

MELBOURNE WATER CLIMATE CHANGE STUDY

*Implications of Potential Climate Change for
Melbourne's Water Resources*



Implications of Potential Climate Change for Melbourne's Water Resources

A collaborative Project between Melbourne Water and
CSIRO Urban Water and Climate Impact Groups

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Executive Summary

In 2002, the Water Resources Strategy for the Melbourne Area Committee released its final report *Water Resources Strategy for the Melbourne Area*. The report recognised the increasing body of scientific evidence that gives a collective picture of a warming world and other climate changes and the potential of significant implications for our water resources systems. The Committee recommended that Melbourne Water and the retail water companies continue ongoing, active evaluation of climate change impacts on water supply and demand measures (Recommendation 17). Accordingly, Melbourne Water engaged CSIRO to undertake a study to investigate the implications of climate change for Melbourne Water's water, sewerage and drainage systems. This study is believed to be among the first globally to examine these systems in a combined manner.

The study has involved:

- Development of Melbourne area climate change scenarios for 2020 and 2050 based on the Inter-governmental Panel on Climate Change (IPCC) scenarios.
- An overview of the potential implications of climate change coupled with potential water demand scenarios for Melbourne's water, sewerage and drainage systems including identification of major risk areas.
- A detailed quantitative case study for Melbourne's water supply system and potential adaptation options.
- Semi-quantitative case studies of the potential for increased sewerage overflows and local flooding.
- Identification of potential adaptation strategies to mitigate the impacts of climate change given the range of uncertainties identified during the study.

Findings of the Melbourne Climate Change Study are summarised below.

Climate Change Projections

In spite of uncertainties associated with climate change predictions consistent trends for Melbourne can be interpreted from the study. These trends include:

- **Increased average and summer temperatures.** Potential average annual temperature increases are projected to range from 0.3 to 1.0°C in 2020, and 0.6 to 2.5°C in 2050.
- **Reduced rainfall** with models suggesting annual average precipitation changes of -5 to 0% in 2020, and -13 to +1% in 2050.
- **More extreme events** with more hot days, more dry days and increased rainfall intensity during storm events.

Areas of Risk

Workshops and specific case studies were undertaken to identify the range of implications of climate change scenarios for the water supply system and water availability, the sewerage system, the drainage network and Melbourne's waterways. The workshops with staff and external experts highlighted a range of potential risks to Melbourne Water's systems. The major risks identified included:

Water Supply

- Reduced water supply due to decreased streamflows
- Increased risk of bushfires in catchment areas with associated risk of decreased streamflows
- Reduced environmental condition of streams with associated implications for water harvesting in regulated and unregulated streams

Sewerage System

- Increased potential for corrosion and odours caused in the sewerage network as a result of increased sewage concentrations associated with water conservation, increasing ambient and seasonal temperatures, and longer travel times within the sewer network
- Increased incidence of sewer overflows due to increased rainfall intensity during storms
- Increased risk of pipe failure and collapse due to dry soil conditions
- Increased salinity levels in recycled water due to rising seawater levels resulting in increased infiltration to sewerage network and at wastewater treatment plants

Drainage

- Increased flooding risk and property damage due to increased rainfall intensity during storms
- Increased risk of damage to stormwater infrastructure and facilities (e.g., underground drains, levee banks, pump stations etc) due to higher peak flows

Receiving Waters

- Reduced health of waterways due to changes in base flows
- Potential for negative water quality impacts in Port Phillip Bay due to increased concentration of pollutants entering Bay (longer periods between runoff events and then high intensity events leading to concentrated pollutant runoff) and higher ambient Bay water temperatures.

Adaptation Strategies

Climate change scenarios and the potential implications for water service provision and receiving waters highlight increased uncertainty for future resources planning. Adaptation will require on-going review of climate change, population growth, land-use changes, water use, effectiveness of implemented water demand and supply side programs and the capacity of current systems to cope.

The study identifies a range of initiatives above those currently planned that should be investigated further including changes to water, sewerage and drainage system design

criteria (particularly in greenfield or redevelopment areas) and investigation of additional demand or supply side options including non-traditional sources such as groundwater and desalination.

Case Studies

Three case studies were selected to further explore higher risk areas. These included a review of the water system to identify potential reductions in water availability and the sewerage and drainage networks for increases in sewer overflows and flooding respectively.

Water Supplies

Detailed quantitative analysis of the impact of reduced streamflows found that average long-term streamflows potentially would be reduced between 3% and 11% by 2020, and as much as 7% to 35% by 2050.

Supplies were then analysed against a range of population and water demand scenarios. Although any of the projected climate and population scenarios could eventuate, the greatest confidence is in the mid-range area.

Results of the “mid-range” climate change scenario project an 8% reduction in the average annual volume of water able to be supplied by the system in 2020 rising to 20% by 2050. Planned demand and supply side actions should compensate for decreased supply through 2020 although some actions may need to be implemented sooner than currently planned.

Mid-range estimates are quite conservative of the impacts on Melbourne’s water supplies. The estimates do not account for the cumulative impact of climate effects beyond parameters evaluated in the case study, assume that the 15% per capita demand reduction target will be met by 2010 and assume that further per capita demand reductions and system augmentations to Tarago treatment plant, O’Shannassy pipeline duplication, Winneke treatment plant upgrade and East-West transfer upgrades will occur by 2050.

After 2020 the magnitude of supply side changes may require additional action to be taken including desalination or other system augmentation. Melbourne Water’s ability to cope with climate change will be dependent on the rate at which climate change, population growth and water use reductions occur. Contingency planning is required to ensure appropriate water supply adaptation techniques are available if major step changes to climate should occur.

Sewer Overflows and Flooding

Intensity of storm events has been identified as the most important variable for the drainage and sewerage systems. Under climate change scenarios, changes in rainfall totals, temporal patterns and intensities of storm events could increase the risk of sewer overflows within both the transfer system and local reticulated sewage collection system. These same climate patterns could lead to increased local flooding.

SECTION 1 – Introduction

Over the past century and a half Melbourne has grown from a city of a few hundred thousand people to over 3.5 million people, and is expected to continue to grow during this century. In response to increasing population and the demands of households, industry and institutions, large systems and networks have been developed to ensure adequate and safe water supplies, sewage treatment and drainage. These systems and infrastructure have brought considerable benefits. They have contributed greatly to the liveability of Melbourne by providing surety of water supplies and by helping to buffer the community against the impacts of climate variability, such as major droughts with subsequent water restrictions and periodic flooding.

There is an increasing body of scientific evidence that gives a collective picture of a warming world and other climate changes. This will have significant implications for our water resources systems. In recognition of this Melbourne Water commissioned CSIRO to undertake a study on the implications of the impact of possible future climate change for the management of Melbourne's water, sewerage and drainage systems.

The study has involved:

- Development of Melbourne area climate change scenarios for 2020 and 2050 based on the Inter-governmental Panel on Climate Change (IPCC) scenarios
- An overview of the potential implications of climate change coupled with changes in water demand for Melbourne's water, sewerage and drainage systems including identification of major risk areas
- A detailed quantitative case study for Melbourne's water supply system and potential adaptation options
- Semi-quantitative case studies of the potential for increased sewerage overflows and local flooding
- Identification of potential adaptation strategies to mitigate the impacts of climate change given the range of uncertainties identified during the study

While a number of significant studies have been undertaken on the implications of climate change this study is believed to be among the first globally to examine water, sewerage and drainage systems in a combined manner.

This report brings together the main findings of this detailed study. Technical details associated with the areas of assessment are contained in supporting reports, including:

- Climate Change in the Greater Melbourne Region
- Demographics and Models
- Cases Studies for Water Supply, Sewerage and Drainage Systems

SECTION 2 – Climate Change

This section reviews the current understanding of climate change at the global and regional scale, the tools used in its assessment, current uncertainties in projecting future climate change and potential impacts on water resources. It also contains ranges of projected climate change for the Greater Melbourne Region and catchment areas of Melbourne Water.

Historical Patterns

Since 1950, temperature over Victoria has increased at the rate of 1.06°C per century for maximum temperature, 0.67°C per century for minimum temperature and 0.86°C per century for average temperature. This increase is likely to reflect enhanced greenhouse warming in combination with natural variability. This trend has affected the Greater Melbourne Region, and the metropolitan area has also experienced climate change due to the urban heat island effect.

Observed rainfall over Victoria shows significant decadal to multi-decadal scale variability with no strong evidence of trends. There was a jump to wetter conditions in the later 1940s and more recently a shift to drier conditions since the mid 1990s. Decadal rainfall variability will continue to be important under climate change. Climate change must be considered with ongoing climate variability. In the past there have been many periods when rainfall has spent several decades above or below long-term average rainfall. These conditions can shift quite abruptly and their dynamics are poorly understood. The recent decrease in observed rainfall change in eastern Australia was preceded by a similar decrease in Western Australia in the mid 1970s.

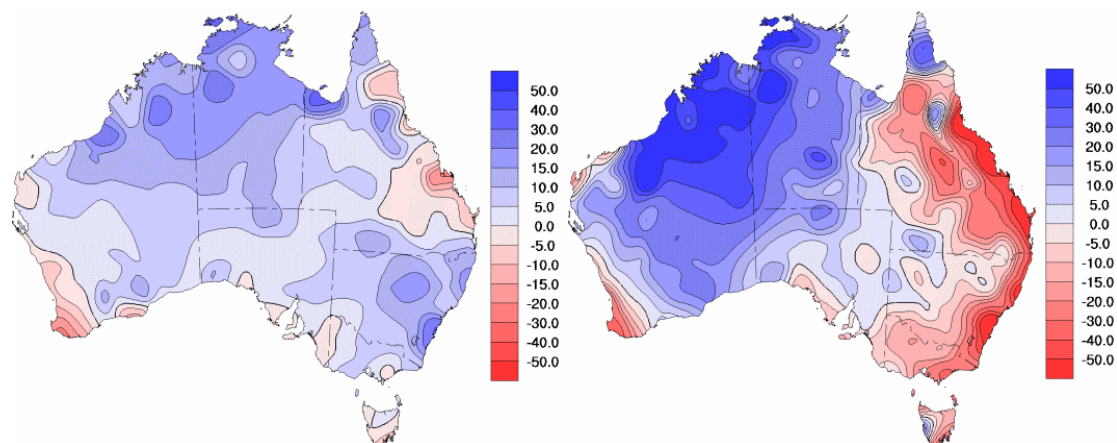


Figure 1: Rainfall trends in Australia for (a) 1900 to 2003 and (b) 1950-2003. Trends are shown in mm per decade. Source: Australian Bureau of Meteorology

Current weather patterns in Victoria, shown in Figure 2, are assumed to be due to variability but could be the result of climate change. It is too early to tell whether this pattern will be short lived, will persist over the long term, continuing for several decades before shifting back to wetter conditions, or is the result of a permanent shift in climate.



Figure 2: Accumulated rainfall for the period October 1996 to May 2004 showing that the greater Melbourne Region has had its lowest rainfall on record compared to all other periods of similar length. Source: Australian Bureau of Meteorology.

Projected Climate Change Scenarios

Global mean warming is expected to range between a 0.4°C to 0.9°C increase from 1990 to 2020 and 0.9°C to 2.2°C to 2050 as shown in Figure 3. There is a range of uncertainty in these scenarios, due to uncertainty in future Global CO₂ emissions and in the global circulation models used to assess temperature increases.

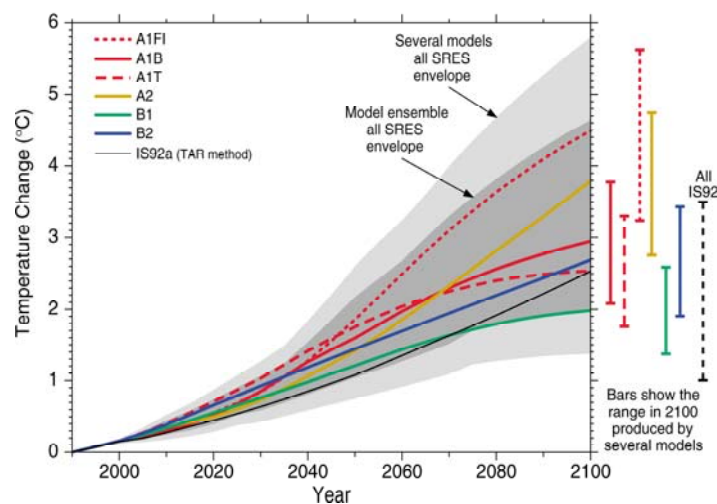


Figure 3: Global mean temperature projections for the six illustrative IPCC “Special Report on Emissions Scenarios” (SRES)

For the Greater Melbourne Region, CSIRO prepared ranges of change in average rainfall, temperature and potential evaporation. These ranges are based on the results of 13 climate models and allow for key uncertainties such as the United Nation's Intergovernmental Panel on Climate Change (IPCC) range of future greenhouse gas emission scenarios, the IPCC range of global warming, and model to model differences in the regional pattern of climate change. The ranges of change per degree of mean global warming are shown in Figures 4, 5 and 6 and the resulting ranges in values are shown to the left of the Figures:

TEMPERATURE:

Annual temperature increase is 0.3°C to 1.0°C, with a mean of 0.5°C in 2020 and 0.6°C to 2.5°C, with a mean of 1.4°C in 2050. There is a slight tendency for the warming to be higher in summer and less in the other seasons.

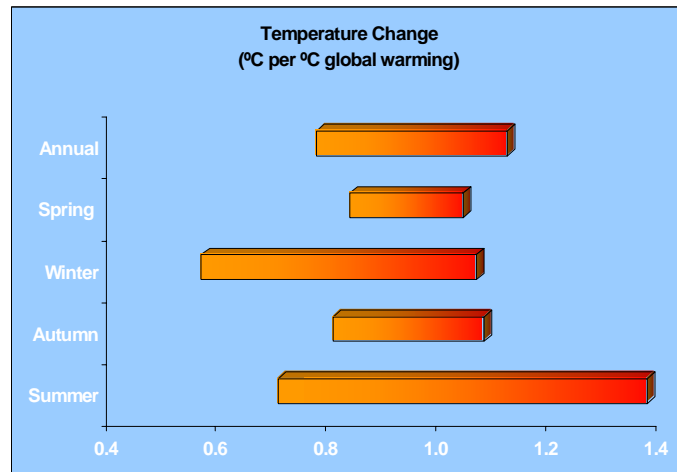


Figure 4: Ranges of increase in Melbourne's annual and seasonal temperature with every degree of mean global warming

RAINFALL:

Annual precipitation change is 5% to 0%, with a mean of -2% in 2020 and -13% to 1%, with a mean of -4% in 2050. Two patterns of change became apparent. One pattern is typical of southern Australia and tends towards decreased rainfall in spring towards increase in summer and autumn. The other pattern is typical of Tasmania and tends towards increases in winter and decreases in summer.

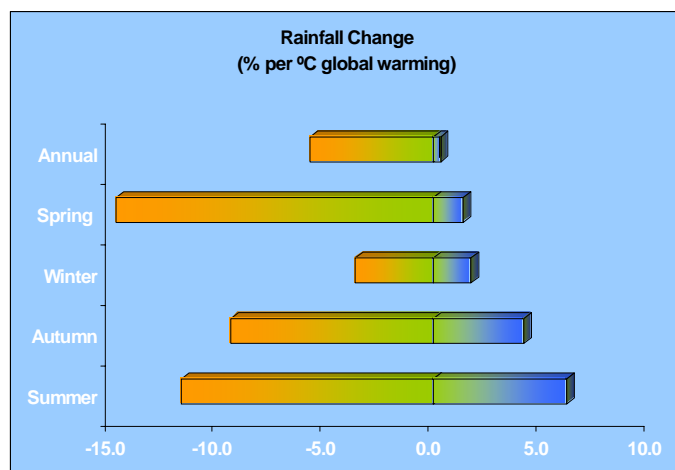


Figure 5: Ranges of change in Melbourne's annual and seasonal rainfall with every degree of mean global warming

Significant uncertainty exists around rainfall change for Melbourne due to its location at the junction of the Southern Australian and Tasmanian weather patterns, but the models suggest higher probabilities of decreased rainfall.

EVAPORATION:

Annual potential evaporation change is 1% to 7%, with a mean of 3% in 2020 and 3% to 18%, with a mean of 8% in 2050. Seasonal changes are largest in the winter-spring period.

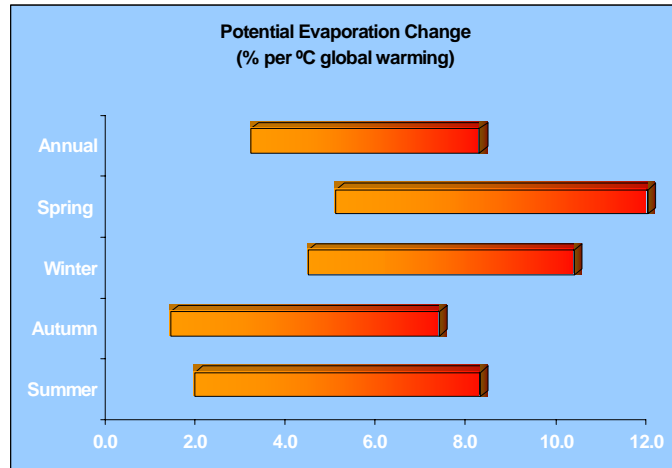


Figure 6: Ranges of increase in annual and seasonal potential evaporation with every degree of mean

Other aspects of change to regional climate change include:

- Increase in the number of hot days. Although highly variable, on average Melbourne experiences 9 days per year above 35C. This average frequency is expected to increase to 10-12 days by 2020 and 12-18 days by 2050.
- Increase in number of dry days but with increases in the frequency and magnitude of the heaviest rainfall events. The magnitude of these changes is difficult to quantify for impact assessment with further dynamic modelling of extreme rainfall required.

SECTION 3 - Impact Assessment and Adaptation

Water Supply System

Melbourne Water provides wholesale water and sewerage services to three retail water companies: City West Water Ltd, South East Water Ltd, and Yarra Valley Water Ltd. Melbourne Water also provides water supplies to Gippsland Water, Southern Rural Water and Western Water. Melbourne's water supply system is shown in Figure 7.

An extensive transfer system links Melbourne's storage reservoirs with the city's three retail water companies and their customers. The major storage reservoirs supply water via large transfer mains to the service reservoir sites that are located throughout the metropolitan area to meet consumption needs. The water is then transferred to the retail water companies, which operate the reticulation network across the Melbourne area.

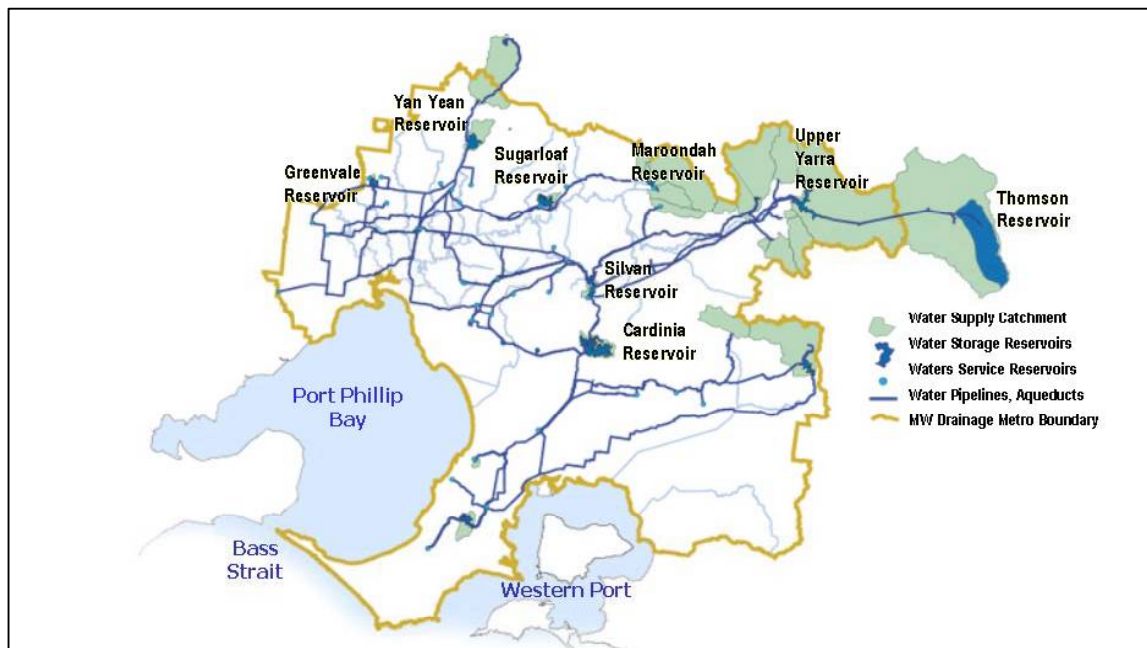


Figure 7: Reservoir Sites

Key characteristics of the Melbourne water supply system include:

- **Catchment areas.** Approximately 90% of Melbourne's water comes from uninhabited and restricted access catchment areas located high in the Yarra Ranges. Water from these catchments is predominantly unfiltered and requires only minimal treatment before distribution to customers. Approximately 50% of Melbourne's forested catchment areas are Ash type species such as Eucalyptus Regnans. Forest hydrology research on Ash species has shown that catchment yields can be significantly reduced some 20 to 40 years after disturbances such as bushfire.

- Multiple water diversions and reservoir sites in the Yarra, Thomson and Goulburn River Basins.
- The Melbourne supply system has a total live storage capacity of 1,787,500 million litres. A major advantage of these storages is the ability to transfer and distribute water by gravity. The Thomson reservoir represents approximately 60% of the total storage capacity of the Melbourne system.
- Around 10% of Melbourne's water is sourced from catchment areas that are subject to human and agricultural activity. This area, upstream of Yering Gorge in the Yarra Valley is largely used for agricultural and viticultural purposes. This water is fully treated at the Winneke treatment plant to provide high quality water.

Sewerage System

Melbourne Water undertakes the wholesale function for Melbourne's sewerage systems, operating the larger main and trunk sewers and treatment plants. The sewerage system is shown in Figure 8. The three retail water companies, City West Water, South East Water and Yarra Valley Water, manage customer relations and operate the reticulation system from individual properties and the branch sewers. This pipe network delivers flows to Melbourne Water's transfer system and some small regional treatment plants. The transfer system incorporates underground pipelines, pumping stations, emergency relief structures and detention tanks. The sewers generally transfer flows by gravity. However, a number of major pumping stations required to lift sewage and enable continuous transfer in the system are located at Hoppers Crossing, Brooklyn, Kew and North Road Caulfield.

Melbourne Water maintains approximately 43 emergency relief structures through the transfer system. These structures provide a controlled means to discharge sewer flows to waterways when the sewers become backed up or overloaded due to high rainfall infiltration or a blockage. Approximately 95% of Melbourne's sewerage is treated at the Western Treatment Plant at Werribee and the Eastern Treatment Plant at Bangholme. Limited interconnection exists to allow flexibility to transfer approximately 14 % of flows from some areas to either treatment plant.

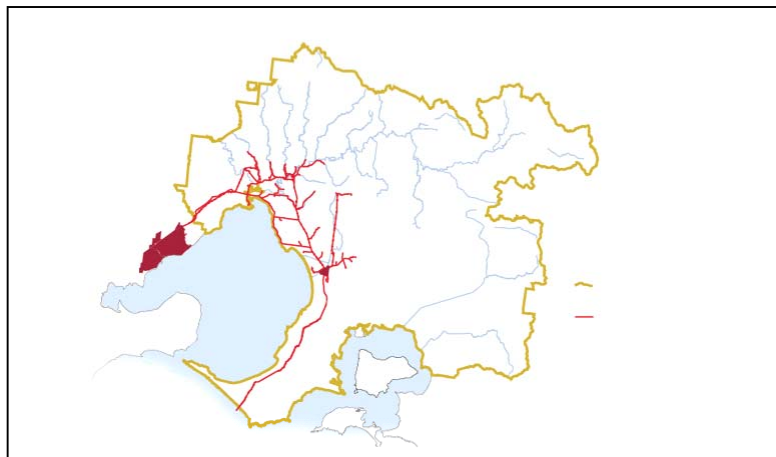


Figure 8: Sewage Transfer Network

Drainage System

Melbourne Water is the drainage authority for the Greater Melbourne area and the Flood Plain Management Authority by delegation from the Minister responsible for the Water Act. It is responsible for regional drainage management, including large drains, rivers and creeks, and works closely with local councils, who control local drainage systems, and the Port Phillip and Westernport Catchment Management Authority. Melbourne Water is also a referral authority in the planning system and receives applications for subdivisions and other developments from councils.

The Melbourne area of responsibility contains a range of infrastructure assets that assist in managing drainage, including 140 retarding basins, 193km of levee banks, four tidal gates and 1125km of underground stormwater drains and 4500km of natural waterways. This excludes the vast extent of local council drainage structures. The drainage system network prior to the release of Victorian Government's water strategy "Securing our Water Future Together: Our Water Our Future" in June 2004, is shown in Figure 9.

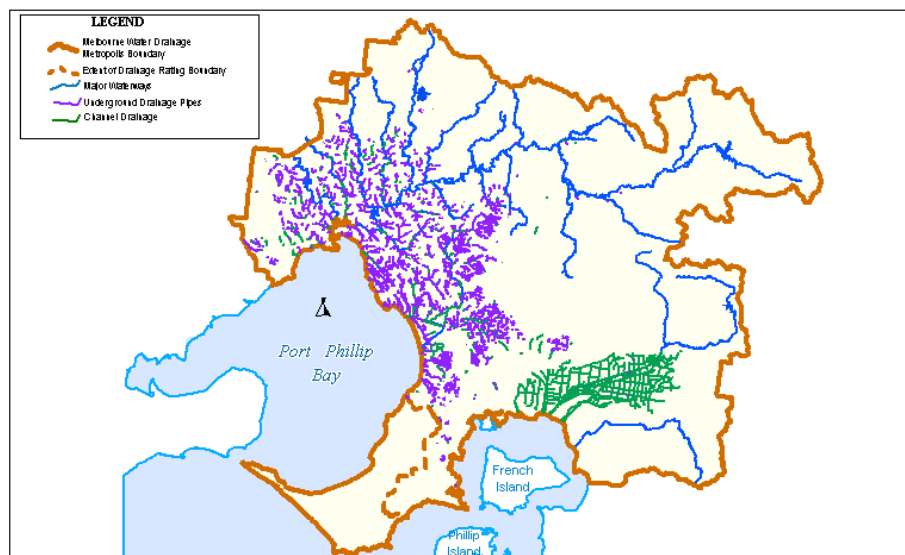


Figure 9: Drainage System considered for the Study

Major Risk Areas

In July 2003 an internal workshop was held with staff from across Melbourne Water's water, wastewater, drainage and waterways areas. This was followed by an external workshop in August 2003 and a forum in November 2003. These workshops accessed the collective knowledge of the individuals to identify and assess potential impacts (risk areas) to Melbourne Water systems due to changing climate conditions.

Over 100 potential risk areas were identified and prioritised. Table 1 is a summary of the qualitatively assessed potentially significant risks to Melbourne's water, sewerage, and drainage systems and Melbourne area receiving waters. Further studies would be required on many of these issues to identify the extent of impact due to climate change. However, in a number of cases combined impacts may be more significant than those identified.

In addition, many risk areas identified were those impacting on other water resources managers and stakeholders including retail water companies and Government Departments. On-going assessment and adaptation will require engagement of a range of stakeholders to assist in timely and appropriate response. This study will provide a useful first step in this process for the Melbourne area.

Table 1: Major Risk Areas

	Potential Risk Areas
Water Supply	<ul style="list-style-type: none"> • Reduced water supply due to decreased streamflows • Increased risk of bushfires in catchment areas with associated risk of decreased streamflow • Reduced environmental condition of streams with associated implications for water harvesting in regulated and unregulated streams
Sewerage System	<ul style="list-style-type: none"> • Increased incidence of sewer overflows due to increased rainfall intensity during storms • Increased potential for corrosion and odours in the sewerage network caused by increased sewage concentration as a result of lower dry weather flows associated with water conservation, increasing ambient and seasonal temperatures, and longer travel times within the sewer network • Increased risk of pipe failure and collapse due to dry soil conditions • Increased salinity levels in recycled water due to rising seawater levels

Table 1(continued): Major Risk Areas

Drainage	<ul style="list-style-type: none">• Increased risk of flooding due to increased rainfall intensity during storms• Increased risk of damage to stormwater infrastructure and facilities (e.g. underground drains, levee banks, pump stations etc) due to higher peak flows
Receiving Waters	<ul style="list-style-type: none">• Reduced health of waterways due to changes in stream base flows• Potential for water quality impact in Port Phillip Bay due to increased concentration of pollutants entering Bay (longer periods between runoff events and then high intensity events leads to concentrated pollutant runoff) and higher ambient Bay water temperatures.

Adaptation Strategies

Water Supplies

There are many potential water resource management initiatives that could aid adaptability or provide a buffer for climate change. Many of these initiatives have been investigated for Melbourne or in other locations throughout Australia and the world. For water supply, many of the initiatives that are described in detail in the Victorian Government's 21st Century Melbourne: a WaterSmart City (Oct 2002) and more recently in "Securing Our Water Future Together: Our Water Our Future" (June 2004) are being considered or implemented. The range of options that could be considered in adapting to climate change for water supply management include:

Maintaining focus on efficient domestic water use

- Long term behaviour change achieved through a range of levers including education and regulation (e.g. restrictions, incentives, pricing and rating schemes)
- Water efficient fittings, showerheads and appliances
- Improved gardening and outdoor water use practice
- Installation of rainwater tanks, greywater, effluent and stormwater recycling systems and water sensitive urban design, particularly in new developments
- Closed loop water systems in new commercial and residential high-rises

Industrial and commercial water use efficiency

- Water audits and management plans
- Improved water efficiency and increased use of recycled water

Open space management

- Audits and water management plans
- Improved water use practices and recycling schemes

Water authorities

- Leakage reduction
- System optimisation

Surface water supply augmentation options from within the existing supply system:

- Reconnection of Tarago Reservoir
- O'Shannassy reservoir pipeline and reconnection of Cement Creek to recover water forgone through the decommissioning of the O'Shannassy aqueduct
- Additional pumping from the Yarra River into Sugarloaf reservoir

Catchment and reservoir management

- Manage forested catchments to minimise the water yield impacts from disturbances such as bushfires or logging
- Evaporation reduction or rainfall enhancement measures

New water sources

- Desalination
- Major recycling schemes to supplement or replace water currently supplied from drinking water sources including releases for environmental flows
- Aquifer storage and recovery of recycled water
- Water markets and trading between sectors (eg irrigation and urban) and basins (eg north of the Great Dividing Range)

Planning

- Include climate change within periodic reviews of major strategies such as water supply plans, drought plans and environmental flow assessments.

Sewerage System

Investigation of the potential implications of climate change scenarios overlaid on expected long-term changes in population and demographics and subsequent sewage flows suggest that gradual climate changes could be more readily adapted to than rapid shifts in climate. Strategies to assist the sewerage system in adapting to climate change are consistent with normal planning practices and might include:

Measures to reduce peak flows in wet weather

- Increased indoor demand management activities that lower sewage flows and reduce overflow risk
- On-going and periodic review of sewerage system strategies and operations
- Local treatment plants to reduce network loading during peak flows
- On-going review of strategies to address hydraulic constraints and overflow risks
- Increase storage capacity within system
- Limit growth expansion and/or connections to parts of the system where there are potential capacity constraints
- Review strategies for emergency relief structure operations
- Monitoring and maintenance of sewer systems to reduce infiltration
- System rehabilitation
- Encourage sewer construction methods which have much lower infiltration rates in new developments

Measures to manage sewage quality

- Lining of concrete sewers to avoid “corrosion” by sulfuric acid producing microbes
- Ongoing monitoring of trends in sewage quality, quantity and temperature, treatment processes
- Maintain sewer rehabilitation and cleaning regimes
- Examine potential for oxygen injection and odour control to manage changes in temperature

Other Initiatives

- Increase levee bank height along lagoons at Western Treatment Plant to provide buffer against sea level rises

- Encourage cluster systems and local treatment to aid recycling options
- Seek long term improvements to sewage water quality to reduce salts, nutrients and other pollutants which will assist recycled water quality
- Industrial waste minimisation
- Domestic sewage quality eg soaps, detergents etc
- Auditing of new installations
- Increase community education on sewers, effluent quality, garden plants etc to assist in improving sewerage quality and infiltration
- On-going development of recycling schemes, including new developments, sewer mining and opportunities for retrofits

Drainage and Waterways

Potential drainage management adaptation strategies include:

- On-going and periodic review of waterways and strategies, flood modelling and/or drainage schemes to take account of potential climate change scenarios
- On-going monitoring, including water quality, environmental indications and groundwater levels, particularly in wetlands
- Water sensitive design in new developments to reduce runoff rates and improve water quality
- Retain flood plains and floodways in new urban developments
- Identify options for upstream flow attenuation for flood mitigation
- Education to assist local waterway management and maintenance
- Maintain programs for stream rehabilitation and stream frontage management
- On-going review of planning and operational strategies for:
 - Drainage network at a local and system level to take into account current knowledge of potential climate change scenarios
 - Floodgates, levees, storage and pump stations
 - Combined sea level, surge and storm frequencies in specific areas
- Periodic review of environmental flows, drought plans, streamflow management and water allocations and water allocation principles for managing diversions from waterways for climate change
- Develop incentives to aid water use and allocation efficiencies

Case Studies

Three case studies were selected to further explore key risk areas identified for the Melbourne Water system. These included a review of the water supply system to identify potential for reductions in water availability and the sewerage and drainage networks for increases in sewer overflows and flooding.

Case Study 1 – Water Supply

Changes to reservoir inflows are one consideration when assessing the impact of climate change on Melbourne's water supply system. The other is the linkage with potential future water use. A water supply case study was undertaken to assess the potential impacts of alternative climate change scenarios on Melbourne's water supply system.

The specific objective of the water supply case study was to assess the combined impact of climate change and population growth on water supply system demand, supply (i.e. streamflow in harvesting catchments) and water supply system yield in 2020 and 2050. Water supply system yield is the average annual demand that can be reliably supplied to consumers under a given set of planning assumptions. The process followed in this case study is shown in Figure 10.

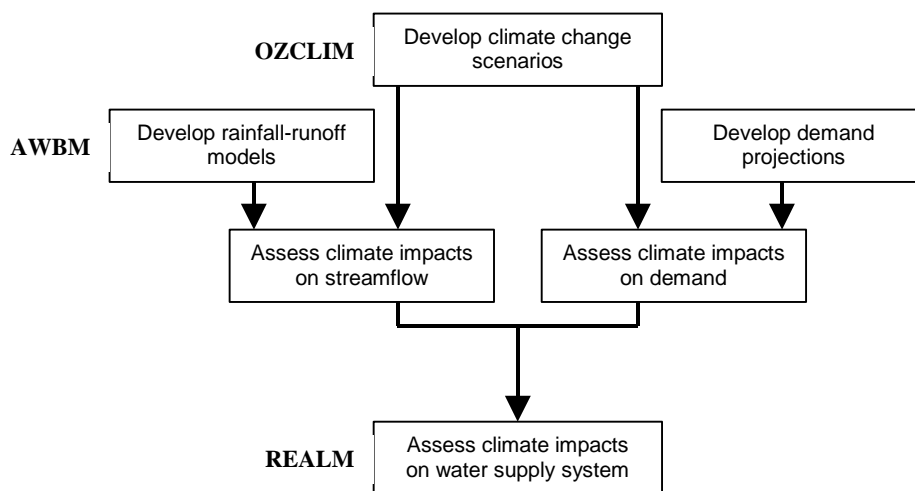


Figure 10: Modelling process flowchart for water supply case study

The process required the development of several modelling capacities including the ability to:

- simulate rainfall and streamflow processes for seven catchments
- vary input climate data for assessing changes to streamflow and water demand under climate change scenarios
- integrate changes in streamflow with changes in demand for the Melbourne area caused by both climate and potential demographic change

The uncertainty existing around future climate change affects both streamflow and demand projections. To accommodate this an assessment system was developed that could explore as wide a range of climate scenarios as possible, and then use risk analysis to select three joint streamflow and climate driven demand scenarios for both 2020 and 2050 (low, mid range and high) for use in water resource assessment models

Most of Melbourne's water supply is sourced from four major harvesting storages: Thomson, Upper Yarra, Maroondah and O'Shannassy Reservoirs. Three other catchments were required for modelling: Yan Yean, Tarago and Yering (mid and upper Yarra outside storage catchments). AWBM (Boughton, 2002) was chosen to simulate the effect of climate on daily streamflows in major harvesting catchments and a regression model was developed to simulate the effect of climate on total water supply system demand on a monthly basis. The period 1952–2001 was used as the baseline due to the ability of the streamflow models to represent this period. All changes to streamflow and demand in this section are referenced from that baseline period.

Changes from ten global climate models outputs and three scenarios encompassing the widest climate range of change possible were used to obtain a sample of 30 simulations. These 30 simulations were then used to create a simple relationship relating input climate changes to change in mean annual streamflow and total demand on the supply system. Risk analysis techniques were then used to create a probability distribution for change in annual streamflow and demand for the Melbourne system. From this, three climate scenarios were chosen for both 2020 and 2050 representing mild, medium and severe scenarios.

The second step of the modelling process involved assessing the impact of regional climate change scenarios on streamflow in harvesting catchments and system demand using appropriate catchment and demand models. Finally, a water resources system model was used to simulate the impacts on Melbourne's water supply system.

Changes to the total average annual streamflows into the four major storages indicate the impact of potential climate change scenarios on the harvestable water available to Melbourne and are shown in Table 2. Severe climate change scenarios are representative of limited global response for climate change and are considered less likely than medium change scenarios.

Table 2: Projected changes in average annual inflow to Melbourne's four major harvesting storages

Climate Change Scenario	2020	2050
Mild change	- 3 %	- 7 %
Medium change	- 7 %	- 18 %
Severe change	- 11 %	- 35 %

Table 3 shows projected changes to the average annual total water demand in Melbourne in 2020 and 2050 due to climate change. These are based on current seasonal use patterns with the Melbourne water models and do not include long-term changes that can be anticipated with initiatives outlined in “Our Water our Future”. The impact on streamflow and water consumption have been assessed for the mean annual volumes in terms of the percentage change from the modelled baseline, which indicated a case where model simulations were carried out with the historical climate data, i.e. without the effect of enhanced greenhouse gas emissions.

Table 3: Forecast changes in average annual demand in Melbourne

Climate Change Scenario	2020	2050
Mild change	+ 0.5 %	+ 1.3 %
Medium change	+ 1.3 %	+ 3.1 %
Severe change	+ 2.3 %	+ 6.2 %

The demand projections were chosen to examine the combined impact of climate change and population growth on both system yield and behaviour. The three demand projections were all based on demand management savings of 15% per capita in 2010 and 23% per capita in 2050 but used three different population scenarios based on Melbourne 2030 forecasts. These demand projections were not adjusted for climate change which would have required further assessment.

Table 4: Low, medium and high population projections for Melbourne

Population scenarios (millions rounded up)			
Year	Low	Medium	High
2020	3.75	4.08	4.26
2050	3.58	4.60	5.12

Figure 11 shows total water demand projections used to consider the climate change scenarios. These projections were developed by combining the low, medium and high population projection with various per capita water use projections starting from a base level of 387 litres per capita per day or about 500 billion litres year in 2001 as per the Water Resources Strategy for the Melbourne area.

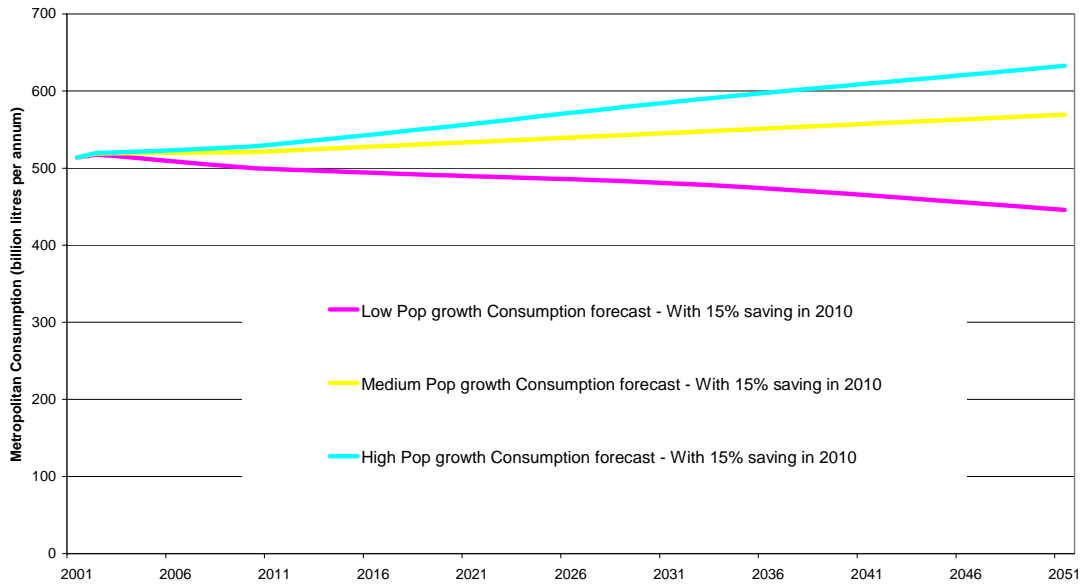


Figure 11: Demand projections used in water supply case study

In 2020 water demand is projected to be about 530 billion litres under a medium population growth scenario but could range between 490 and 560 billion litres depending on both population growth and the impact of demand management strategies. Over the longer time frame demand becomes harder to project due to uncertainties surrounding population and water use but could range between a “low-case” of 450 billion litres and a “high-case” of 630 billion litres.

The impact of climate change on overall demand rates was also assessed under warmer, drier conditions and with higher evaporation rates. Under these conditions demand could be expected to increase.

Impact on Water Supply Availability

To assess the impact on water supply availability, both streamflow changes due to climate change and population growth scenarios were used. The system yield analysis showed that the streamflow reduction for the mid-range climate change scenario in Table 2 would result in an 8% reduction in the average annual volume able to be supplied in 2020 rising to 20% by 2050. This data was then used to assess the shortfall and buffer between supply and demand. The results are presented in Tables 5 and 6.

Table 5: Potential Buffer (positive value) or shortfall (negative value) of system yield for climate change and projected average annual demand (billion litres) scenarios in 2020

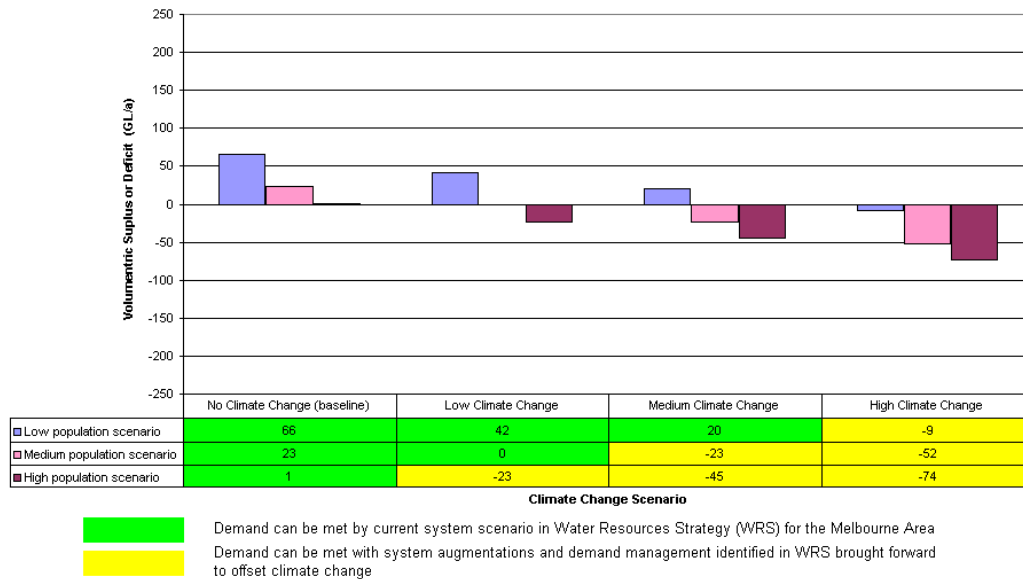
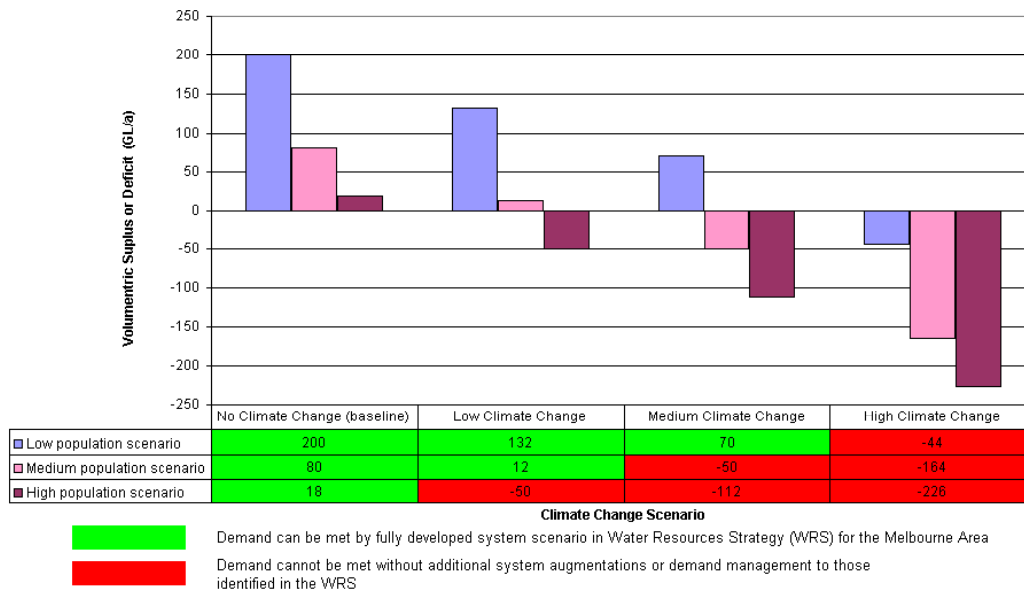


Table 5 results indicate ‘buffers’ or ‘shortfalls’ of system yield compared to the forecast average annual demand in 2020 for various combinations of future demand and climate change scenarios. The yield estimate for 2020 was based on the current system configuration. Green shaded cells in Table 5 represent climate change scenarios where the projected demands could be readily met without supplementing the current water harvesting system. Yellow cells indicate scenarios where demand could be met by bringing forward enhancements to the water harvesting system as outlined in the Water Resources Strategy or by undertaking additional demand management actions.

Demand management measures and water supply augmentations identified in the Water Resources Strategy for the Melbourne Area were found to provide sufficient buffer for climate change to be adequate in 2020 across the full range of climate change and alternative demand forecasts considered in this case study. Demand management however, has long lead times and is incremental, requiring long-term behavioural change to ensure realisation of water savings. There is uncertainty about effectiveness over the long-term requiring on-going evaluation, review and adaptation. It should be noted that this analysis does not include actions or impacts arising from the Victorian Government’s water strategy “Securing our Water Future Together: Our Water Our Future” which was released subsequent to the technical work undertaken for this study.

In addition, this study recognises that further detailed assessment would be required to identify the appropriate supply enhancement and demand management actions at the time including environmental assessments and measurement of the effectiveness of demand management strategies.

Table 6: Potential Buffer (positive value) or shortfall (negative value) of system yield for climate change and projected average annual demand (billion litres) scenarios in 2050



Year 2050 results shown in Table 6 were based on the full utilisation of resources within the Yarra and Thomson basins within water allocations used in the Water Resources Strategy. This includes system augmentations such as Tarago treatment plant, O’Shannassy pipeline duplication, Winneke treatment plant upgrade and East-West transfer upgrades. These supply options have been included on the basis that they were identified in the Water Resources Strategy for the Melbourne Area. However, further investigations would be required to assess the volumes now available from these resources given the recommendations on basin caps and studies identified in “Securing Our water Future Together: Our Water Our Future.

The red shaded cells represent climate change scenarios where demand cannot be readily met without harvesting additional water resources to those identified in the Water Resources Strategy and considerable review of the range of strategic options for managing supply and demand. Under these scenarios a range of further options would need to be activated, including desalination and additional recycling.

Some of the system augmentations outlined in the Water Resources Strategy by 2050 may be required by 2020 to maintain existing levels of service, especially if anything other than mild climate change should occur. Additional measures to those outlined in the Water Resources Strategy will likely be required between 2020 and 2050 to maintain existing levels of service, especially if anything other than mild climate change and growth projections occur. Monitoring for climate change and undertaking on going reviews of strategic and contingency options are required to ensure on-going reliable and safe supply. It should be noted that this analysis does not include actions for further demand management or other initiatives arising from the Victorian Government’s water strategy “Securing our Water Future Together: Our Water Our Future” which was released subsequent to most of the work undertaken for this study.

Case Study 2 – Potential for Increased Sewer Overflows

Melbourne's sewerage system is separate to the drainage system and is designed to operate independently. However, water may enter the sewerage system as infiltration into pipelines from rainfall, or through illegal property connections (mainly stormwater runoff from roofs) going directly into the sewerage system. Rainfall does result in extra volumes of water entering the sewers. During extreme storm events high volumes of infiltration can result in increased flows in sewers and in local areas this can cause sewers to overflow from emergency relief structures to the environment. Melbourne Water maintains approximately 43 emergency relief structures through the transfer system.

Under climate change scenarios, rainfall totals and intensity are expected to increase. However the extent of these changes and the implications for storm events and the design of sewerage systems is highly uncertain.

Detailed modelling and analysis of the hydraulic behaviour of sewer flows in the main transfer system operated by Melbourne Water for the 1 in 5 year storm event enables assessment of the potential for sewer overflows under future development, flow and storm scenarios.

Rainfall temporal patterns and storm event rainfall totals are key factors in assessing the changes in expected flow rates and the risk of sewer overflows. CSIRO Division of Atmospheric Research suggested a preliminary estimate of a 5% increase in total storm event rainfall per degree of climate warming. These estimates are preliminary and were provided solely for the purpose of assessing the sensitivity of the sewerage system to such variations in rainfall totals.

Assessment of the potential implications of change to rainfall totals for the sewerage transfer network suggests that changes in rainfall totals of up to 10% for a given recurrence interval event may not impact on system performance, but the extent of overflows is affected, indicatively, by larger shifts in rainfall totals on current events.

While the climate change models suggest the potential for increased storm intensity, the translation of the climate change scenarios to local storm and catchment events is highly uncertain given the range of influences on local conditions. The transfer system model was run and system behaviour assessed for:

- Current design event behaviour for 2020
- System behaviour in 2020 with a 5% and 10% increase in rainfall totals per degree of climate change

The 24-hour rainfall duration events are critical event for the design of Melbourne Water's sewerage transfer network. Shorter duration events are generally more critical for the design of smaller catchments and pipes.

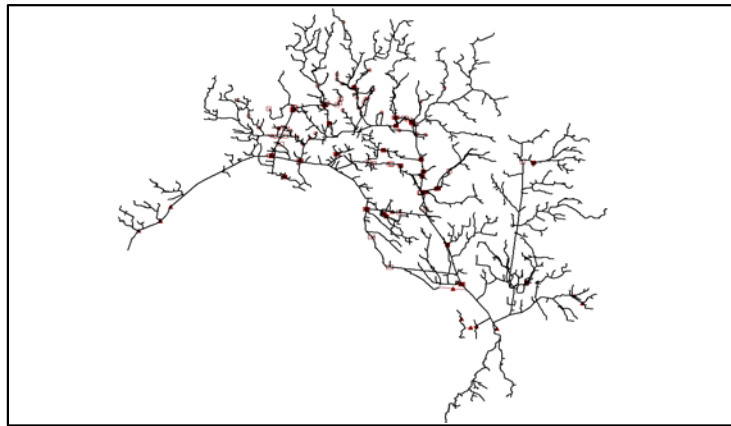


Figure 12: Schematic of the Melbourne Sewerage Transfer System

Under the above mentioned scenario total rainfall increases for point rainfall the 1 in 5 year Average Recurrence Interval (ARI) were of the order of 2.2 mm for the 24-hour duration event. This represents a 3% increase in rainfall totals over current design totals. Preliminary assessment showed that this small increase in rainfall total over the 24 hour duration event will result in minimal increase in the modelled rainfall induced infiltration to the sewerage transfer network and to the risk of overflows in the sewerage network.

The modeling study showed that the sewerage transfer network in the year 2022/23, under current augmentation plans, would be compliant for the 1 in 5 year event with the small shift in additional rainfall anticipated under climate change.

This preliminary model result suggests if the shifts in rainfall totals were to increase for a given ARI, for example rainfall events of the 1 in 10 year ARI were to become a 1 in 5 year event, there may be some limited increases in sewer overflows. This increase in rainfall total from a 1 in 5 to a 1 in 10 year ARI event represents a 10.6mm or 14% increase in rainfall totals. This suggests a potential increase in infrastructure investment to meet standards should storm event totals change significantly under climate change.

Storm events are the key factor contributing to sewer overflows from emergency relief structures in the sewerage transfer networks. Under climate change scenarios, rainfall totals and intensity are expected to increase. However the extent of these changes and the implications for recurrence intervals for storm events is highly uncertain. Under climate change scenarios, changes to rainfall totals, temporal patterns and intensities in storm events could increase the risk of sewer overflows both within the transfer system and local reticulated sewage collection system. This risk will also be dependent on other factors such as development patterns and sewage system repair and renewal rates.

Case Study 3 – Flooding

Factors affecting the frequency, depth and duration of flooding in urban areas are very complex, and may be influenced by a range of interacting influences. Local property impacts of flooding, often the most visible and costly impact of flooding, will also be influenced by local factors including:

- Local backwater influences and wave action
- Design standards used for property siting. This includes the return period for the flood event and the freeboard above the flood level to provide for local uncertainties such as backwater and wave action
- Extent of hail and rubbish in runoff and extent of flow blockage during an event
- Prior warning of storm, flood or potential flooding conditions

Melbourne's drainage system has been in place for more than 70 years. Current design standards, which have been in place in for new development areas for more than twenty-five years provide for a '100 year' ARI design standard for flooding. This ARI is used to define the extent of the overland flow along the drainage system or flooding from overtopping of river banks which would occur on average once in every 100 years. In other words, it means that there is a one-percent chance in any one year of such an event occurring.

In many parts of the greater Melbourne area, often in older established areas the drainage system was built to the standards of flood frequency and severity that existed when they were designed which may be less than that provided under current standards in newer areas. In areas where drainage systems were developed prior to the 100 year ARI standard and there is local redevelopment, Melbourne Water has a capital works program to improve infrastructure and work with local councils to address flooding issues.

Rainfall temporal patterns and storm event rainfall totals are key factors in assessing the changes in expected flood frequency, depth, extent and duration over current estimates for a given recurrence interval flood event. CSIRO suggested a preliminary estimate of a 5% increase in total storm event rainfall per degree of climate warming. The translation of the climate change scenarios to local storm and catchment events is highly uncertain given the range of influences on catchment flooding described above.

A desk study was undertaken of a small catchment in the outer eastern suburbs of Melbourne for which detailed flood studies for flood mitigation works for the 100 year ARI event have been undertaken. The drainage infrastructure in this catchment is typical of that in many urban areas of Melbourne.

The use of an area for which flood studies had been undertaken enabled existing catchment models to be used for quantitative assessment of the impact of climate change scenarios using calibrated catchment models on the expected flow rates associated with flooding and flood levels.

Modelling work for the 100 year ARI event has shown that the 2-hour duration event produces critical flows for the case study catchment. Rainfall totals for the 100 year ARI, 2-hour storm event were factored in accordance with a 5% increase in totals per degree of climate change for years 2020 and 2050 and were based on a mean temperature increase for the years 2020 and 2050 of 0.6°C and 1.5°C respectively. Flood flow rates and their impact were seen for each scenario.

Table 6 shows the results of 5, 10 and 20% increases in rainfall per degree of climate change for the case study and shows the changes in flow rates and flood levels for the year 2020.

Table 6: Case Study Results – 5, 10 and 20% increase in rainfall totals per degree of climate change

Change by 2020	5%	10%	20%
Total rainfall (mm)	60	61.7	65.2
Increase in total rainfall from current (mm)	1.8	3.5	7
Increase in peak flow rate (cumecs)	0.5 (4%)	1.0 (8%)	2.0 (17%)
Average increase in Flood Levels (mm)	10	30	50

The table indicates that for a small catchment there are limited incremental shifts in rainfall totals, peak flow rates and flood levels associated with a 5% increase in rainfall total. In particular, flood level changes are well within the 300mm freeboard criteria adopted for developments in potential flood areas, and well within the expected local on-site variability from model error, backwater effects and wave action and local variability. In order to test the sensitivity of the results to the increase in rainfall total, further assessment were undertaken assuming a 10% and 20% increase in rainfall per degree temperature increase for the 100 year ARI. Table 6 shows that for the 10% and 20% case studies the average increases in the flood levels are 30 to 50 mm in 2020 respectively. Freeboard allowances included in existing and proposed development provide a significant buffer for climate change. Even in older areas, many properties, particularly along waterways, currently have a freeboard of up to 600mm.

Climate change is projected to reduce the interval between intense events. As shown in Table 7, a 5% increase in rainfall intensity will see the current 130 year event become a more frequent 100 year event by 2020. With a 20% increase in rainfall intensity the current 210 year event could be expected to occur every 100 years.

Table 7: Results of ARI Analysis

Case Study	Scenario	Rainfall Total (mm)	Average Rainfall Intensity (mm/h)	Average Recurrence Interval (years)
5%	Year 2020	60.0	30.00	130
	Year 2050	62.6	31.30	160
10%	Year 2020	61.7	30.85	150
	Year 2050	66.9	33.45	240
20%	Year 2020	65.2	32.60	210
	Year 2050	75.7	37.85	>500

It would cost the community billions of dollars to upgrade the existing drainage system to the 100 year ARI in all areas. In these circumstances the most practical and equitable solution is to adapt development to suit the existing drainage system.

Further work is required to assess the implications of climate change on rainfall totals as well as temporal patterns. At this stage it is difficult to make a direct interpretation of climate change impacts for flooding other than in general terms. Flood impacts are likely to be site specific and will need to be reviewed for local conditions and in the context of local flood management controls and investment.

The drainage case study was done for only a single catchment, and may not reflect the effects of increased rainfall on other catchments as the impacts of rainfall events and flooding will be site dependent. Data on storm events within catchments at a neighbourhood scale is limited. Other factors such as the permeability of soils under different climatic conditions are also poorly understood.

Section 4 - Way Forward

Most water infrastructure has a long design life (e.g. reservoirs, pipelines, retarding basins, sewerage and drainage networks, treatment plants) and will have been designed under a set of assumptions and uncertainty considerations. Climate change represents an additional, significant uncertainty for which resource systems must adapt. This study recommends that the following actions be progressed to better understand and adapt to climate change.

Climate

- Periodic review of climate change scenarios based on available climate change research.
- Develop better understanding of climate variability, particularly decadal rainfall variability.
- More site specific research into changes to rainfall totals, temporal patterns and intensities associated with storm events.

Water

- Periodic review of the “Water Resources Strategy for the Melbourne Area” to incorporate implications of climate change including cost/benefit analysis.
- On-going monitoring of climate change impacts on streamflow, water supplies and water demand along with population trends.
- Risk assessment/modeling of multiple, potentially cumulative factors such as reduced streamflows coupled with increased bushfires in the catchments and increased environmental flow requirements.
- Evaluation of long-term contingency options to respond to severe climate change.
- Monitoring of effectiveness of water use reduction strategies.
- Incorporation of climate change projections into the design, planning and operation of major resource management systems where consistent with a “no-regrets” policy. i.e. the action taken would generate net benefits whether or not there is climate change

Sewerage System

- Ongoing planning and development of the sewerage system to provide for increasing flows due to population growth and in-fill development (increased impervious surface and hence additional runoff) will assist in maintaining compliance with overflow design standards.
- Conduct further evaluation of the implications of climate change on storm event temporal pattern and return intervals.

Drainage

- Further research into temporal patterns that can be expected due to climate change and the implications for:
 - Changes to flooding risk and extent of flooding in existing drainage infrastructure.
 - Design of new drainage systems.
 - Capacities of storage and conveyance within given drainage systems or sub-catchments.
 - Combined risks of storm events, and sea level and storm surges in local areas
- Link improved storm intensity models with models that quantify changes in impervious surface and hence runoff associated with development.

In addition to the above this study has raised some basic questions about the use of historical records in establishing climate and hydrological baselines in a time of significant climate change. Further analysis is needed in this area as it has significant implications for design of systems and interpretation of hydrological results.