis would also be warranted to evaluate the overall costs and benefits of alternative future urban form for Melbourne.
- Include energy implications as well as the energy of water use and total urban systems energy use when water management strategies are prepared. This is important to ensure true energy-neutrality (and in future carbon-neutrality) of water supply strategies. It will also help establish the relative contribution to energy and greenhouse conservation that is being progressed by the water sector.
- Develop more detailed and far-reaching scenarios with input from government, industry and the community. By developing more detailed analyses of key drivers (including urban form, demographics, life-style and end-use water and energy demand, technology adoption, climate and energy and water supply), there is an opportunity to greatly improve our knowledge of these complex interactions and inform policy accordingly. Consideration of wider-scale reuse including potable substitution would be warranted.
- Undertake analysis to separate the water and energy savings of scenarios involving solar hot water systems and water demand management – in combination with water supply options (e.g. reuse, desalination and water conservation). This would enable improved understanding of the relative magnitude of policy choices in these domains.
- Clarify the “relative environmental benefit” of water and energy savings. As an example, current policy enables new developers to choose between “water” options such as rainwater tanks and “energy options” such as solar hot water systems. Each of these strategies will have a different (water or energy) outcome; however, it is not yet clear which achieves the “best” overall outcome (or how much energy outcome is worth how much water outcome).
- Analyse industrial and commercial water and related energy use. Preliminary information suggests that consumption of energy by industry associated with the “industrial” use of water is at least as large as residential energy use for water, yet relatively little information exists at present in the public domain.

- Review virtual water accounting methodologies to inform their application in an Australian context. Particular issues to address include water abstraction versus rainfed systems, international trade and water reuse. Future simulations to inform projections of virtual water flows through Melbourne are also recommended.
- Characterise greenhouse gas emissions (including methane, nitrous oxide) through the urban water cycle from water storages, through use and downstream to wastewater treatment and discharge. No detailed analysis was possible in this study due to limitations in underlying data sets.
- Develop reporting mechanisms and indicators to help improve the base-level understanding of urban water and energy interactions. Research and consultation is necessary to develop suitable reporting approaches. An example would be that our guides for reporting by water utilities (e.g. WSAA 2005, National Water Commission 2007) could be expanded to include energy use associated with water use. Similarly, performance indicators for Melbourne’s total energy budgets could be developed together with allocations for its components.

Appendix A Overview of the VRSFF Model

The VRSFF account covers the main flows of the UN System of Environmental-Economic Accounting for Water (SEEAW) framework (UNSD 2007) (Figure 11).

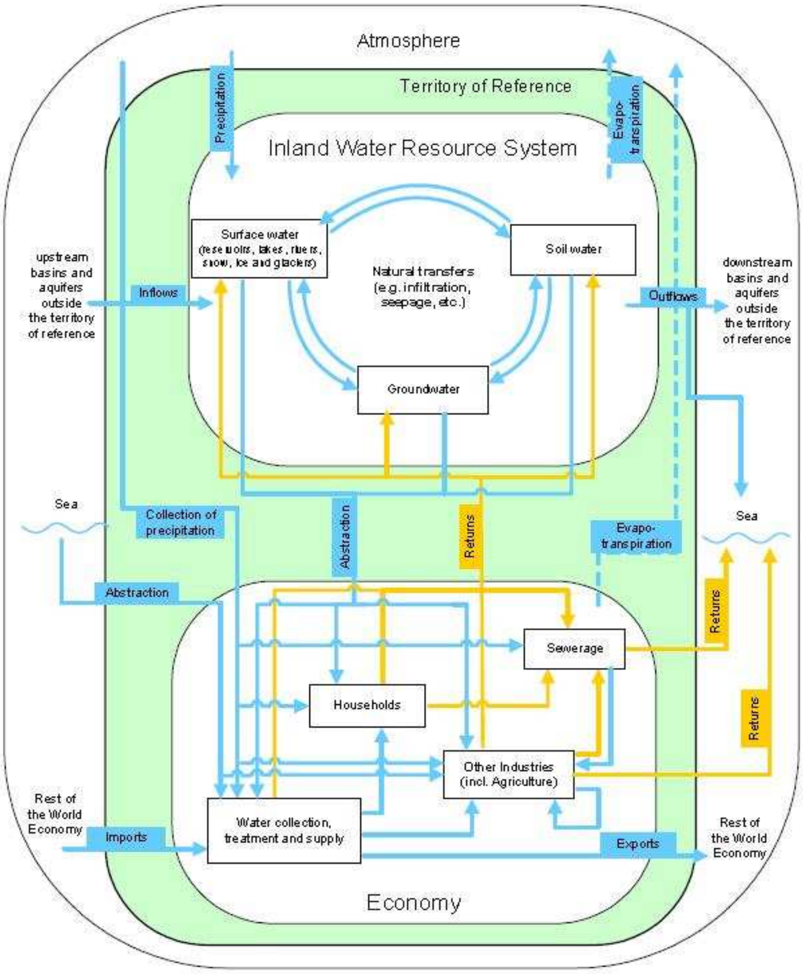


Figure 11 The System of Environmental-Economic Accounting for Water (SEEAW) framework developed by the United Nations Statistics Division [2007], effectively covered by the VRSFF Water Account

Water Accounting

A high level outline of modules within the VRSFF water account and the data flow between them (Figure 12) indicates how implications of changes permeate through the model. Calculations and connections relating primarily to water demand are on the left side, while those relating to supply of water are on the right. Implications of scenario settings made higher up the hierarchy in influence calculations in lower modules as indicated by the arrows.

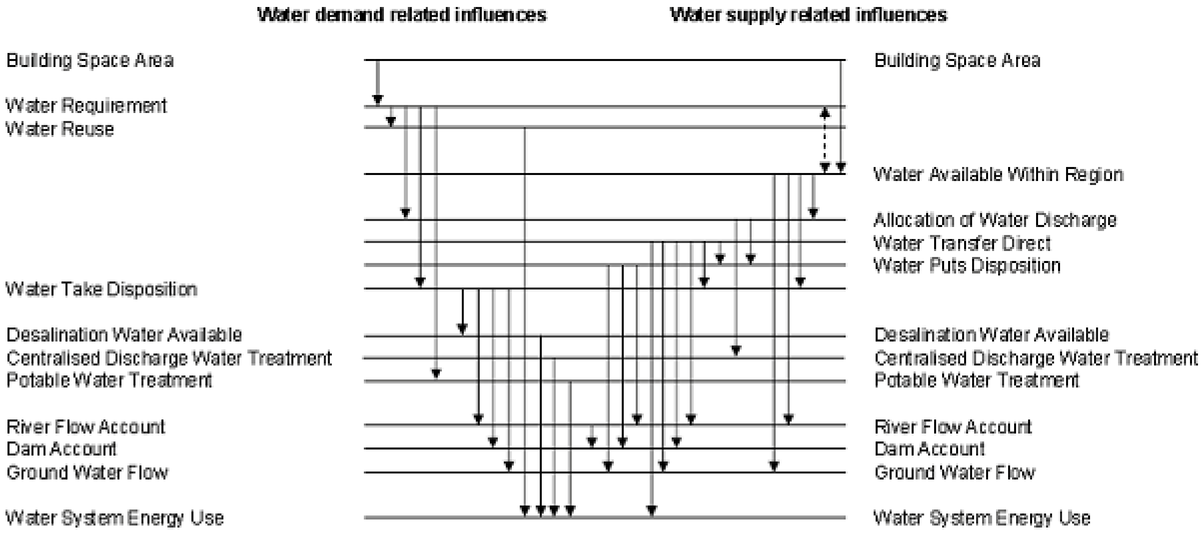


Figure 12 Influence diagram summarising the data connections (shown by arrows) from modules higher in the hierarchy of the water account to lower modules

Building Space Area, for example, influences both the water requirement, and water available (e.g. through rainwater tanks or stormwater flow). The “Building Space Area” module (the top of Figure 12) influences both the “Water Requirement” and “Water Availability Within Region” modules. The “Water Requirement” module represents a key part of the “demand” side of the water system; it also takes information from other Stocks and Flows Frameworks about the level of water use associated with various economic activity. The “Water Availability Within Region” module represents a key part of the “supply” side or natural input of the water system. Following calculations in these modules, both pass data to other modules, as indicated by the arrows.

Energy use by the water sector (in both the demand for water and supply of water) is calculated at the lower part of the hierarchy. Other modules of VRSFF calculate energy supply; however, this is not shown in the figure.

Tensions between the demand and supply settings (in this example for water) may arise in the “Dam Account” and “Ground Water Flow” modules as a result of scenario settings higher up the water account hierarchy. The water account framework does not directly incorporate a means for resolving tensions (such as deficits in water storages); instead it is intended to facilitate a variety of solutions to be designed and compared. These solutions may involve simulation of engineering projects (e.g. greater dam capacity), technological innovation (e.g. water recycling) or behavioural or structural change (e.g. less water use).

The structure of the data flow within the framework is a key feature for facilitating understanding of the water system and creating solutions to tensions. As Figure 12 indicates, the cause of tensions that are collected at the bottom of the diagram can be traced back up through the framework.

In addition to manually resolving tensions, supplementary scripts can be written to display collected or manipulated outputs, or they may be written to enter data into the exogenous variables external to the model. A combination of these scripts can be used to form feedback loops that resolve tensions, such as maintaining dam levels by adjusting diversions and extractions from the river network.

Each of the modules in the framework contain detailed calculations which are used to simulate the flow of water through Victoria’s physical economy under different scenarios – as an example, part of the “dam account” is shown in Figure 13. More detail is provided in Turner et al. (2007).

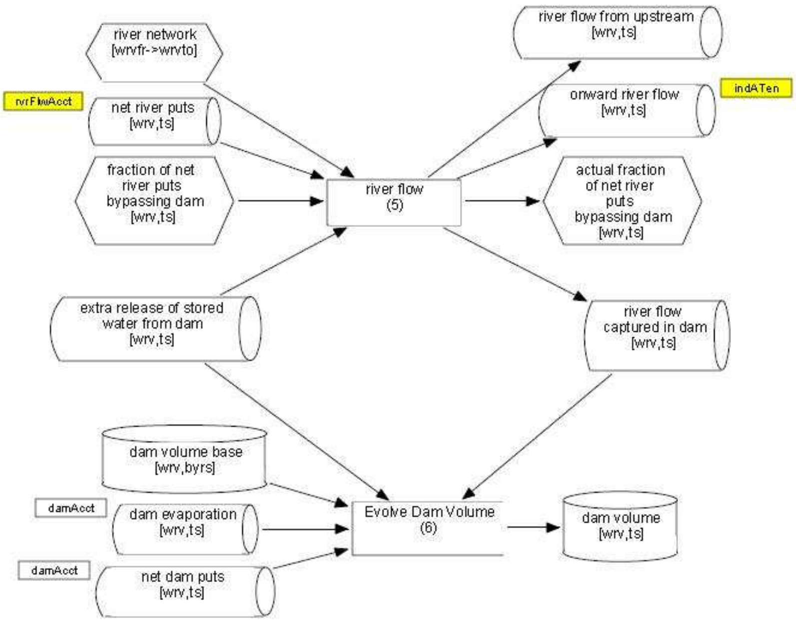


Figure 13 Stocks (barrels) and flows (pipes) variables from the “dam account” module

Urban Form of Melbourne

The following figures present the Victoria in Future state population densities modelled by VRSFF. Darker shades show higher proportion of land area used for the land-use indicated (e.g. low, medium and high density residential development). They also show the influence of the compact and sprawl scenarios described in this report.

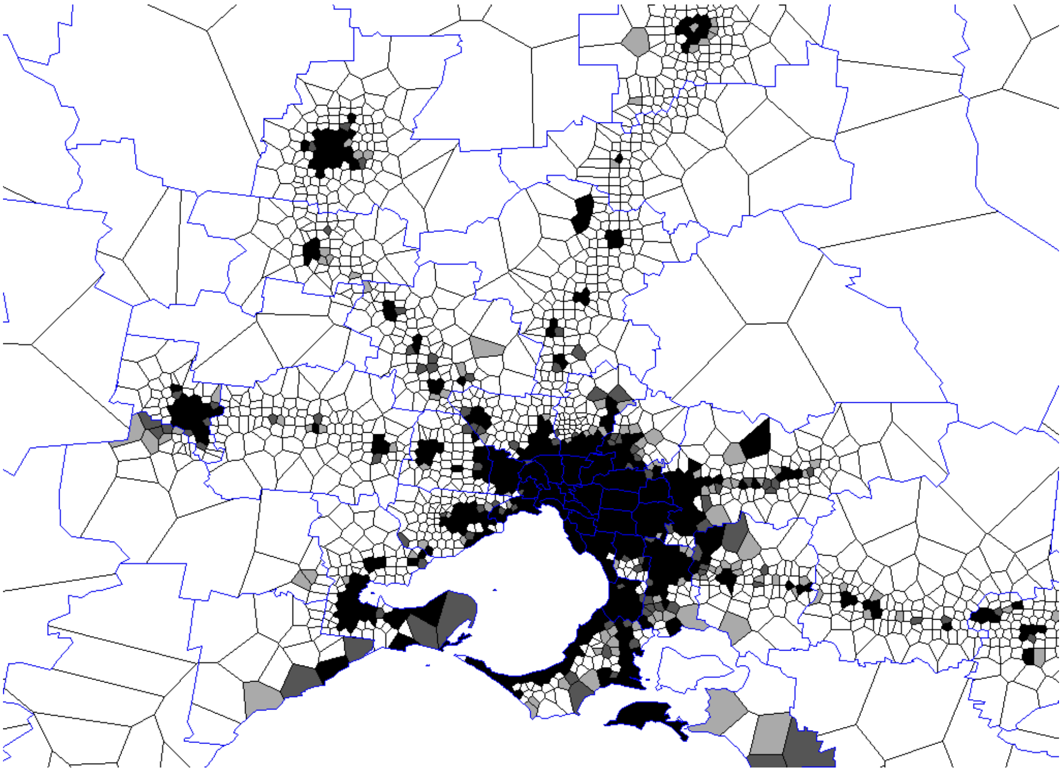


Figure 14 Spatial pattern of low density residential development in 2002

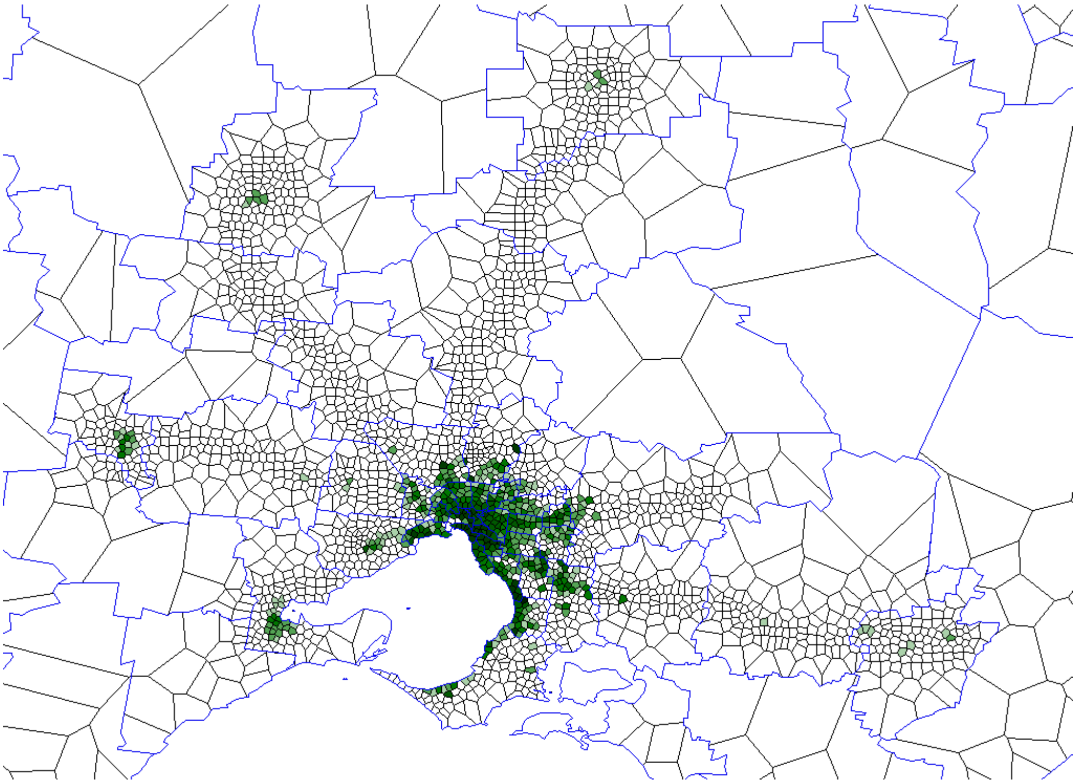


Figure 15 Spatial pattern of medium density residential development in 2002

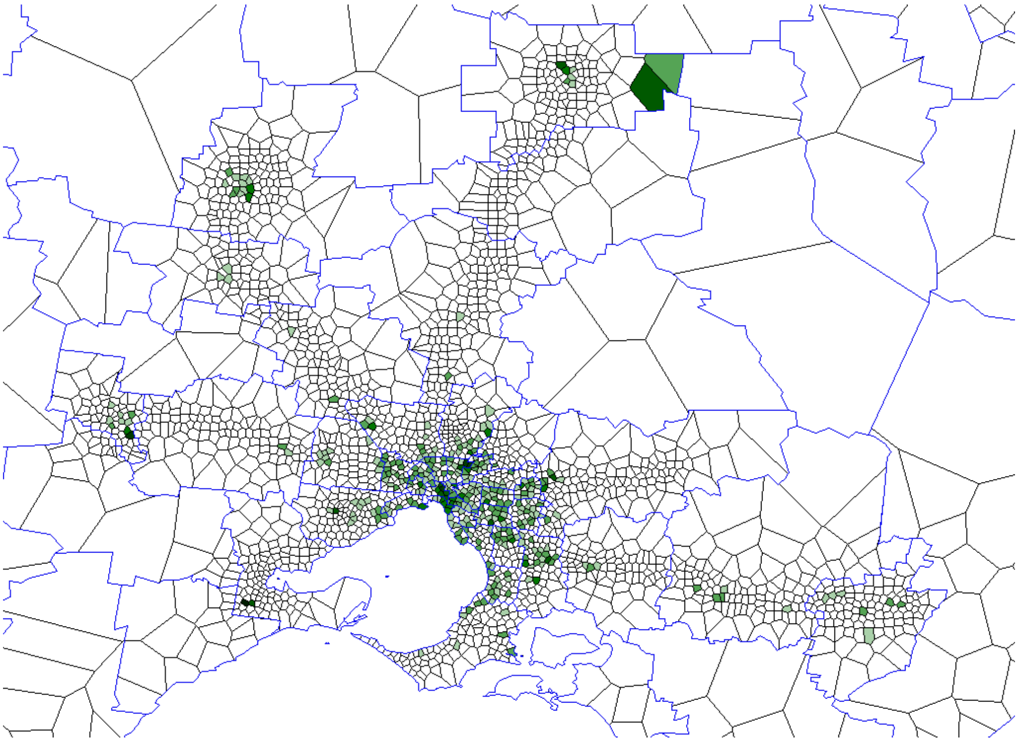


Figure 16 Spatial pattern of high density residential development in 2002

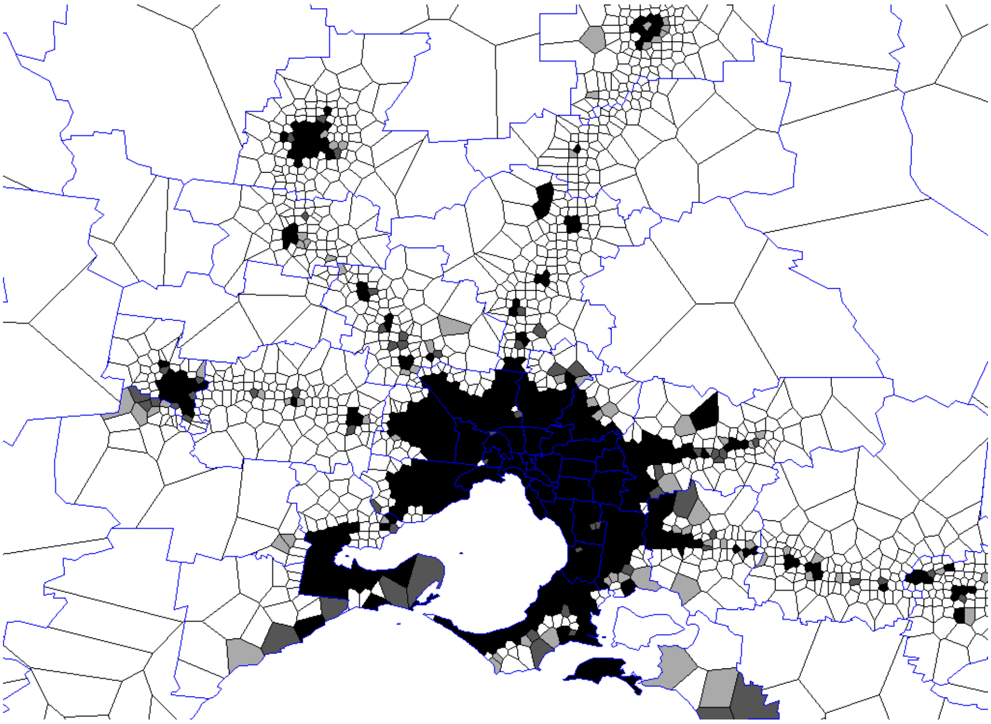


Figure 17   Spatial pattern of low density residential development in 2100 representing Scenario Set 2 through to 2100

Note that many areas on the fringe of Melbourne include a higher density of low density residential development when compared to 2002. In this Scenario Set, almost all new residential development is for low density development and medium and high density development remains relatively unchanged.

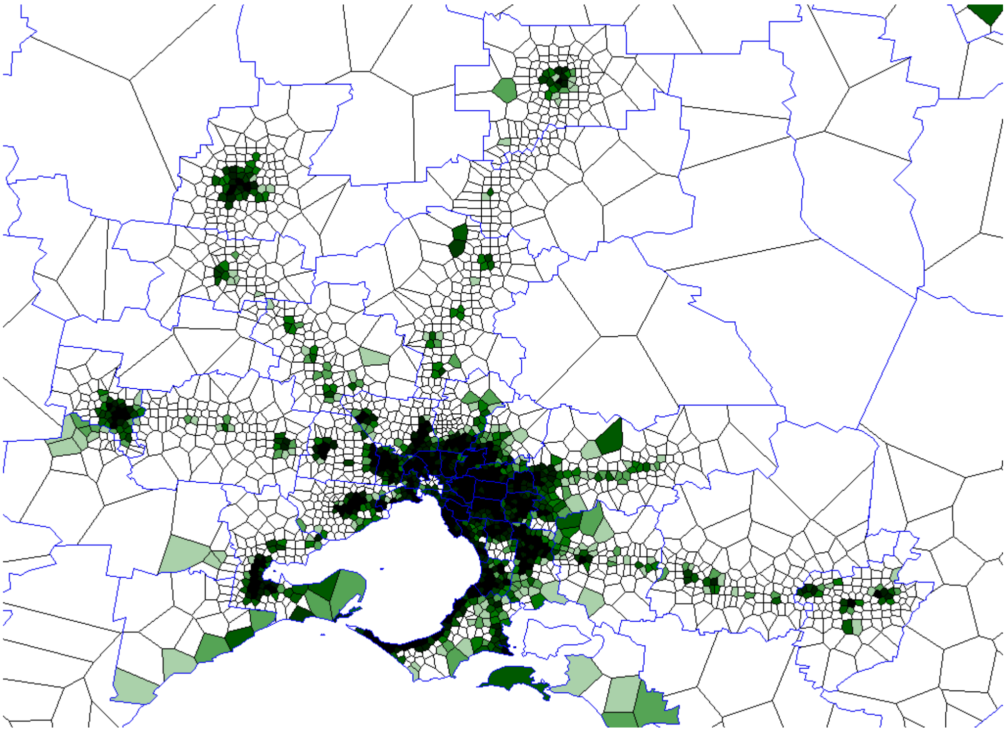


Figure 18 Spatial pattern of low density residential development in 2100 representing Scenario Set 1 (compact urban form)

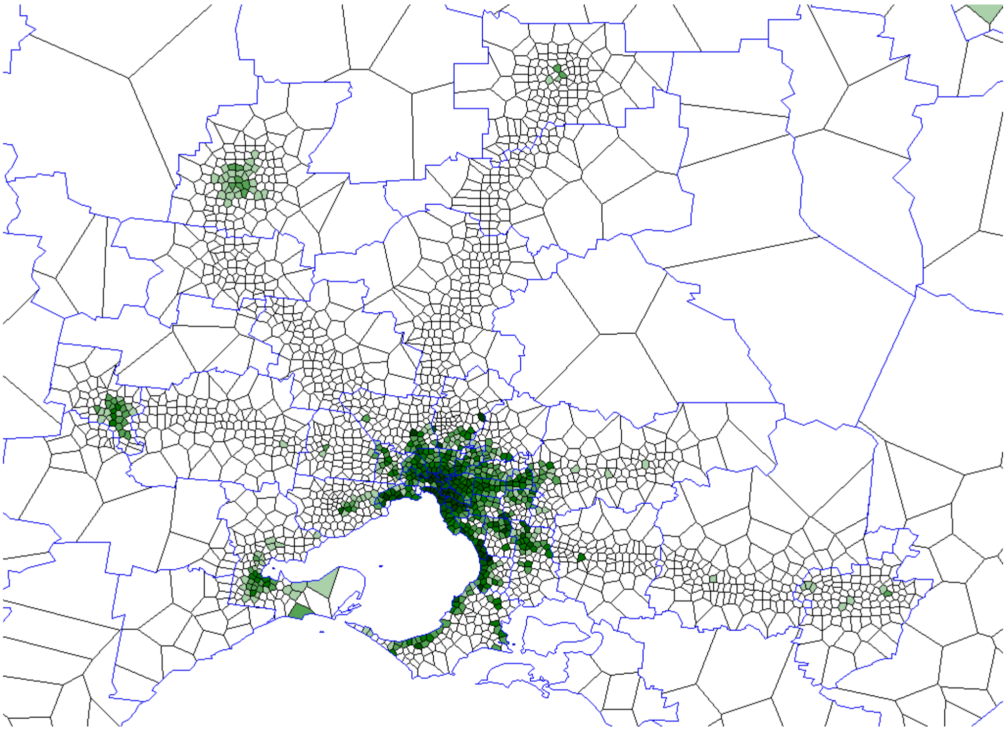


Figure 19 Spatial pattern of medium density residential development in 2100 representing Scenario Set 1 (compact urban form)

Note the increased density of medium density residential land use around Melbourne's edges as well as on the edge of "satellite" around Melbourne.

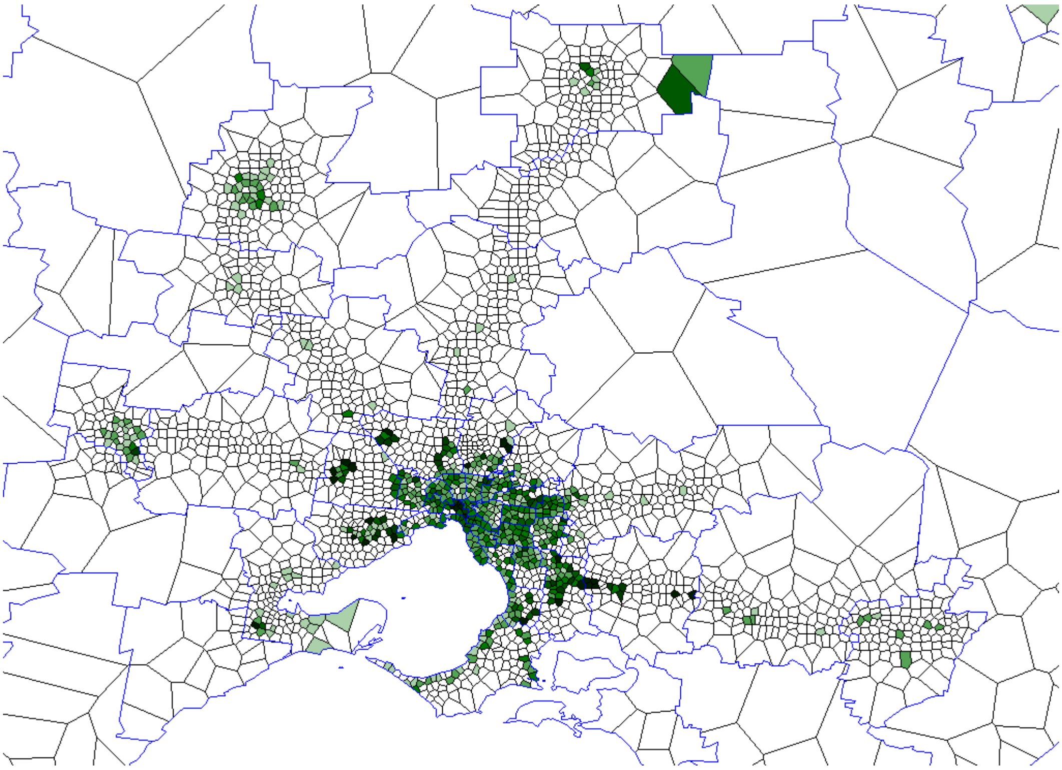


Figure 20 Spatial pattern of high density residential development in 2100 representing Scenario Set 1 (compact urban form)

Again note the growth, relative to 2002.

Appendix B Water and Energy Assumptions

Water-Energy Intensity Assumptions

The modelling process for this study undertaken in VRSFF assumed the following with regard to energy-intensity of water options which were used for the whole simulation period:

- that the treatment of discharged wastewater (and transfer) requires 3384 J/L
- that the treatment of potable water requires 468 J/L
- that desalination requires 17753 J/L and
- that reuse uses 50% of the energy for potable treatment (234 J/L) and
- that inter-regional water transfers use 2.4 J/L/km
- that rainwater tanks would consume negligible additional energy.

The basis of these assumptions are described below. Since this modelling analysis has been completed more detailed characterisation of energy use through the water cycle in Melbourne has been undertaken (Kenway et al 2008b). Consideration of this more recent detailed energy data would help improve the detail of analysis options.

Melbourne's discharged water treatment energy requirements are higher than most Australian cities because the sewerage has to be pumped further. For 2004-05 a system average of 0.39 KWhr/m^3 was used for treatment alone (1404J/L) but including pumping of discharged water this is 0.94 KWhr/m^3 (3384 J/L). Currently the VRSFF Water Account does not track the distribution of discharged water flows in the same way it does potable water transfers, and so, the energy cost of treatment and transfer of waste water have to be considered together in the one intensity – otherwise the energy for transporting discharged water would not be counted at all. Melbourne's Eastern Treatment Plant's (ETP) energy consumption for the treatment of sewerage in 2003/04 = 719 TJ (719 X 10^{12}J) and 116 TJ was used for sewerage transfer with 305 TJ generated from renewable sources http://www.melbournewater.com.au/content/publications/reports/annual_report.asp

Melbourne Water treated 130,516 ML at ETP in 2003/04, hence an intensity of 719 TJ / 130,516 ML = 5509 J/L for treatment alone or 6398 J/L including discharge transfers (the assumption here is that all of Melbourne Water's energy for pumping sewerage was for discharges from the ETP) (Melbourne Water's Annual Report 2003/04). These reports do not say what energy was used for what level of treatment, though the Victorian Water Review 2003/04 Figure 39, p72 states that the following split in waste water treatment occurred for Melbourne's water retailers:

For 2004-05 Melbourne used 0.02 KWhr/m^3 for potable water treatment alone but included here is the water distribution energy intensity for a total of 0.13KWhr/m^3 = 468J/L (Melbourne's potable water treatment energy requirements are lower than most Australian cities because of the quality of the water). The energy costs of distribution are separate to other major inter-regional water transfers. Note that even the additional energy intensity of distribution is low compared with most other Australian cities because Melbourne’s water is mostly gravity fed. How this applies to Victorian water supplies outside Melbourne is uncertain. These assumptions were valid at the time of modelling. Subsequent more detailed characterisation of energy through the water cycle (e.g. Kenway et al 2007) confirms the overall pattern and would provide a more detailed basis for future analysis.

For the proposed Sydney desalination plant, The Australia Institute quoted 900GWhr / 182,500,000 kL per year (17,753 J/L).

In the process of collecting information on water supply and discharge, extensive data on the reuse of water were found in ABS (1998, 2001, 2006) and used to estimate the electricity required for water reuse. This reuse mainly occurs in mining, processing and assembly and heavy industries. Where the energy intensity of the treatment of reused water was unknown it was estimated as half that of potable water treatment noting that much higher energy usage would be required to produce high quality water from wastewater.

The single figure used for all inter-regional water transfers is 2.4J/L/km. This is the end result of a historical calibration process that subtracts the total energy required in potable and discharged water treatment and distribution, from the figures quoted by ABARE in table F (row 541) for the total energy requirements for the Victorian Water sector. This produces a residual amount of energy which is divided by estimated quantities of water transferred (based on historical reports) and the estimated distance that water travels based on known canal or pipeline lengths, where possible, or centroid to centroid distances between CMAs otherwise.

It was assumed that rainwater tanks would be used for non-potable internal purposes, lawn watering and could be installed to avoid the use of additional pumping.

Reliability of Rainwater Tanks

The reliability of rainwater tanks in meeting residential indoor non-potable demand (toilet flushing) has been calculated using Aquacycle®. Aquacycle is a water balance computer model (Mitchell 2004) that can be used to analyse water balance outcomes for different servicing options.

The assumptions used in modelling reliability of rainwater tanks included:

- tank size of 1 KL
- 200m^2 roof area, with 50% draining to rainwater tank
- end-use demand for toilet flushing of 101 litres/property/day.

In order to simulate the impact of climate variability across Melbourne a weather station climate record was selected for five Surface Water Management Areas (SWMAs) and assumed to be representative of this area. There is significant spatial variation in rainfall across each SWMA, so this assumption was limiting. The selection of weather station was taken near the major urban centre for each SWMA in order to best represent potential for residential rainwater capture.

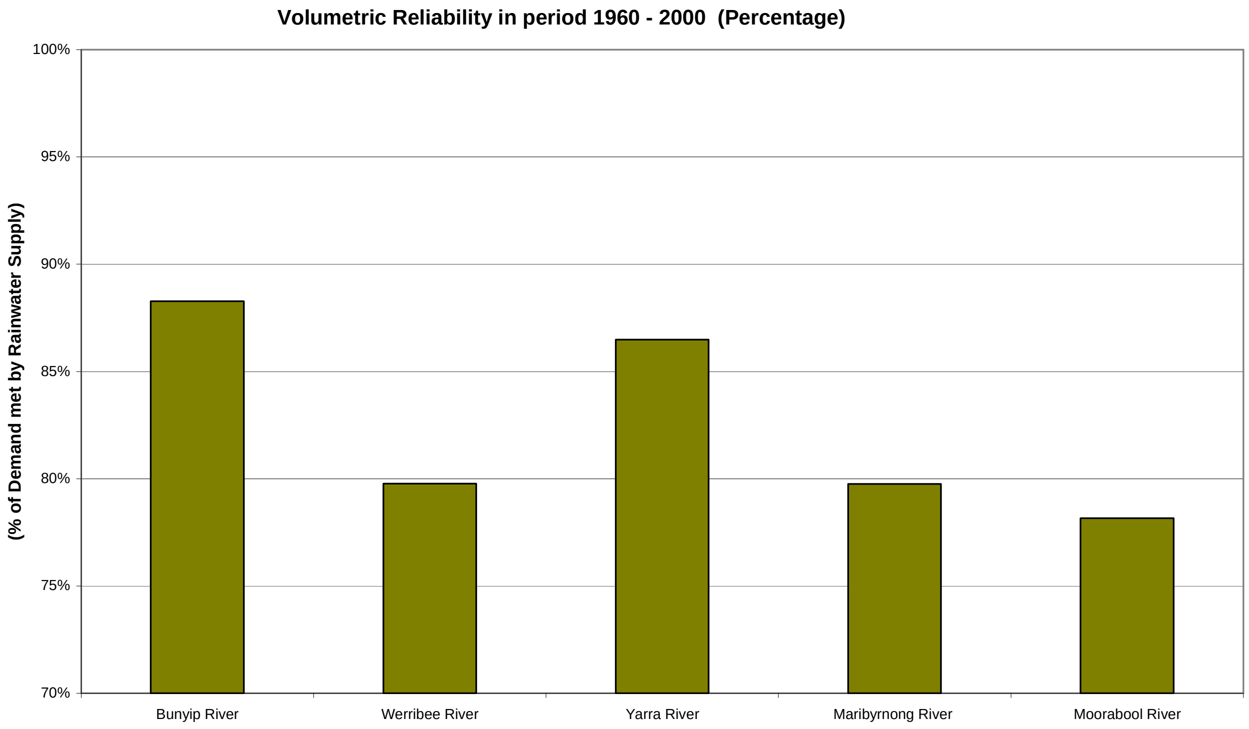


Figure 21 Volumetric reliability for 1 KL rainwater tanks – Melbourne surface waters

Appendix C VRSFF Land Use and Water Intensity Assumptions

The following details the assumptions relating to land use and water intensity contained in the various scenarios. Water intensities used in the VRSFF Water Account:

Land use – with buildings	**Indoor Water intensity**
Low density residential	413 litres/year/m^2
Med density residential	354 litres/year/m^2
High density residential	358 litres/year/m^2
Admin and commerce	0.57 litres/year/m^2
Higher education	0.57 litres/year/m^2
Acute Care	0.57 litres/year/m^2
Other Institutions	0.57 litres/year/m^2
Retail and business	0.57 litres/year/m^2

From ABS 4610.0 Water Accounts 2001 p 89, the indoor/outdoor use split in Victoria is approximately 65/35, respectively. This was applied to the total water use per dwelling by these dwelling types (According to P. Troy "Domestic Water Consumption in Sydney" Report to Sydney Water 2005): Low Density = 309 000L/yr; Medium Density = 251 000L/yr; High Density = 218 000 L/yr. These were not the final numbers used because when these intensities (split by indoor and outdoor use) were applied to Victorian dwellings, the total was different to what ABS (2001) reported as the total Household water use in Victoria, 472 266 ML. Intensities were adjusted to get the right aggregate but maintained the intensities in proportion to one another.

Assumed characteristic floor space area for dwelling units of these dwelling density types for business as usual are: Low Density = 300 m^2, Medium Density = 250 m^2, High Density = 200 m^2. These remained constant through to 2045 for all scenarios.

With the demand management scenario, these intensities reduced to:

Land use – with buildings	**Indoor Water intensity** litres/year/m^2
Low density residential	380
Med density residential	326
High density residential	329
Admin and commerce	0.57
Higher education	0.57
Acute Care	0.57
Other Institutions	0.57
Retail and business	0.57

In all scenarios the following assumptions were made about outdoor water use:

Land use – with buildings	**Outdoor Water intensity**
Low density residential	680kL/year/ha
Med density residential	680kL/year/ha
High density residential	680kL/year/ha
Admin and commerce	0 kL/year/ha
Higher education	0 kL/year/ha
Acute Care	0 kL/year/ha
Other Institutions	0 kL/year/ha
Retail and business	0 kL/year/ha

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