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Systems Analysis of Water Cycle Systems

Analysis of base case scenarios for the Living Ballarat project

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Disclaimer

This report was written under the jurisdiction and management of the Office of Living Victoria. Nevertheless, any unintended errors or potential misinterpretations of the data presented herein are only the authors' and we would welcome further dialogue around alternative interpretations of our research.

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Executive summary

The Living Ballarat project was initiated by the Victorian Government as a demonstration of a new approach to integrated water cycle management (IWCM) for regional cities and towns. This project is collaboration between local stakeholders and the Office of Living Victoria in the development of a whole of water cycle management framework for the Ballarat region. A Project Control Board (PCB) provided oversight and local governance for the development, delivery and implementation of the Ballarat IWCM Framework. A local Strategy Development Team (SDT) with membership from multiple agencies and leadership from the Office of Living Victoria's Chief Scientist has providing the PCB with systems analysis of the water cycle across the region.

The Ballarat region chosen for this investigation includes 144 State Suburbs, 7 local government areas and significant river basins managed by 5 Catchment Management Authorities. Central Highlands Water provides urban water supplies to 15 water districts and reticulated sewerage services to 10 districts within the region. The region is also dependent on groundwater resources and bulk water allocations from the Moorabool, Campaspe, Goulburn, Loddon and Yarrowee River catchments. These shared regional water resources are also subject to management by Southern Rural Water, Goulburn Murray Water and the Murray Darling Basin Authority.

This report focuses on the base case behaviour of the Ballarat and Maryborough water districts from the context of the performance of the entire region and whole of water cycle behaviours. A Systems Framework of the Ballarat region was developed as part of the Living Ballarat Project to allow understanding of whole of water cycle challenges and opportunities across the region.

A base case Systems Framework for the Ballarat region included ongoing interactions with stakeholders via the Strategy Development Team (SDT). The Strategy Development Team was guided by the Office of Living Victoria's Chief Scientist in the collation of information, data and insights underpinning the analysis presented in this report. This process also included liaison with a broader group of collaborators including local Catchment Management Authorities, Local Government, land developers and environmental groups via formal workshops and various discussions.

The Systems Framework of the base case for the Living Ballarat project is complete. This framework includes high population growth and climate change scenarios. The Systems Framework was built up from local scale land uses from across the region and includes whole of water cycle processes at local, suburb, town and regional scales. This structure captures the spatial, temporal and behavioural variations of the water cycle across the region.

The framework has been developed to a state where it can be reliably and robustly applied to detailed and targeted 'what if' analyses, including assessments of future water security under a range of climatic and population growth scenarios, and future management options. The spatial and temporal detail within the Systems Framework allowed understanding, reproduction and testing of the complex interactions between waterways, reservoirs, operations, water demands and water restrictions. The Key Insights from this investigation are summarised as follows:

1. Key drivers for water cycle management in the Ballarat region include a variable climate, population growth, interactions with surrounding regions, health and viability of river basin, flooding, water security and climate change.

2. The Systems Framework for analysis of the base case water cycle management scenarios for the Ballarat region is complete. The Framework can be reliably utilised to test scenarios and options for water cycle futures, to optimise the performance of water operations and to investigate policies for water allocations (including stormwater) and protecting waterways

3. Water Cycle management in the Ballarat region involves strong interaction with surrounding regions including dependence on bulk water allocations and impacts on waterways. These surrounding regions often experience lower rainfall depths and frequencies than the immediate Ballarat region.

4. There is a high level of spatial and temporal variation across the region for most of the parameters impacting on water cycle management. Analysis using monthly or annual average assumptions would not reliably capture these important variations and hence would limit the associated understanding of challenges and opportunities.

5. The region is subject to cyclic patterns of wet and dry conditions which drive strong variations in spatial weather conditions. As a consequence, there are stark differences in the resilience of river basin and water catchments across the region.

6. The characteristics of water uses throughout the region have changed dramatically over the last decade. A majority of buildings and households have already incorporated measures which deliver increased water efficiency.

7. The Systems Framework has successfully reproduced the water cycle behaviours over the last decade including water demands and the performance of reservoirs.

8. The Ballarat West bore field, local water efficiency measures and water restrictions had a significant impact on the water security of Ballarat during the last decade. Introduction of the connection to the Campaspe and Goulburn River via the Goldfields pipe and flooding rains ended the critical water shortages for Ballarat that were associated with drought.

9. A majority of reservoirs and extractions for water supply to the region are situated in the headwaters of river systems that are subject to highly variable flows and their location and functionality has significant impacts on downstream catchments and waterways.

10. Inclusion of the Goldfields pipe and the Ballarat West bore field has changed the operating behaviour of the water supply system for Ballarat.

11. The water supply systems in the region are highly sensitive to a range of assumptions and display strong variations in responses to operating rules. This understanding has been

unlocked by the detail in the Systems Framework. There is substantial opportunity to optimise water cycle systems using the Framework.

12. Regional storages that provide bulk allocations are subject to highly variable irrigation and evaporation demands that can impact on the availability of water allocations.

13. The predictions of future average water demands for Ballarat and Maryborough are consistent with the published Water Supply Demand Strategies. However, the detail in the Framework has produced an improved understanding of substantial variability in the magnitude of future demands.

14. The Ballarat district is not expected to experience unacceptable levels of water restrictions within the planning horizon to 2051. This trigger for augmentation of the water supply is later than previously reported. However, there is a probability of requirement for higher allocations from ground and surface water within the planning horizon.

15. The linked spatial and temporal detail that is incorporated in the time based analysis in the Systems Framework is substantially different to static methods of estimating "yields" from systems using average inputs at a coarser temporal scale.

16. Waterways throughout the region are impacted by extractions for water supply, population growth, urban stormwater runoff, rainwater and stormwater harvesting, wastewater discharges and climate change. The future of regional waterways includes potential increased impacts on waterway health and higher flood risks. The Systems Framework can guide the development of necessary policies for management of waterways and aquifers from the perspective of the entire water cycle.

17. It is an important insight that the waterways throughout the region are subject to cumulative impacts including loads of contaminants, flood risks from high flows and diminishing fresh water flows. Whilst indicators for water quality (as indicated by concentrations of contaminants), peak flows (flooding) and average flows or flow regimes (waterway health) may be acceptable at a location in a catchment (especially in the headwaters), the resultant downstream cumulative impacts may not be acceptable.

18. There are a considerable number of properties that are subject to flood risks and there may be opportunities to manage water supply storages in the upper catchment to also mitigate some of the flood risks.

19. The West Moorabool River is currently highly stressed due to low flows and this situation is expected to worsen into the future. There is a need to decrease extractions for water supply from the river.

20. The Yarrowee River is likely to experience substantial increases in stream flows by 2051 that are generated by increased inflows of effluent from wastewater treatment and flows in river are expected to be dominated by effluent from the Ballarat South wastewater treatment plant.

Substantial increases in nutrient loads are likely that may impact on the health of the waterway. These impacts can be mitigated by reducing extractions of fresh water from the Yarrowee catchment and reducing discharge of wastewater to the river.

21. Burrumbeet Creek may experience greater peak flows with associated increased flood risks. These flows are likely to be decreased by the climate change scenarios. The creek will be subject to moderate increases in nutrient loads because discharges of effluent from the Ballarat North wastewater treatment plant are diminished by reuse of treated wastewater.

22. Bet Bet Creek in the Maryborough district may be subject to increased peak flows and associated flood risks by 2051.

23. This investigation has revealed some interesting paradoxes including an understanding that replacement of agricultural land uses with urban development results in the decreased loads of nutrients in waterways. However this waterway health impact is countered by increased nutrient loads from wastewater discharges and increased frequent flows in waterways.

24. Urban areas in Ballarat and Maryborough generated greater stormwater runoff than water demands during the last decade. A combination of urban stormwater runoff and wastewater discharges to existing treatment plants generated water volumes that were at least twice the volume of water demands.

25. By 2051, the Ballarat district will be highly dependent on bulk water supplies from external sources whilst discharging volumes of urban stormwater runoff and wastewater that are three times the volume of water demands. There is an opportunity to utilise local water sources to minimise impacts on surrounding communities and ecosystems.

26. By 2051, water supply to Maryborough will be highly dependent on the surface water extracted from the headwaters of McCallum and Stoney Creeks with back up from bulk water allocations and ground water, whilst discharging volumes of urban stormwater runoff and wastewater that are six times the volumes of water demands. There an opportunity to utilise local water sources to minimise impacts on surrounding communities and ecosystems.

1 Introduction

The Living Ballarat project was initiated by the Victorian Government as a demonstration of a contemporary and robust approach to integrated water cycle management (IWCM) analysis and planning techniques for region cities and towns. This project represents collaboration between local stakeholders and the Office of Living Victoria in the development of a whole of water cycle management framework for the Ballarat region.

A Project Control Board (PCB) provided oversight and local governance for the development, delivery and implementation of the Ballarat IWCM Framework. A local Strategy Development Team (SDT) with membership from multiple agencies and leadership from the Office of Living Victoria's Chief Scientist provided the PCB with systems analysis of the water cycle across the region.

The Strategy Development Team collected and analysed substantial data and information that underpins the local Systems Framework presented in this report. The project includes 144 State Suburbs, seven local government areas, five catchment management authorities with interaction across many river basins from the Goulburn River to the Moorabool River. The extent of the Living Ballarat project is illustrated in Figure 1.1.

Figure 1.1 revealed that the region adopted for the Living Ballarat project incorporates a substantial spatial area that includes interactions with a large number of local government areas. The region also includes a diverse topography as shown in Figure 1.2.

This data and information was used to construct the Systems Framework for the Ballarat region. This process has involved forensic analysis of the water cycle across the region with automation of processes to simplify the validation and testing of the impacts of different assumptions and inputs. The detailed Systems Framework revealed that water management systems throughout the region are highly sensitive to assumptions and operating rules – this report has evolved in response to a number of iterations in the analysis to seek optimum base case performance. Substantial opportunities remain to establish optimum performance.

On Wednesday 18 December, a verbal briefing was provided to the Project Control Board (PCB) on the findings from the systems analysis of the region as defined by the physical performance of the whole of water cycle systems. The PCB requested more detailed findings, insights, supporting evidence and completion of the final report on the base case behaviour of the region as soon as possible. Timely provision of this report allowed greater knowledge of the processes and provide ample time for questions ahead of the PCB meeting in March.

The Living Ballarat PCB requested the following information:

- A final written report on the progress to date with analysis of the base case for water cycle management
- Includes in the report the analysis of risks and ranges of uncertainty under two scenarios:
    - climate change (high emissions)
    - high population growth as defined by the Victoria in Future 2012 (VIF 2012) forecast population for 2051 achieved at 2041.
- Additional detail about waterway health and flooding

Figure 1.1: Extent of the Living Ballarat project

The Office of Living Victoria has acknowledged the comprehensive nature of this request and clarified that this report should be finalised as soon as possible. As such, this report is limited to the physical performance of the whole of water cycle systems for the Ballarat and Maryborough regions. This does not include the financial and economic analysis that is published in a companion report.[1] It includes analysis of the risks and uncertainty from two scenarios of climate change (high emissions) and high population growth (VIF 2012 forecast population at 2051 achieved at 2041).

[1] Coombes P.J., and M.E. Barry (2014). Systems analysis of water cycle systems for the Living Ballarat project – economic analysis of Options and Scenarios. Report by the Chief Scientist at the Office of Living Victoria

This report also documents the methods, inputs, assumptions and the consultative processes utilised to develop a systems framework accurately reproduces the water cycle behaviours throughout the Ballarat region with a focus on the Ballarat and Maryborough urban areas.

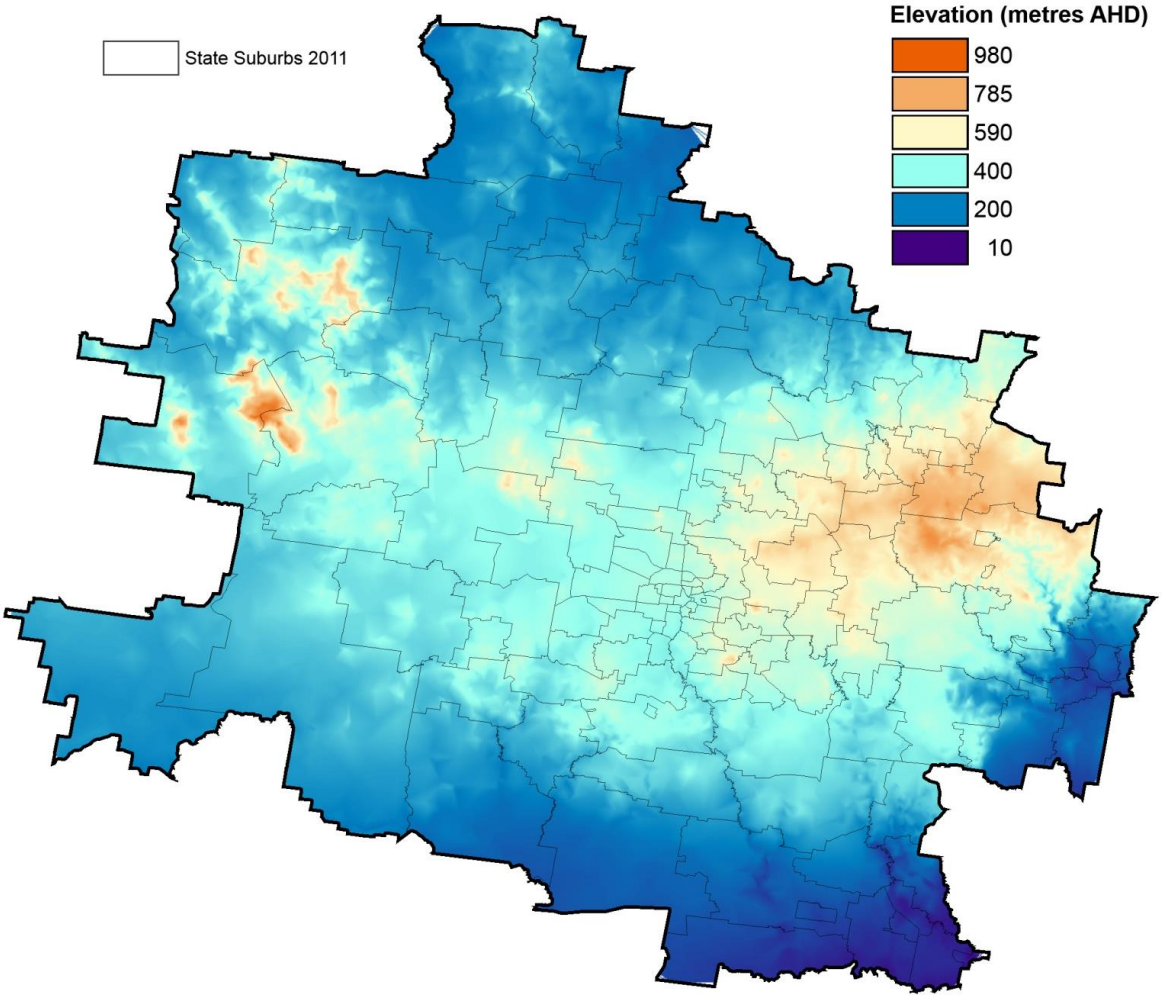

Figure 1.2: Topography of the Ballarat Region

Figure 1.2 demonstrates that the Ballarat region is characterised by an area of higher elevation that includes the location of the City of Ballarat and lower land elevations throughout the remainder of the region.

The topography demonstrates that the City of Ballarat is situated in the headwaters of river catchments that flow in north, south and easterly directions. The state-wide annual average rainfall depths and frequencies are shown in Figure 1.2a. The City of Ballarat area is subject to relatively high rainfall depths and frequencies in comparison to surrounding areas.

These topographical characteristics also correspond to a high level of spatial variation in climate parameters across the region. For example, the variation in the average annual rainfall depth, frequency of rainfall, average daily maximum and minimum temperature are presented in Figures 1.3, 1.4, 1.5 and 1.6 respectively. These parameters influence water use behaviours and the performance of waterways and water cycle management systems.

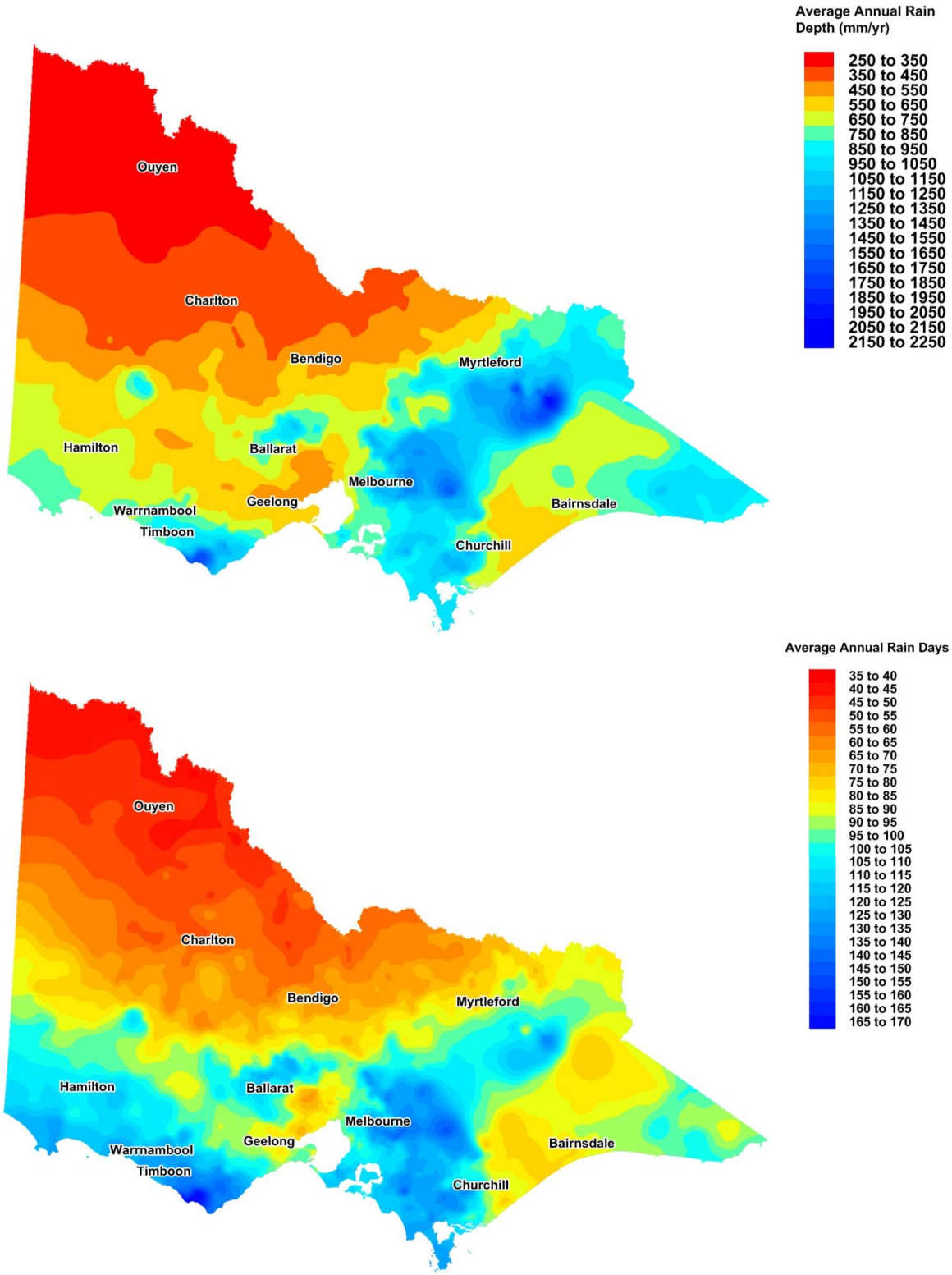

Figure 1.2a: Average annual rainfall depths and frequency for Victoria – showing the relative spatial weather behaviours.

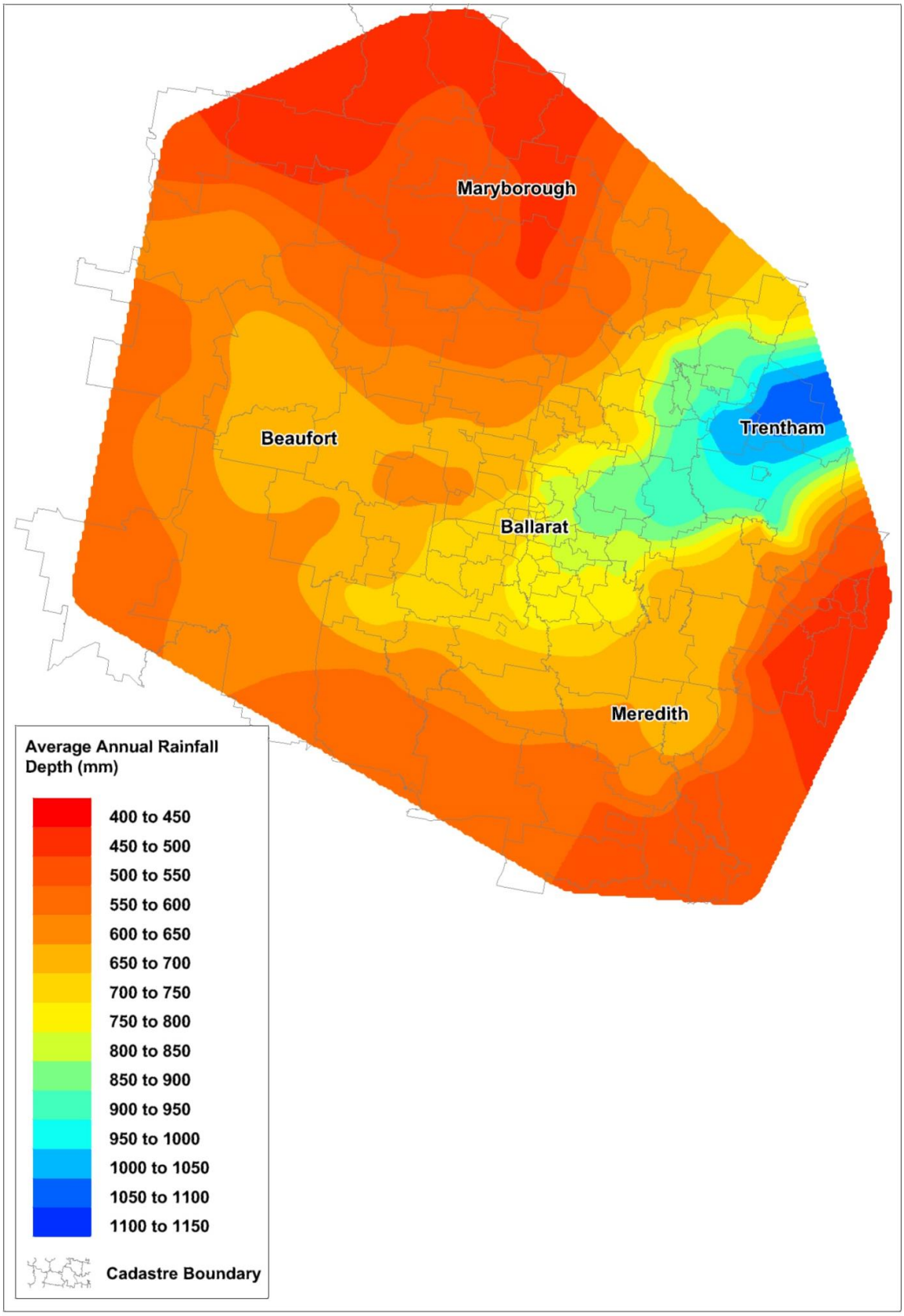

Figure 1.3: Average annual rainfall depth as an indicator of spatial climate variance

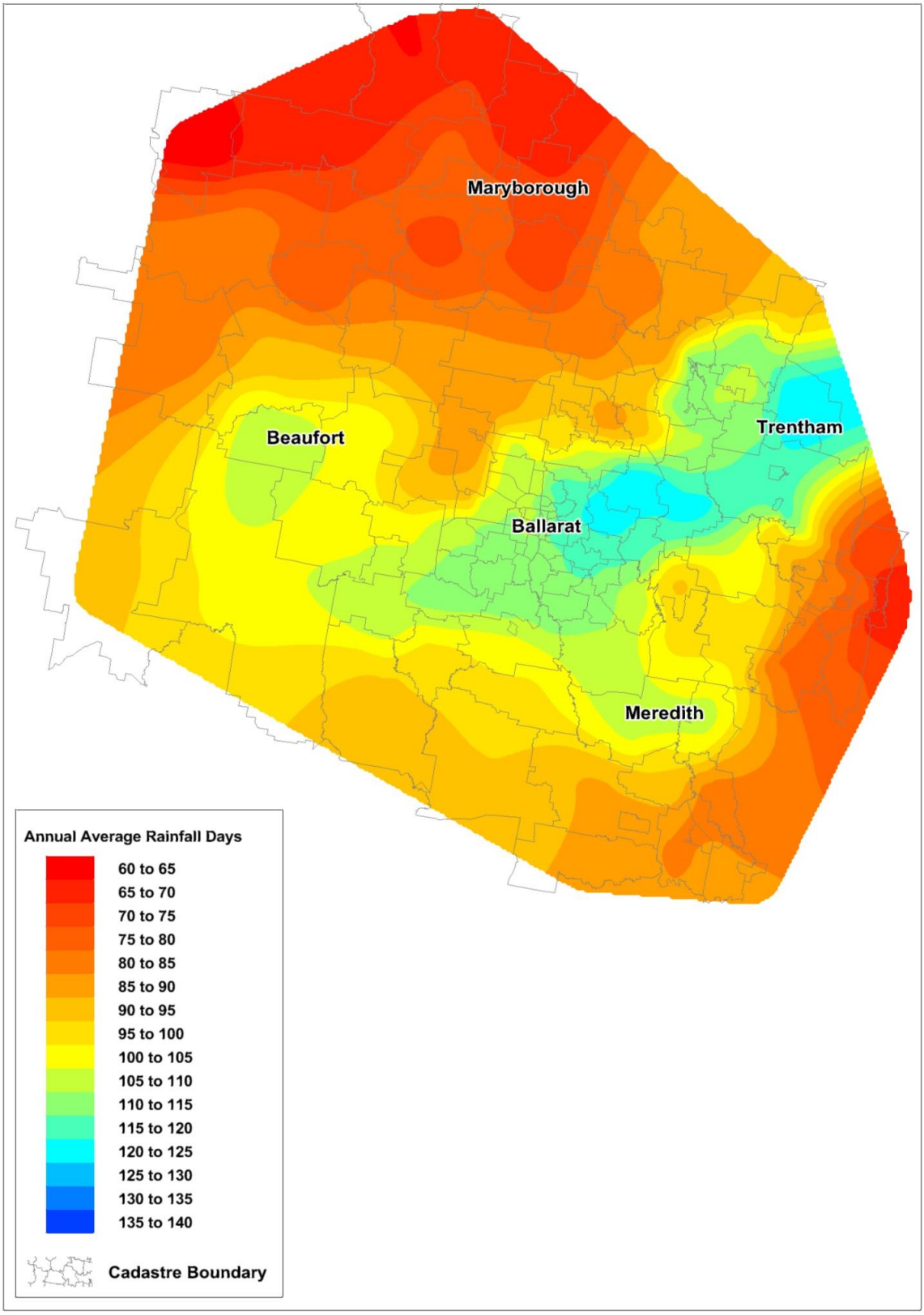

Figure 1.4: Average annual frequency of rainfall as an indicator of spatial climate variance

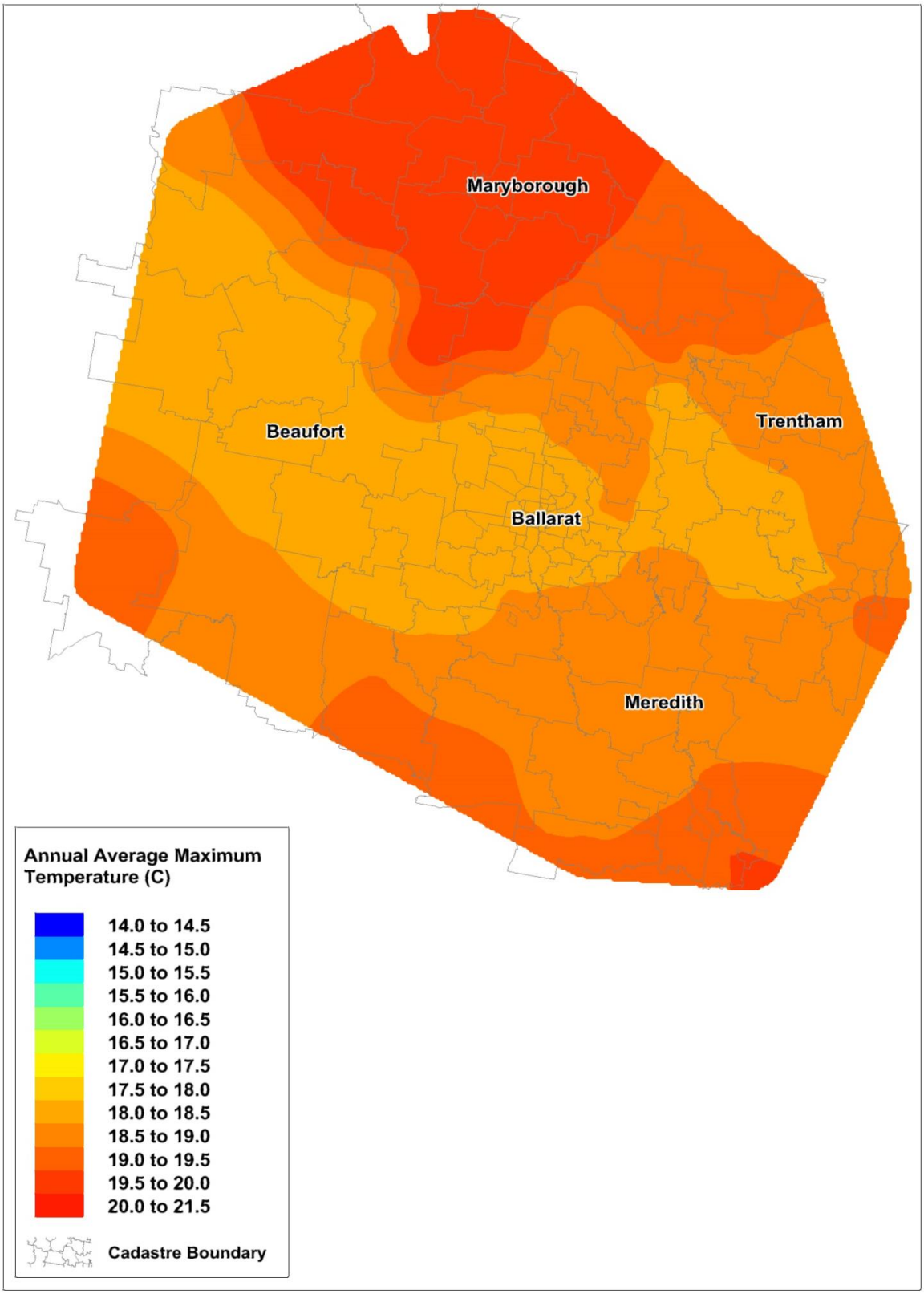

Figure 1.5: Average annual daily maximum temperature as an indicator of spatial climate variance

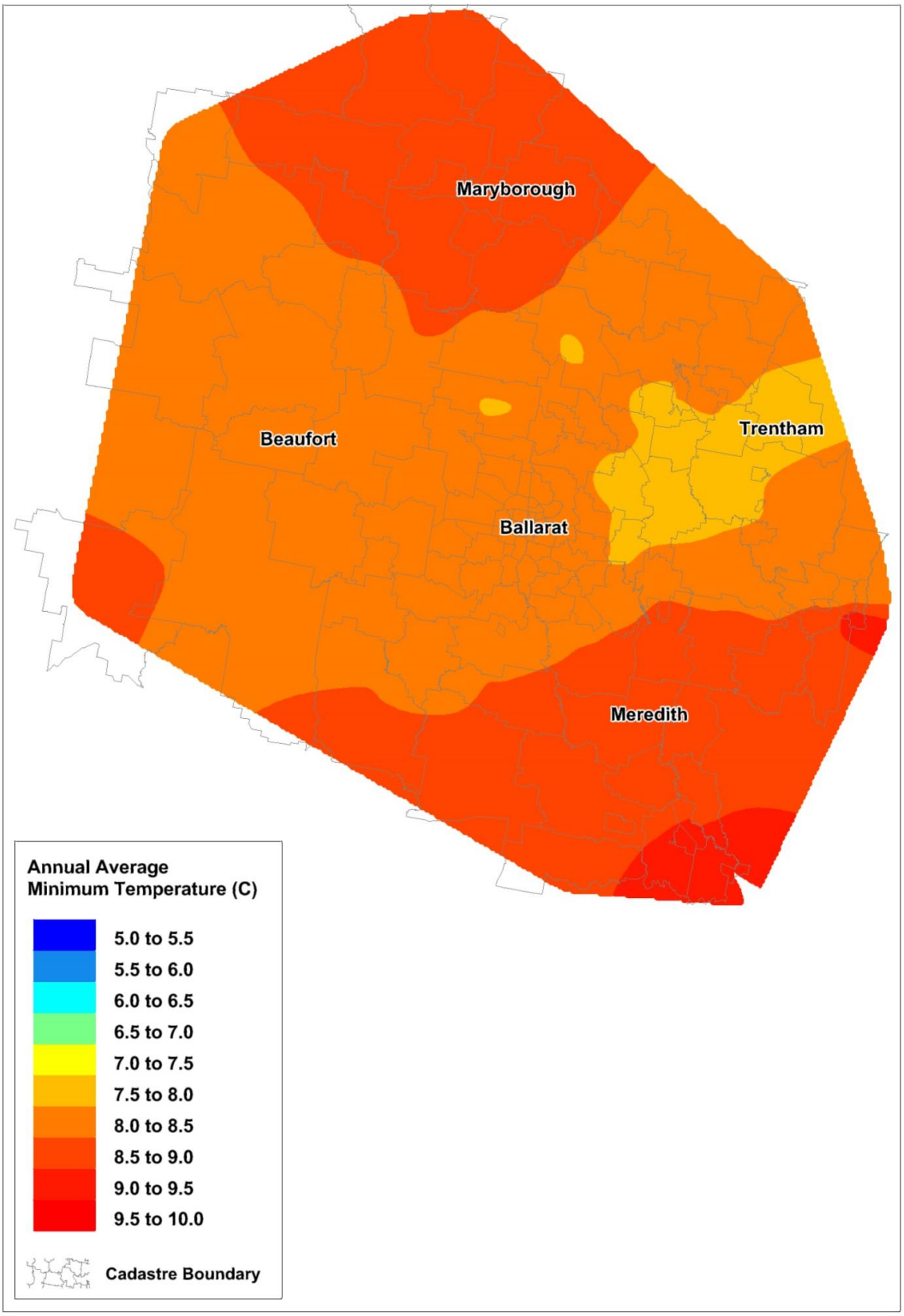

Figure 1.6: Average annual daily minimum temperatures as an indicator of spatial climate variance

Figures 1.3 and 1.4 reveal that the depth and frequency (reliability) of rainfall varies across the region. Higher frequency rainfall is experienced at the higher elevations (such as at the City of

Ballarat) and substantially lower frequency rainfall is experienced at lower elevations (for example at Maryborough and Heathcote). Similarly, Figures 1.5 and 1.6 demonstrate that the region is subject to substantial variation in maximum and minimum daily temperatures. This high level of variability of weather across the region will impact on water use behaviours and the performance of water supply systems.

Central Highlands Water provides urban water supplies to 15 water districts and reticulated sewerage services to 10 districts within the region as presented in Figure 1.7.

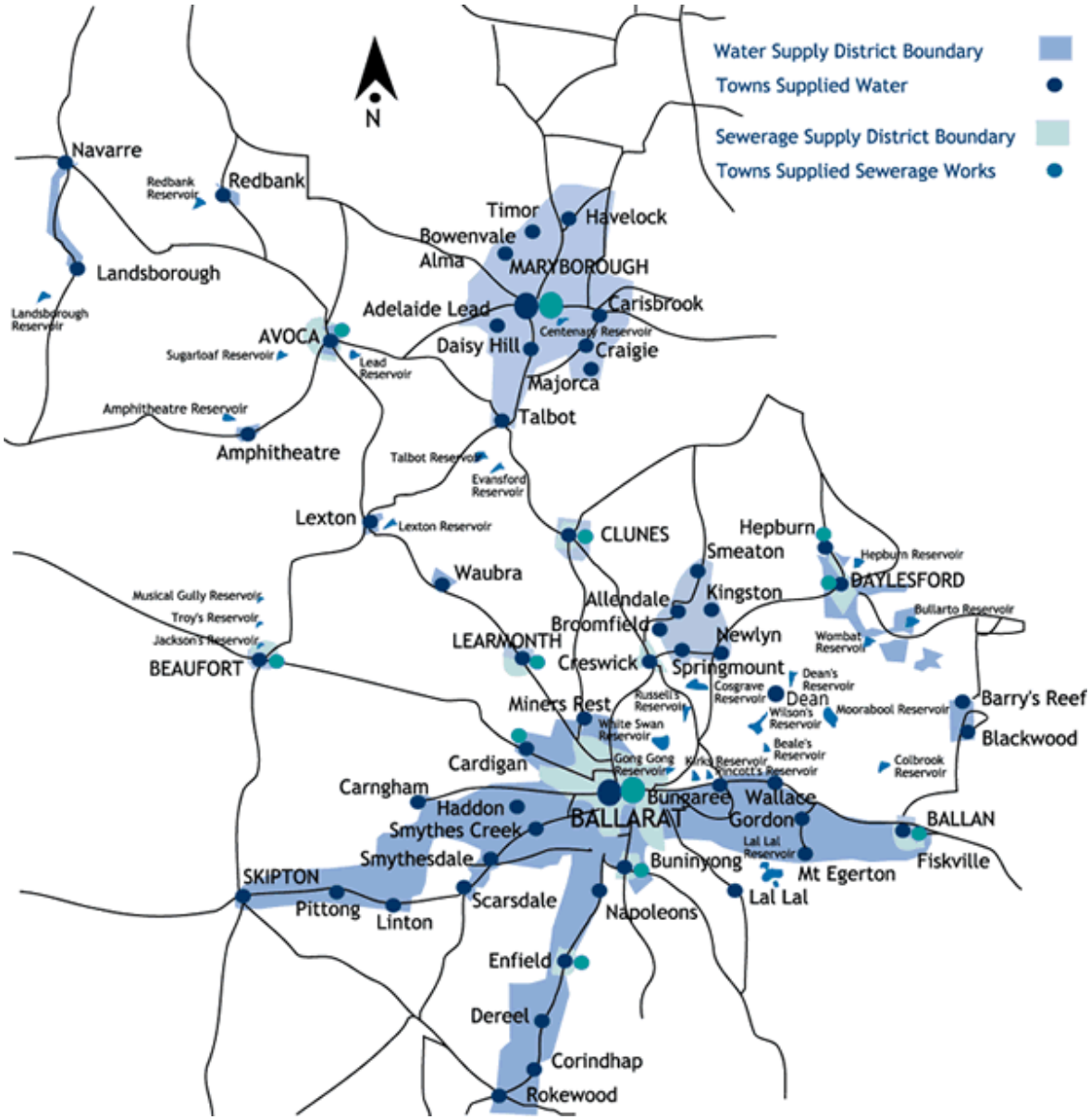

Figure 1.7: Water supply and sewage districts managed by Central Highlands Water in the Ballarat Region

Figure 1.7 highlights that the region includes spatially diverse and separated water and sewage districts. The region is also dependent on groundwater resources and bulk water allocations from the Moorabool, Campaspe, Goulburn, Loddon and Yarrowee River catchments as shown in Figure 1.8. These shared regional water resources are also subject to management by Southern Rural Water, Goulburn Murray Water and the Murray Darling Basin Authority.

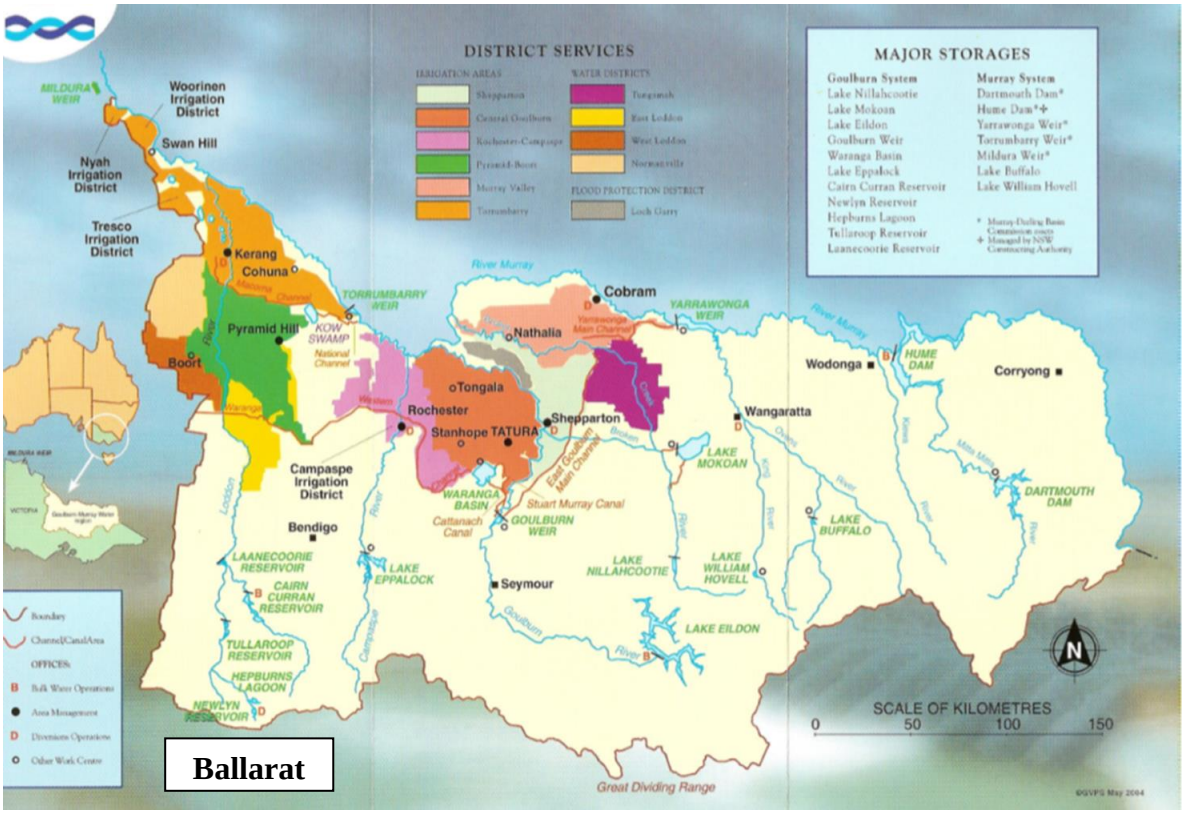

Figure 1.8: Overview of irrigation and water districts linked to the Ballarat region

Figure 1.8 shows the City of Ballarat and surrounding region from the perspective of irrigation districts across Victoria. The Ballarat region interacts with a wide range of irrigation districts via water extractions from the Loddon, Campaspe and Goulburn river basins.

The transfer distances for connections to reticulated water supplies (Figure 1.9) from the nearest water sources and from reticulated sewerage connections (Figure 1.10) to wastewater treatment plants are presented below. These distance of transfer maps also display areas that do not have connections to reticulated services.

This information highlights the spatial characteristics of reticulated water and wastewater services across the region. Note that the water transfer distances from the Goulburn and Campaspe Rivers via the Goldfields pipe are not included in the water transfer distance map.

Water supply from bulk water sources to the Ballarat water district can also involve transfers across long distances and topography with variable heights. For example the transfer of water from the Goulburn River to White Swan Reservoir (Figure 1.11) and from Lal Lal reservoir to Ballarat CBD (Figure 1.12).

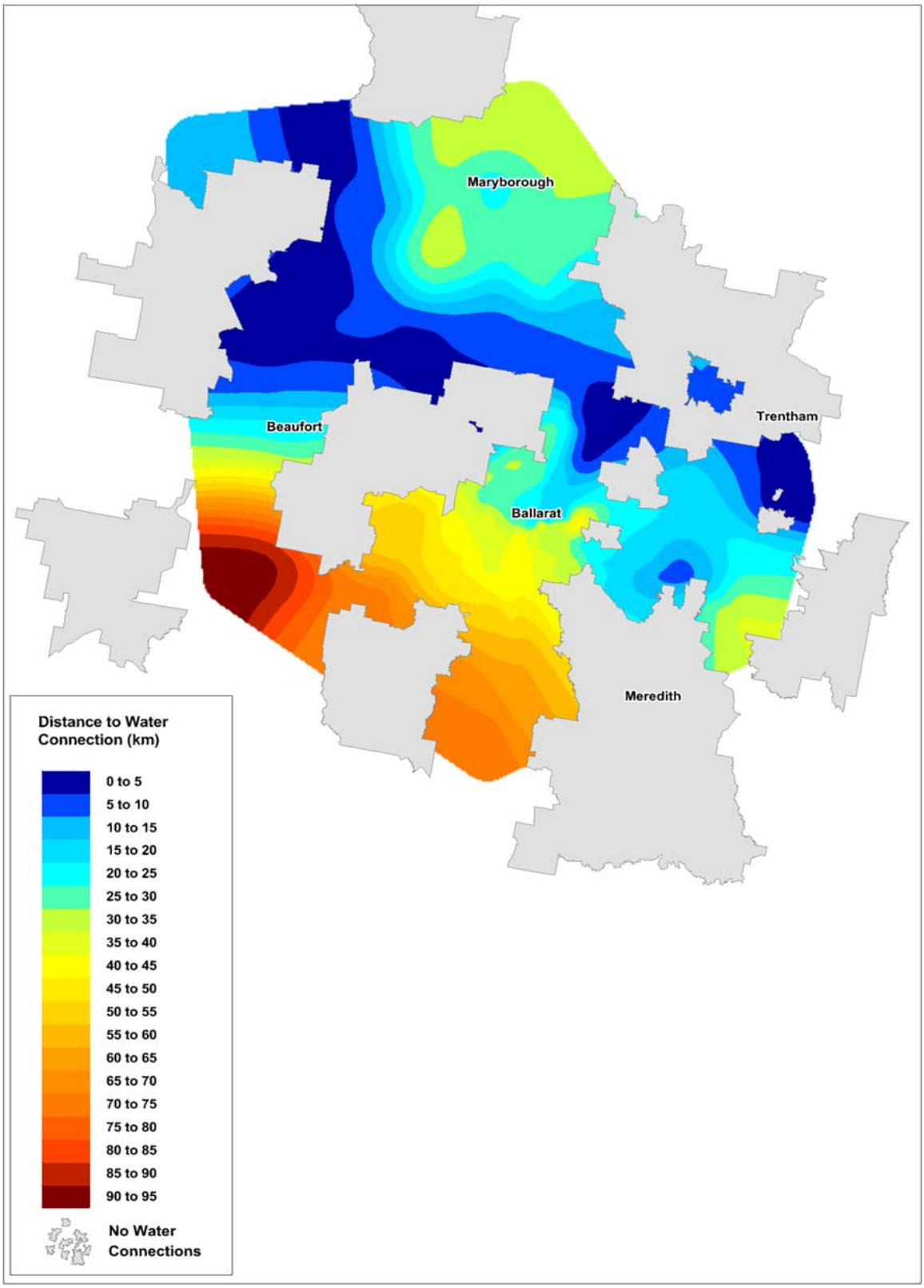

Figure 1.9: Water transfer distances across the region and areas without reticulated water connections (transfer distances from Goulburn and Campapse Rivers via Goldfields pipe not included).

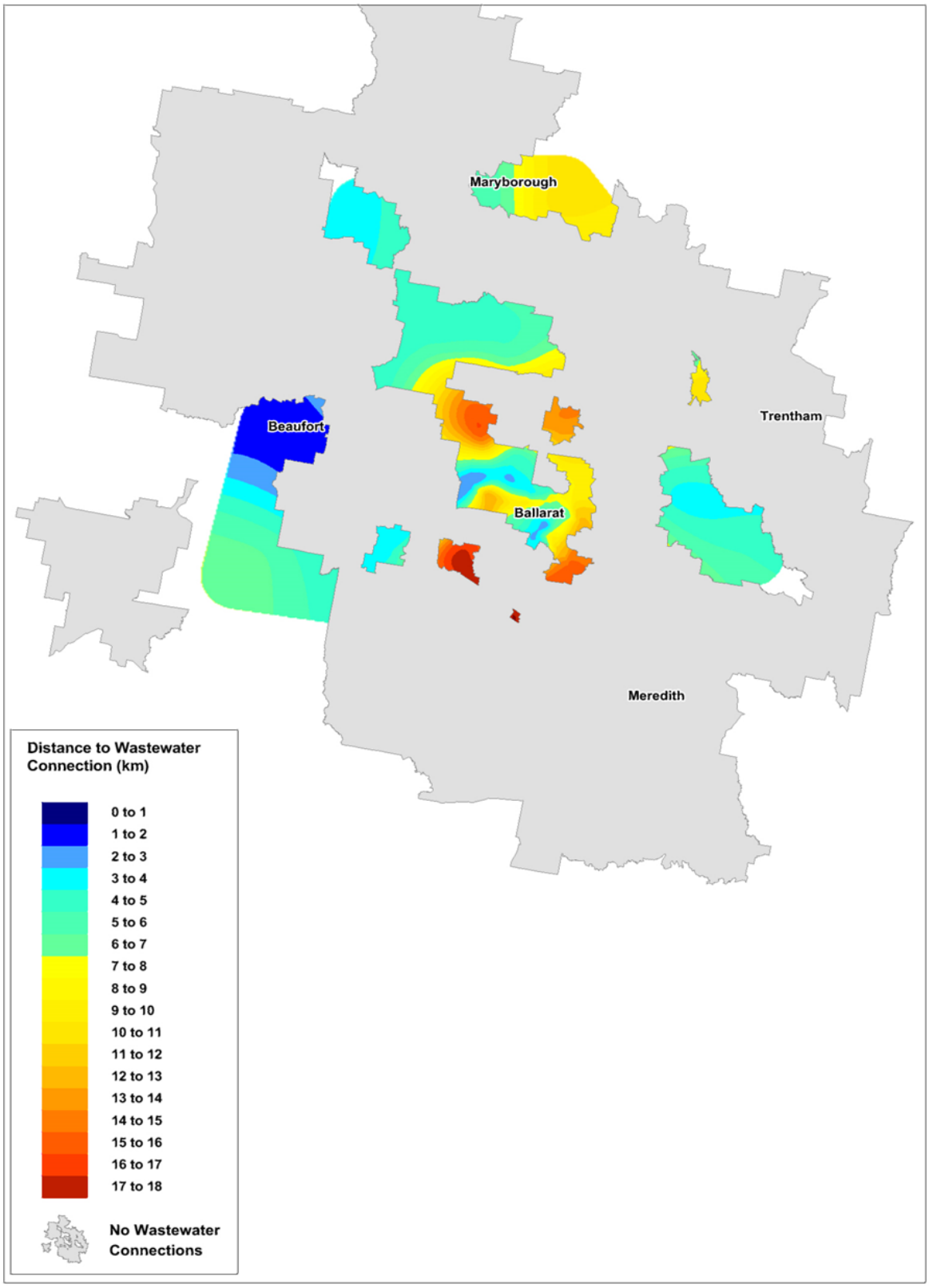

Figure 1.10: Wastewater transfer distances across the region and areas without reticulated wastewater connections

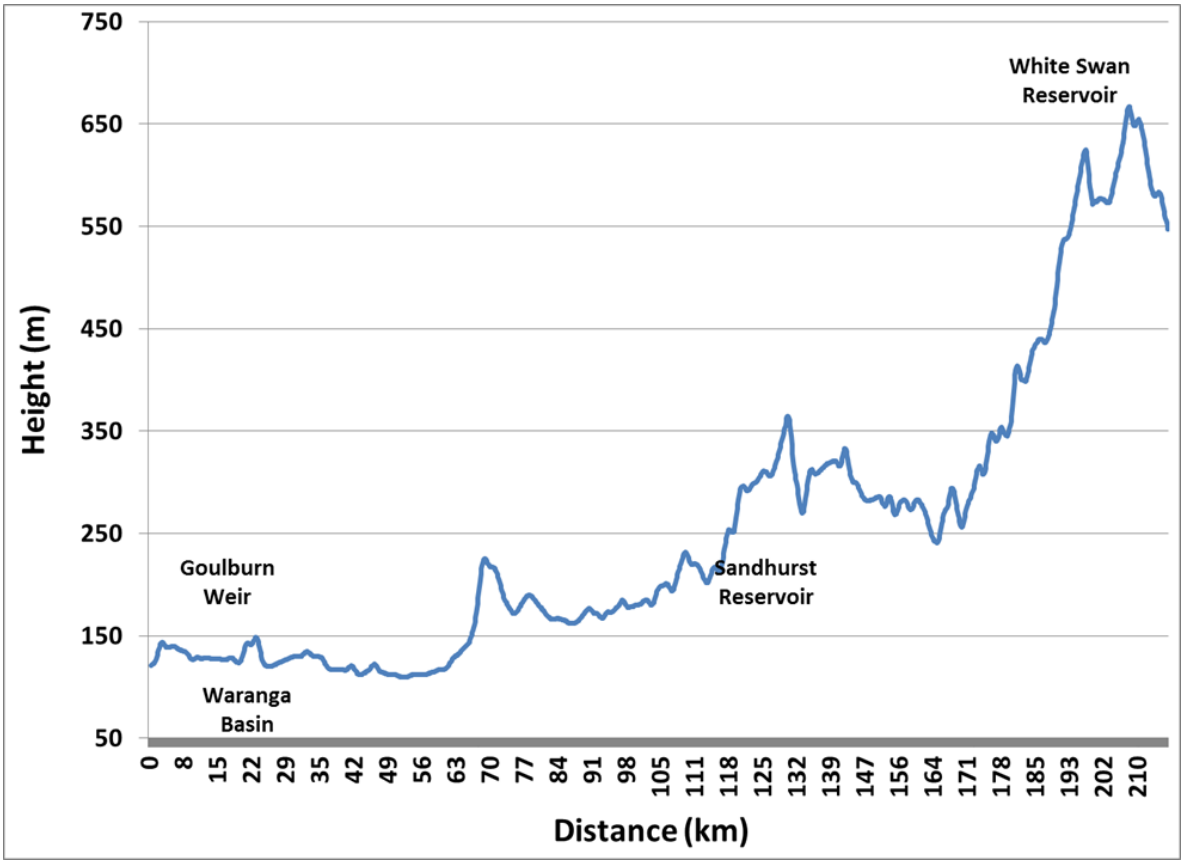

Figure 1.11: Transfer distances and heights for the Goldfields pipe.

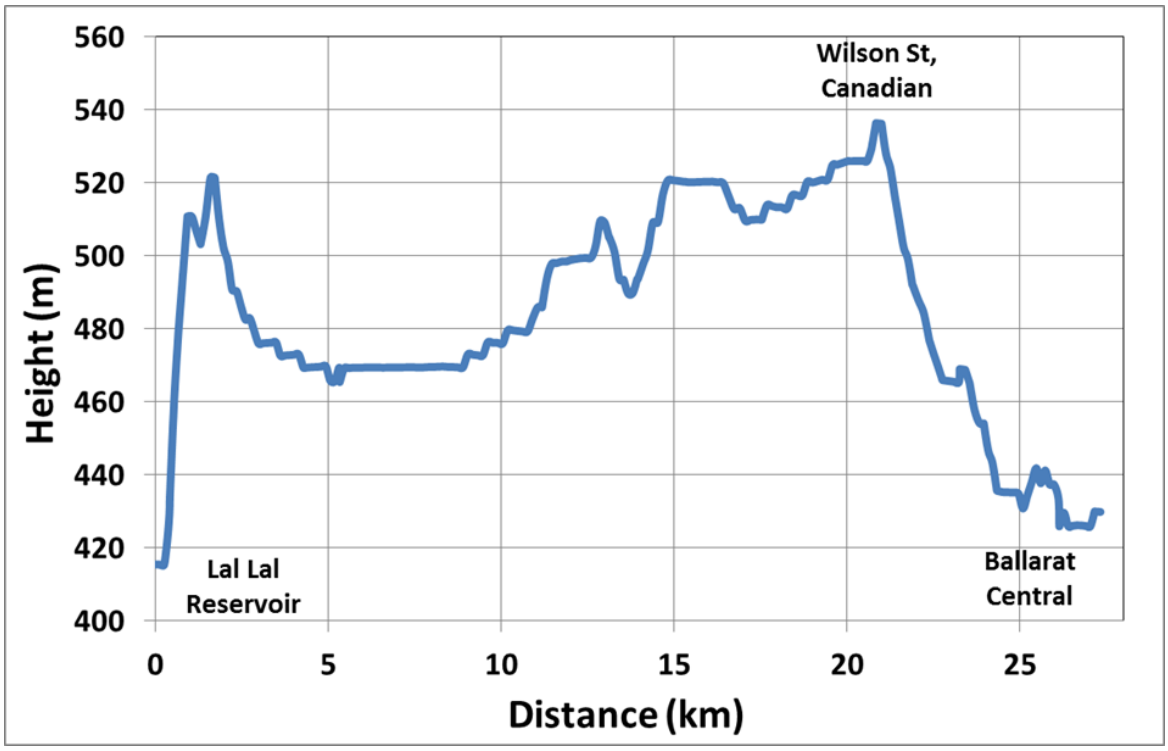

Figure 1.12: Transfer distances and heights from Lal Lal Reservoir

2 The systems framework

A modified version of the Systems Framework that underpinned the Melbourne's Water Future strategy was developed for the Living Ballarat project. The framework incorporates additional detail about non-residential land uses and nested local frameworks that represent town scale behaviours. The Systems Framework is built up from the lot or local scale across multiple scales to the footprint of the region as shown in Figure 2.1.

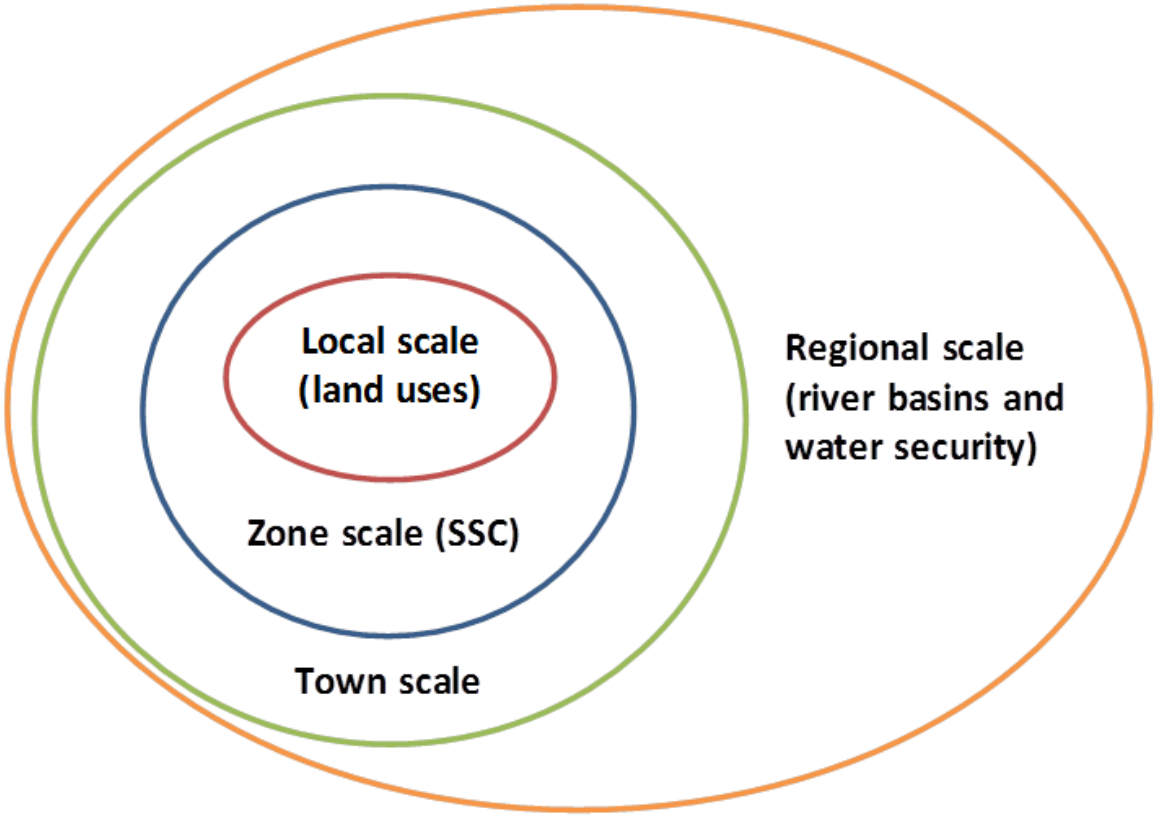

Figure 2.1: Overview of the Systems Framework developed for the Living Ballarat project

Figure 2.1 shows that the Systems Framework used to analyse the Living Ballarat project includes interactions across multiple scales including local land use, suburb, town and regional scales. The regional scale incorporates river basins and irrigation districts.

Development of evidence based policy has garnered substantial interest throughout a range of policy development domains. However, a barrier to the process of developing or implementing evidence based policies can be perceptions of certainty or uncertainty about deterministic data or information from a typically single or limited number of sources.[2]

In contrast, the Systems Framework includes and links multiple layers of temporal and spatial data or information from many different disciplines and from multiple perspectives. The Framework links and processes information across time and space, that include "Big Data Analysis" processes. "Big

[2] Coombes (2013). Systems Frameworks with Big Data Analysis – towards a modern policy frontier. www.urbanwatercyclesolutions.com

Data Analysis" is the collection of large and complex datasets that are difficult to process or understand using traditional database management tools or data processing applications.

This framework for water cycle decision making is based on information, drivers, performance, impacts and trade-offs across the full footprint of the water cycle across scales from the allotment to region. The framework is structured to allow the development of water cycle strategies to provide context and objectives that reflects local community values and preferences for water cycle management across the Ballarat and surrounding regions. It is designed to reveal an optimal mix of centralised and smaller scale investments across regulatory boundaries and to demonstrate the resilience of the strategies and options to uncertain and unpredictable futures.

This process includes many layers of detailed spatial and temporal information from multiple disciplines including climate, waterways, socio-economics, demographic, town planning, water resources management and economics. The Systems Framework used to underpin the Living Victoria policies has been developed over the last decade to describe the bio-physical systems throughout the foot print of the regions. This framework for Greater Melbourne has evolved in collaboration with the water industry throughout the early projects with the Department of Sustainability and Environment (DSE), the Living Victoria Ministerial Advisory Council (LVMAC) phases 1 and 2, review of the Water Supply Demand Strategies and to inform the recently endorsed Melbourne's Water Future strategy.[3]

The analysis is anchored by a regional framework of key trunk infrastructure, demand nodes, discharge points, waterways, wastewater discharges and regional sources of water in a Systems Framework. The previous reports namely, "Study 1 – transitioning to a resilient, liveable and sustainable Greater Melbourne (system wide study)" and "Rainwater tank evaluation study for Greater Melbourne" are not fully included herein and should be read in conjunction with this report.[4,5]

The systems analysis undertaken for this study is substantially different to traditional analysis of water resources in many key areas. The process adopted for this study includes detailed forensic analysis of a wide range of biophysical parameters throughout Ballarat region. The existing integrated systems model of the Greater Melbourne region has been updated and enhanced for use in this project incorporating the latest results from ongoing independent research into analysis of water cycle systems.[6] Similar analysis for Greater Sydney and the Australian Capital Territory (ACT) was subject to comprehensive peer review and feedback.[7] The quasi parallel processes of refining the first principles systems analysis for the water cycles in Greater Sydney, the ACT and Greater Melbourne has also contributed to and enriched the processes utilised in these investigations.

Importantly, the Systems Framework relies on a time based (non-stationary) analysis processes (such as analysis of all expected changes from 2010 to 2051) for any option. This is profoundly

[3] Peter Coombes and Bonacci Water (2012). Living Melbourne, Living Victoria: Greater Melbourne systems model – modelling in support of the Living Victoria Ministerial Advisory Council

[4] Coombes P.J. and Bonacci Water (2011). Study 1 – transitioning to a resilient, liveable and sustainable Greater Melbourne (system wide study). Report to the Ministerial Advisory Council for the Living Melbourne Living Victoria water policy.

[5] Bonacci Water and Urban Water Cycle Solutions (2008). Rainwater tank evaluation study for Greater Melbourne. Report for the Department of Sustainability and Environment.

[6] Coombes, P.J., 2005. Integrated Water Cycle Management – analysis of resource security. WATER. Australian Water Association (AWA). Sydney.

[7] Bonacci Water, 2011. Sydney Water alternative water strategy. A vision of what is possible and a roadmap to get there. Report of the Board of Sydney Water Corporation.

different to traditional analysis that often employs end state (stationary) analysis of options. In addition, all local land use behaviours considered in the Systems Framework build up bundles of different behaviours over time and space that will contribute to an option. This is different to assuming a similar average behaviour or performance across an Option as is the case in traditional analysis approaches. For example, in the Systems Framework, the business as usual (BAU) includes dwellings with different water efficiency attributes that contributes as different proportions of an Option over time in accordance with growth and renovation rates.

3 Scenarios

The systems analysis of the Ballarat region includes a range of scenarios that were selected to reveal the performance of water cycle systems across the region in response to uncertainty about the future. It is noteworthy that a Scenario is different to the choice of an Option for future water cycle management. The scenarios chosen to test the performance of options in the Living Ballarat project are presented in Table 3.1.

Table 3.1: Overview of scenarios

Scenario	Description
Base Case (BAU)	The Base Case is defined as continuing with current water cycle management processes and behaviours that are subject to the trajectory of current climate processes
Climate Change (CC)	High emissions climate change as defined by the fifth report by the IPCC as a rate of increase in average temperature of 0.05°C/annum
High Growth (HG)	High population growth as defined by the Victoria in Future 2012 (VIF 2012) forecast population for 2051 achieved at 2041.
High Growth with Climate Change	High population growth as defined by forecast population for 2051 achieved at 2041 with high emissions climate change as defined by a rate of increase in average temperature of 0.05°C/annum.

Table 3.1 highlights the scenarios that were used to understand the performance of local and regional water cycle management for this investigation.

Base Case (BAU)

The Base Case is defined as continuing with current water cycle management processes that are subject to the trajectory of current and historical climate processes. It is highlighted that historical climate and weather patterns are not stationary as demonstrated by the changes in the Ballarat region since 1910[8] as presented in Table 3.2.

Table 3.2: historical changes in weather for the Ballarat region

Criteria	Change relative to 1910
Mean temperature (°C/year)	Increase 0.005 – 0.01
Average annual rainfall (mm/year)	Decrease 0 – 0.5
Average evaporation (mm/year)	Increase 0 – 2.5

8 Bureau of Meteorology (2013). Australian Climate Change Science Program. www.bom.gov.au/climate/change.

This investigation does not include future options for the augmentation of water supply, wastewater and stormwater systems to highlight the challenges and opportunities that the region may encounter. The Base Case was also deemed to include combinations of the following four variants that approximate the natural variability of the existing building stock across the region:

- BAU: Buildings with a level of water efficiency and water use that is consistent with pre-drought behaviours as defined by water billing records from Central Highlands Water for 2002. These buildings do not utilise rainwater harvesting.
- RWT: Residential buildings with higher levels of water efficiency associated with low flow toilets, showers, taps and clothes washers with associated behaviour change. Rainwater harvested from 100 m^2 of roof area in 3 kL rainwater tanks is used for outdoor water uses. Non-residential buildings include a 10% change in water use from water efficiency measures and behaviour change. Rainwater harvested from 1000 m^2 of roof/ha into 50 kL/ha of rainwater storage is used for outdoor uses.
- RWT1: Residential buildings with the highest levels of water efficiency associated with low flow toilets, showers, taps and clothes washers with associated behaviour change. Rainwater harvested from 100 m^2 of roof area in 5 kL rainwater tanks is used for laundry, toilet and outdoor water uses. Non-residential buildings include a 20% change in water use from water efficiency measures and behaviour change. Rainwater harvested from 1000 m^2 of roof/ha into 50 kL/ha of rainwater storage is used for non-potable indoor and outdoor uses.
- WEA: Residential buildings with the highest levels of water efficiency associated with low flow toilets, showers, taps and clothes washers with associated behaviour change. Non-residential buildings include a 20% change in water use from water efficiency measures and behaviour change.

Although the water billing data provided by Central Highlands Water (CHW) reveals substantial reductions in water use, there is limited information about the processes that provided diminished water use. A survey by CHW reveals that 86% of households with rainwater tanks use rainwater for outdoor uses. The Australian Bureau of Statistics (ABS) reveals that installation of rainwater tanks in regional Victoria has increased to 46.9% of households to 2010.[9] Additionally, the installation of low flow showers and dual flush toilets has increased to 67.4% and 88.6% of households respectively. Water efficiency for buildings has increased throughout Victoria over the last decade.

An opportunity for the adoption of water efficient appliances and rainwater harvesting is provided by new and renovated housing. Investigations by the City of Ballarat have revealed that the annual development of new housing and renovation of existing housing proceeds at rates of 1.5% and 0.6% respectively.

Climate change (CC)

The non-linear and chaotic nature of the climate systems imposes considerable uncertainty about future climate stages that will impact on local weather and hydrology. The Intergovernmental Panel on Climate Change (IPCC) outlines growing confidence in projections of changes in annual to

[9] ABS (2010), Environmental issues – water use and conservation.

decadal average temperature and, to a lesser extent precipitation.[10] The anthropogenic warming of surface air temperature is expected to proceed more rapidly over land areas than over oceans.

Predictions of temperature anomalies relative to ambient average temperatures from the 1986 – 2005 period range from 0.3° to 0.7°C to the 2016 – 2035 period and of 2.6°C to 4.8°C to the period 2081 – 2100 using the high emissions RCP8.5 model analysis.[11] Interpretation of these results to the Australian region indicate an increase in average temperatures of 1°C to 1.5°C to the period 2036 – 2055 relative to the average temperatures in the period 1986 – 2005. This result represents an incremental annual change in average temperature of 0.05°C.

A high emissions climate change scenario was adopted for use in this investigation with incremental change in average temperature of 0.05°C/year that was used to drive changes in weather (rainfall and evaporation) and hydrology in the Systems Framework.

The expected impacts of climate change on the Ballarat region include up 8% increase in evaporation, up to 12% reduction in annual rainfall and 5% to 50% reductions in annual stream flows in the Campaspe, Loddon and Moorabool Rivers.[12]

High population growth (HG)

The High Growth scenario used in this study incorporates accelerated population growth that achieves the expected regional population for 2051 in 2041 as shown in Figure 3.1.

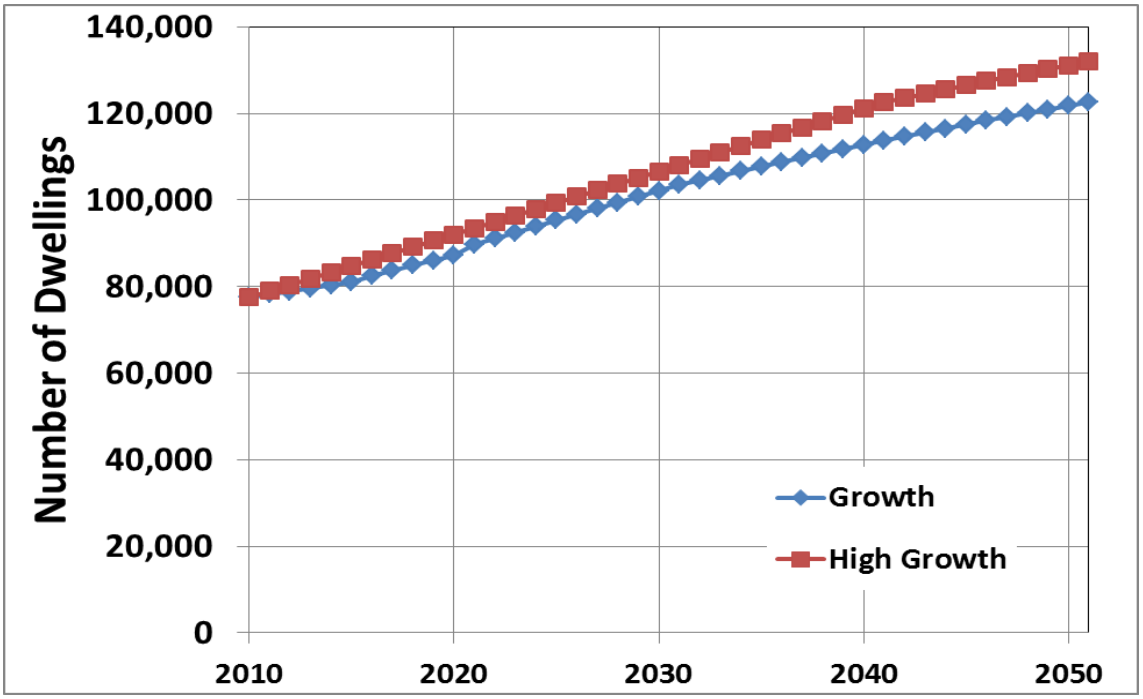

Figure 3.1: Projections of regional population and the High Growth scenario

[10] IPCC (2013), Working group contribution to the Fifth assessment report of the Intergovernmental Panel on Climate Change.
[11] IPCC (2013) Working group contribution to the Fifth assessment report – the physical science basis. Draft underlying scientific and technical assessment.
[12] DSE (2008). Climate change in the Corangamite and North Central Regions. The Victorian Climate Change Adaption program

A high population growth scenario is derived from the Victoria in Future 2012 (VIF 2012) forecast of population from 2016 to 2031 that is published by the Victorian Department of Transport, Planning and Local Infrastructure. These projections for Local Government areas and Statistical Local areas was refined using data from the Australian Bureau of Statistics (ABS) for observed population in 2011 for the 144 State Suburbs included in this investigation. The 144 State Suburbs in the Ballarat region comprised 176,710 people in 2011.

Population projections to 2031 from VIF 2012 were supplemented with estimates for population growth from 2031 to 2051 that were derived from a range of sources including the ABS, local government planning and unofficial Victorian Government projections. The High Growth scenario represents an increase in expected annual population growth from 1.45% to 1.79% which is the inclusion of an additional 618 people/annum in the region.

4 Summary of Methods and Information

The Ballarat region chosen for this investigation includes 144 State Suburbs, 7 local government areas and significant river basins that are managed by 5 Catchment Management Authorities. Central Highlands Water provides urban water supplies to 15 water districts and reticulated sewerage services to 10 districts within the region. The region is also dependent on groundwater resources and bulk water allocations from the Moorabool, Campaspe, Goulburn, Loddon and Yarrowee River catchments. These shared regional water resources are also subject to management by Southern Rural Water, Goulburn Murray Water and the Murray Darling Basin Authority.

This analysis is dependent on detailed local inputs throughout the system, such as demographic profiles and human behaviour, and linked systems that accounts for water supply, sewage, stormwater and environmental considerations. The systems analysis was built on local scale (the people) inputs (a "bottom up" process) rather than traditional analysis of water resources that commences with regional scale assumptions and average (a "top down" process).

The Systems Framework for analysis of the Living Ballarat project was constructed from the basic elements (the local scale land use) that drive system behaviours and account for first principles transactions within the system to allow simulation of spatial and temporal performance of the system. Biophysical systems for the region were constructed using three basic components:

Sources - Regional and local water sources, catchments and waterways

Flux – transport and treatment of water, sewage and stormwater throughout the region

Sinks – Stormwater runoff and wastewater disposal to waterways

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

Major water distribution, stormwater, sewage, demographic, climate and topographic zones are combined in this framework. This process compiles inputs from a wide range of commonly utilised analysis tools, including for local water demands and water balances and hydrology.

This framework incorporates the movement of water throughout the region and connectivity to the water supply headworks system. Similarly, this framework includes the movement of sewage and stormwater throughout the region and connectivity with discharge points, waterways or reuse systems.

The framework also includes behaviour and climate dependent water demands that were modified by a range of processes including adoption of water efficient appliances in some houses, connection to wastewater reuse systems and changes in demographics. This framework for integrated systems analysis will be utilised to examine the base case for the Ballarat region and to provide greater insights into the opportunities and challenges throughout the region.

The Systems Framework includes local, suburb, town and regional scale inputs and processes.

Local scale

The local scale processes in the Systems Framework include the collation of multiple layers of data and information to underpin the analysis. The statistical and spatial data used for the Systems Analysis was collated for the Living Ballarat Project by the project partners and key knowledge holders such as Local Governments, Central Highlands Water, Catchment Management Authorities, rural water agencies and research organisations such as Federation University Australia, along with the contributions of many local individuals. The range of spatial and statistical data, technical reports and planning documents includes (but not limited to), ABS population dynamics, water supply and demand, infrastructure, land use, hydrology and hydrogeological records, rainfall and climate.

Land Use statistics from 2011 for each state suburb were sourced from the most recent Census of Population and Housing conducted by the Australian Bureau of Statistics. The ten categories of land uses employed as inputs to the Systems Framework were Agricultural, Commercial, Education, Medical, Industrial, Irrigated Parkland, Non-Irrigated Parkland, Residential, Transport and Water.

The land area attributed to each of these categories was derived using the Mesh Block Digital Boundaries with the Location of Features of Interest from the VicMap information, the Victorian Land Use Information System and the Mesh Block Census Count at 2011. Aerial imagery was also utilised to rationalise the determination of land uses.

Examples of the determination of land uses for the Sebastopol and Maryborough state suburbs are provided in Figures 4.1 and 4.2.

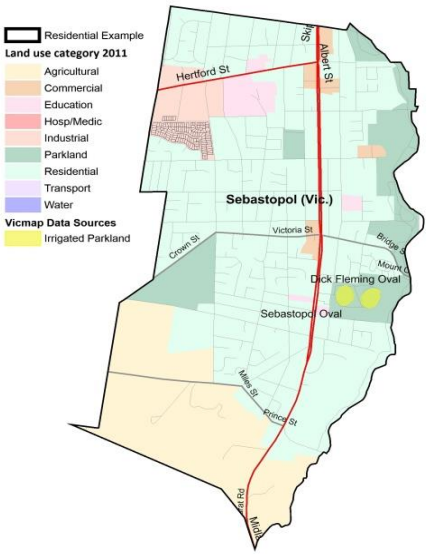

Figure 4.1: Land uses at Sebastopol

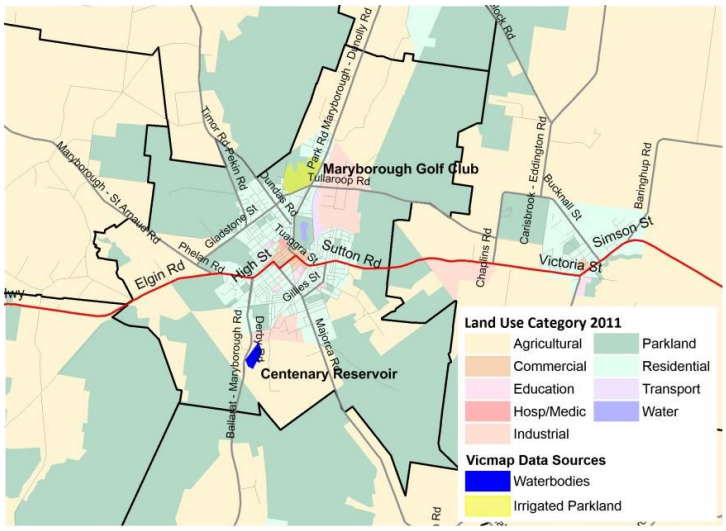

Figure 4.2: Land uses at Maryborough

Land uses were determined for 144 State Suburbs or zones of analysis to underpin the local scale analysis in the Systems Framework. Analysis of the behaviour of land uses in each zone included the historical longest sequences of local rainfall and temperature that were sourced from the Bureau of Meteorology for the continuous simulation of water balances at six minute intervals.

Inputs to the local scale simulations includes local profiles of dwelling types sourced from the Australian Bureau of Statistics that for 3 dwelling types (detached, semi-detached and units) and 5

household sizes (1 person to 5+ people). These residential land uses were combined with non-residential land uses including agricultural, commerce, industry, education, medical, parks, irrigated parks and transport.

Local billing data sourced from Central Highlands Water was utilised to define water demands and discharges of wastewater from each land use and dwelling. The analysis considered the components of the base case including land uses with BAU, water efficient, reduced stormwater impact and rainwater harvesting behaviours.

The water balance model includes climate and socioeconomic dependent behavioural algorithms of water use and related wastewater discharges. These behavioural algorithms were calibrated using the billing data for water use from the period 2000 to 2002 that was not subject to water restrictions, floods or exceptional economic circumstances.

Average residential water use from the simulations of each dwelling type and household size were combined using the proportions of dwelling types and sizes published by the Australian Bureau of Statistics for each Suburb. This allowed comparison to the observed average residential water use for each suburb provided by Central Highlands Water and calibration of the local scale model. Examples of the calibration of water use behaviours are provided for Ballarat Central and Maryborough Suburbs in Figures 4.3 and 4.4 respectively.

Water use algorithms in the local scale models were also calibrated for the other land uses using observed water use data from Central Highlands Water.

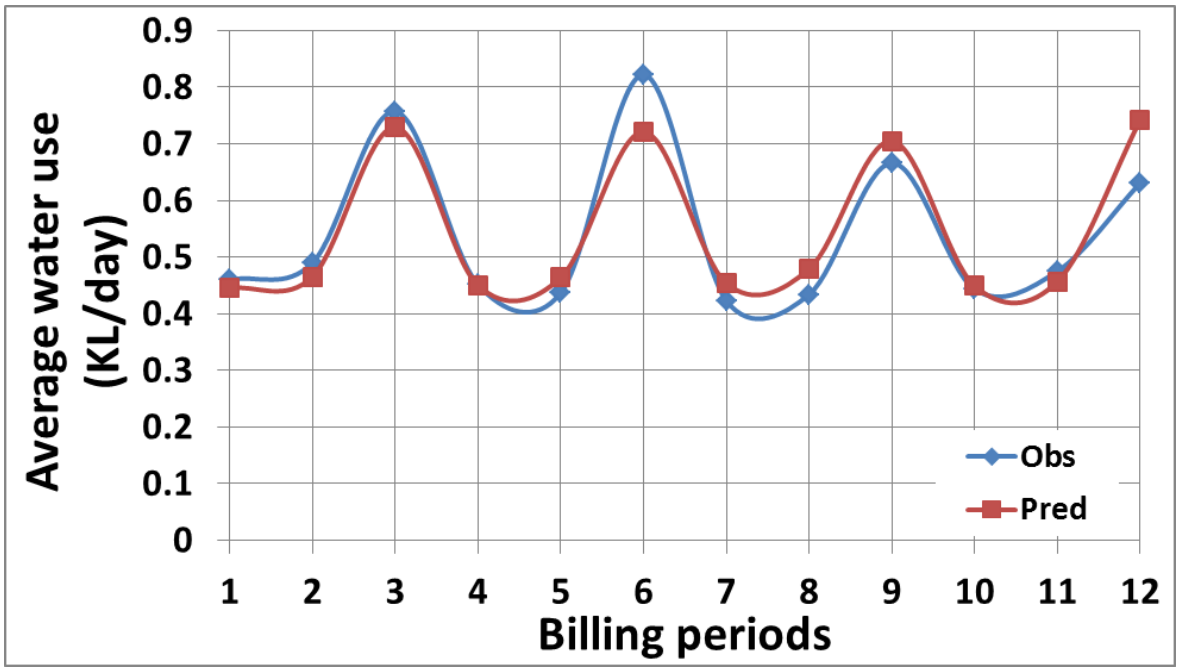

Figure 4.3: Calibration of residential water use for the Ballarat Central Suburb

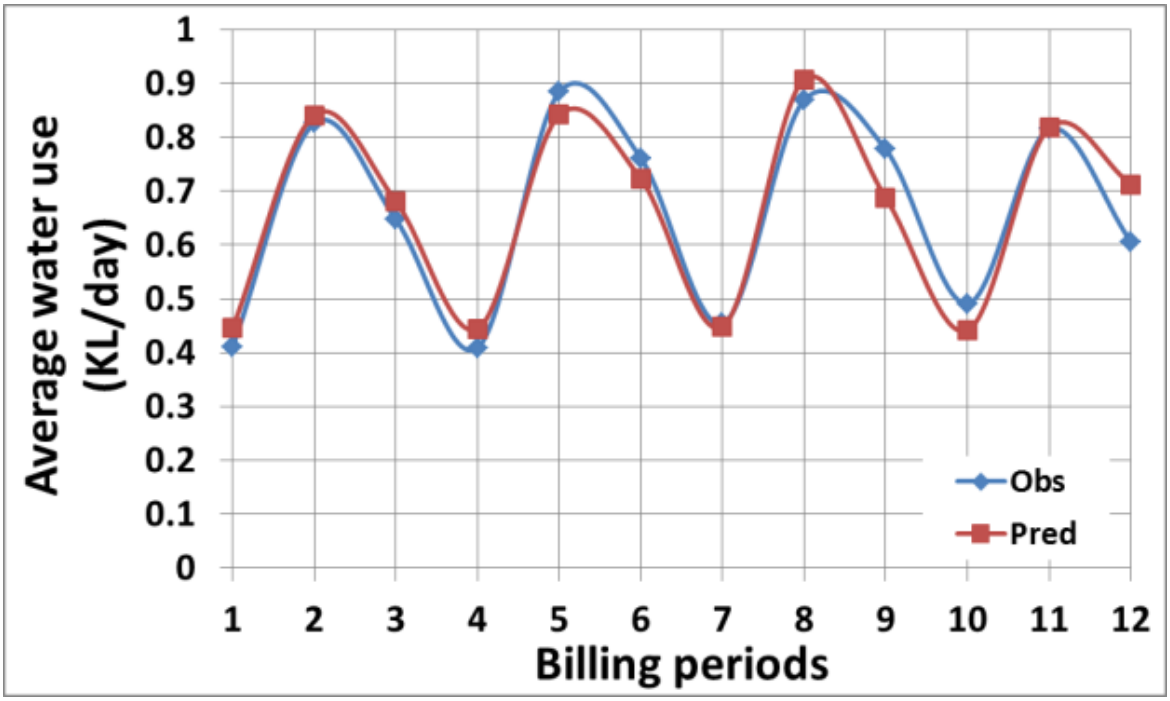

Figure 4.4: Calibration of residential water use for the Maryborough Suburb

Figures 4.3 and 4.4 demonstrate that the local scale model was able to reproduce the patterns and magnitude of water use from residential dwellings. The local scale model produced long sequences of daily water demands, wastewater discharges and stormwater runoff for each dwelling type and household size, and for each land use. These sequences of water cycle outputs were then incorporated in the water cycle profiles for each suburb.

Zone or Suburb Scale

The sequences of water use, wastewater flows and stormwater runoff from local scale analysis are combined for each zone or suburb using town planning projections and spatial climate replicates to combine inputs. This process also combines local scale options to pproduce future projections of water, wastewater and stormwater runoff for use in the Systems framework. These sequences are then verified and calibrated using hind casting of historical inputs for the period 2000 to 2012 (See Section 5).

A transition framework was used to generate daily water cycle responses for each zone as shown in Figure 4.5. Sequences of daily water balance results from the local scale (PURRS) model were compiled using seasonal information and historical climate data including daily rain depths, cumulative days without rainfall and average daily maximum ambient air temperature to create resource files of water demand, wastewater generation and stormwater runoff**.** The method of non-parametric aggregation[13] was then utilised to generate daily water use, wastewater discharges and stormwater runoff in each zone using the historical resource files and climate replicates generated for the simulation of the regional system. Climate replicates are multiple sequences of equally likely future rainfall and temperature.

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

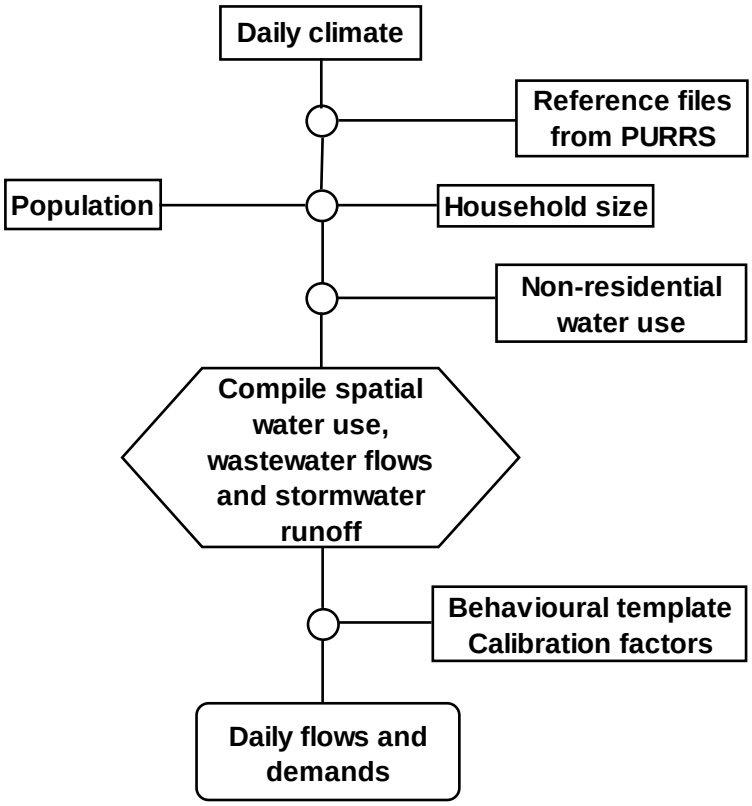

Figure 4.5: The transition framework for combining land use behaviours at the zone of suburb scale

Figure 4.5 demonstrates that at each time step climate variables from the regional model are used to find matching climate variables and coincident daily water use, sewage generation and stormwater runoff results for each dwelling from the reference files.

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

The sequences of data from the PURRS simulations were combined in the transition framework using the framework presented in Figure 4.6. Daily sequences of water cycle information; such as water demands, wastewater discharges and stormwater runoff; were combined for different household sizes and land uses, different dwelling types and a combination of different water cycle management Options for each strategy in the Transition Framework.

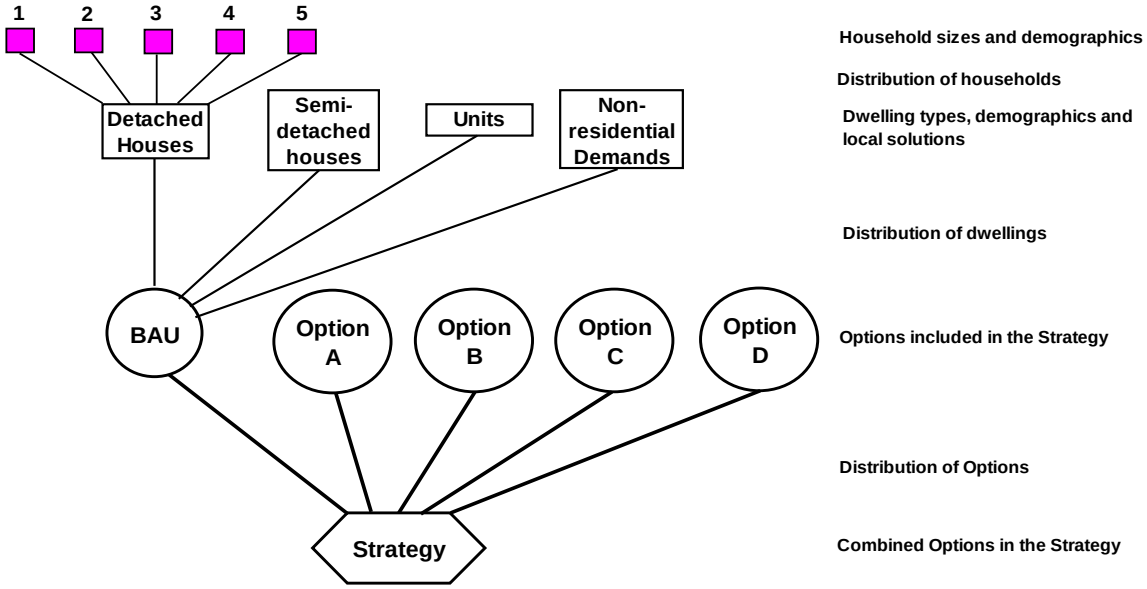

Figure 4.6: Structure for combining different household sizes, dwelling types and water cycle management Options in the Transition Framework

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

Town and Regional Scales

The Systems Framework utilises network linear processes to combine water, sewage, wastewater reuse and waterway system in an integrated network. A wide range of spatial information generated by the lot scale analysis was combined in the zone scale transition for use in the systems analysis.

The movement of water, sewage, recycled water and stormwater throughout the Ballarat region was simulated over a 42 year period using 100 replicates of climate sequences. This allowed analysis of peak flows in trunk infrastructure, assessment for regional sewage discharges, stormwater runoff and water demands.

Water supply to the Ballarat region includes local surface water supplies, ground water, surface water sourced from the Campaspe and Goulburn river basins, shared surface water from the Loddon and Moorabool river basins and rainwater harvesting and increased water efficiency of buildings.

The analysis utilized stream flows, reservoir storage volumes, wastewater discharges and information about the operation of water systems provided by Central Highlands Water, the Victorian Water Data Warehouse, Goulburn Murray Water and Coliban Water as inputs.

An overview of the water transfer system known as the Goldfields pipe linking the Ballarat district with the Campaspe and Goulburn River systems that used in the Systems Framework provided in Figure 4.7. The catchments that contribute to inflows to Goulburn weir and to Lake Eppalock used in the Systems Framework are presented in Figures 4.8 and 4.9 respectively. The catchment areas for the Eppalock and Goulburn system are included in Tables 4.1 and 4.2.

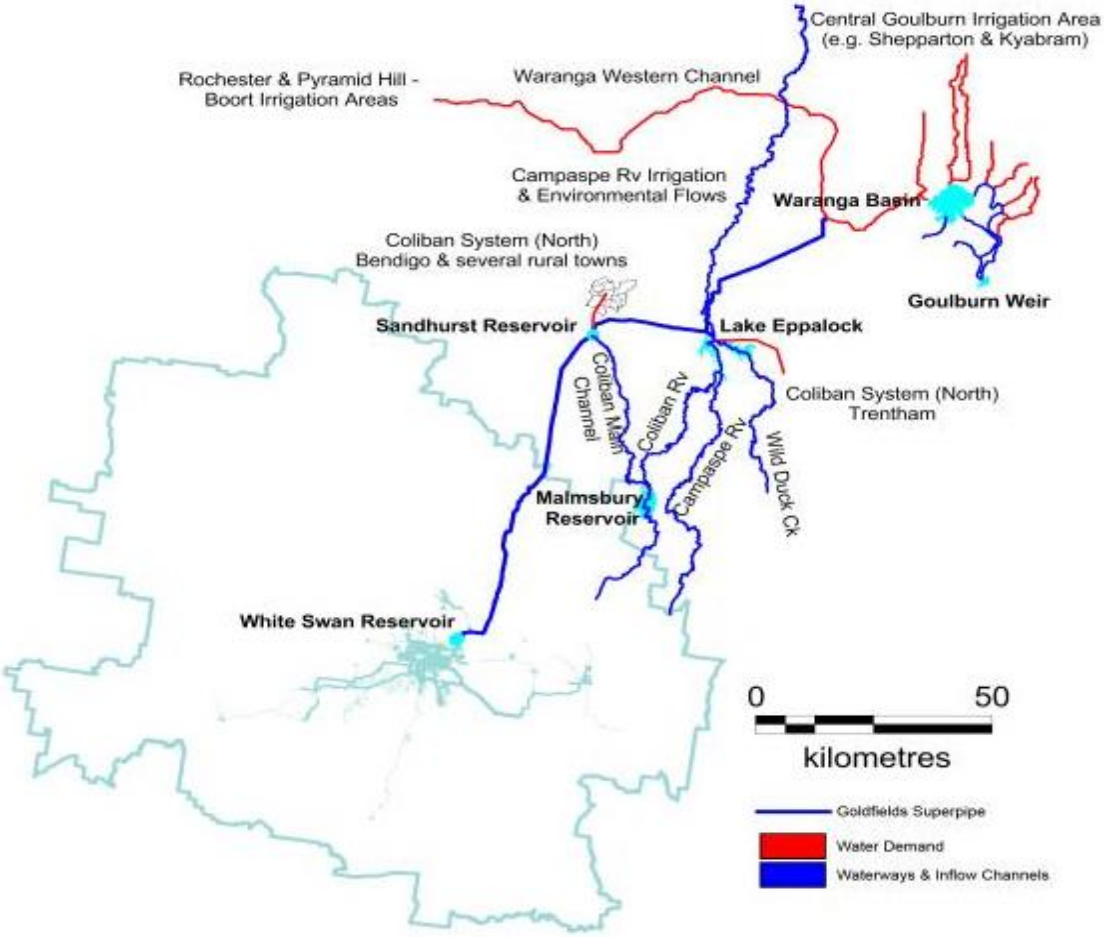

Figure 4.7: An overview of the water supply systems linking Ballarat to the Campaspe and Goulburn River systems

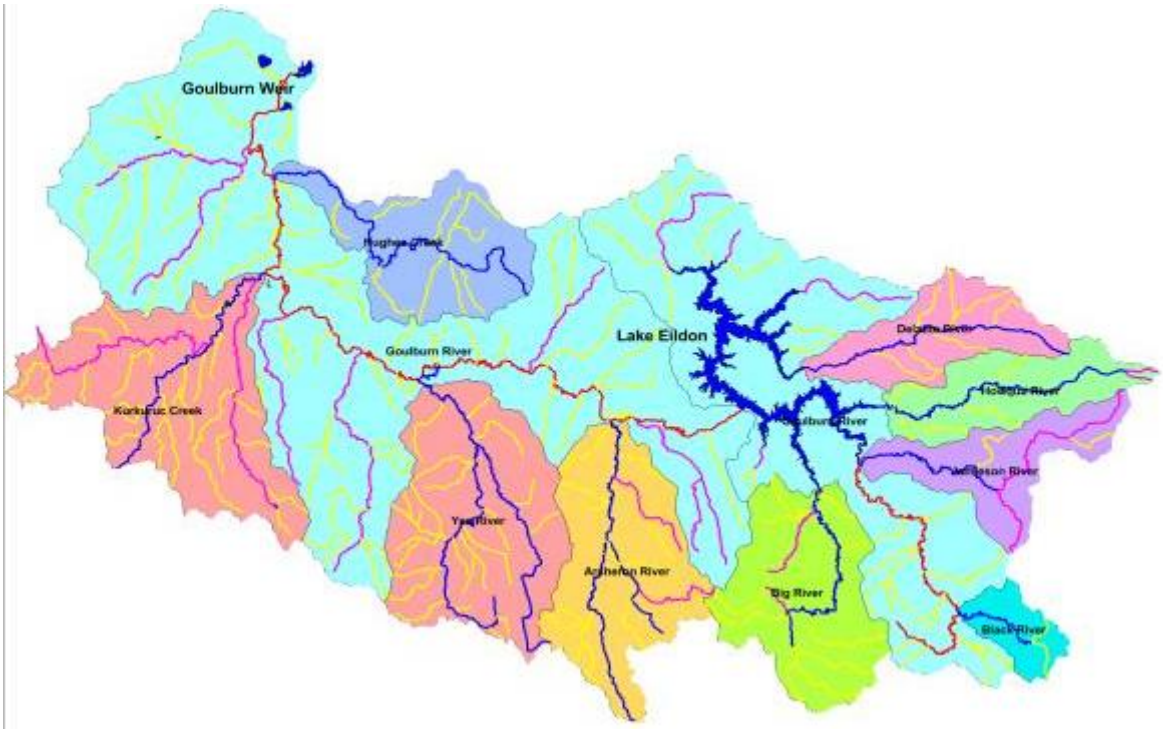

Figure 4.8: Catchments contributing the Goulburn weir used in the analysis

Figure 4.9: The catchments contributing to Lake Eppalock that are utilised in this analysis

Table 4.1: Lake Eppalock catchments

Catchment	**Location**	**Area (km^2)**
Coliban River	Upstream Lake Eppalock	455
Coliban River	Upstream Malmsbury Reservoir	95.5
Coliban River	Upstream Lauriston Reservoir	186.4
Campaspe River	Upstream Lake Eppalock	814.8
Wild Duck Creek	Upstream Lake Eppalock	329.8
Mount Ida Creek	Upstream Lake Eppalock	181.3

Table 4.2: Goulburn River catchments

Catchment	Location	Area (km^2)
Delatite River	Upstream Lake Eildon	394.1
Howqua River	Upstream Lake Eildon	389.2
Jamison River	Upstream Lake Eildon	385.8
Big River	Upstream Lake Eildon	653.3
Black River	Upstream Lake Eildon	139.7
Goulburn River	Upstream Lake Eildon	1917
Goulburn River	Upstream Goulburn Weir	3486
Archeron River	Upstream Goulburn Weir	728.6
Yea River	Upstream Goulburn Weir	907.5
Hughes Creek	Upstream Goulburn Weir	564
Kurkuruk Creek	Upstream Goulburn Weir	979.1

The information about the catchments shown in Tables 4.1 and 4.2 was used in hydrological analysis to supplement stream flow data provided by the Victorian Data Warehouse for use in the Systems Framework. A summary of historical stream flow data used in the Systems Framework is provided in Table 4.3.

Table 4.3: A summary of historical stream flow used in the Systems Framework

Inflow Name	Reservoir	Start Date	End Date	Annual Average Flow (ML)
Kangaroo Ck	Bullarto Reservoir	21/07/1998	21/04/2013	205.5
Long Gully Ck	Long Gully Creek Diversion	1/01/2000	17/03/2013	436.2
Doctors Ck	Lexton Reservoir	1/01/1996	12/12/2012	4,602.2
McCallums Ck	Evansford Reservoir	1/01/2000	8/04/2013	1,686.7
Stoney Ck	Talbot Reservoir	24/06/2000	8/04/2013	147.2
Fellmongers Ck	Gong Gong Reservoir	1/01/1999	2/05/2013	300.9
Lal Lal Ck	Lal Lal Reservoir	7/06/1977	30/06/2013	13,170.5
Black Ck	Lal Lal Reservoir	7/06/1977	30/06/2013	642.5
Woolen Ck	Lal Lal Reservoir	7/06/1977	30/06/2013	511.2
Devils Ck	Moorabool Reservoir	1/01/2002	13/05/2013	1,040.0
West Moorabool R	Moorabool Reservoir	1/01/2002	13/05/2013	864.5
Wilson Res Inflow	Wilson Reservoir	1/01/1999	2/05/2013	300.9
Wombat Inflow	Wombat Reservoir	21/07/1998	21/04/2013	508.7
Coliban R	Lake Eppalock	1/01/1975	30/06/2013	59,734.0
Campapse R	Lake Eppalock	1/01/1976	30/06/2013	63,568.0
Goulburn R	Goulburn Weir	1/01/1996	30/06/2013	1,715,884.5
Mt Ida Ck	Lake Eppalock	26/03/2007	30/06/2013	10,747.9
Wild Duck Ck	Lake Eppalock	1/01/1981	30/06/2013	18,194.4
Crewick Ck	Cosgrave Reservoir	17/01/1996	31/01/2013	1,100.7
Birch Ck	Newlyn Reservoir	17/01/1996	31/01/2013	2,52.5
Tullaroop Ck	Tullaroop Reservoir	3/02/1973	9/11/2012	43,467.3
Moor E	Moorabool Reservoir	21/09/1971	31/01/2013	1,164.2
Epp E	Lake Eppalock	22/08/1973	30/06/2011	1,443.7
War E	Waranga Basin	1/01/1968	31/12/1985	1,516.9
Forest Ck		28/10/1996	21/05/2012	78.2
Lands inflow	Landsborough Reservoir	18/12/1997	31/12/2012	75.0
Redbank Inflow	Redbank Reservoir	9/09/1997	22/05/2012	35.1
Sugar Inflow	Sugarloaf Reservoir	4/08/1997	3/12/2012	243.3
Fiery Ck	Musical Gully	19/08/1997	21/05/2012	187.4
Troy Res Inflow	Troy Reservoir	19/08/1997	21/05/2012	53.8
Spring Ck		21/07/1998	3/12/2012	129.3
Wallaby Ck	Wallaby Creek Diversion	21/07/1998	3/12/2012	41.4
Deans Res Inflow	Deans Reservoir	18/01/1996	28/02/2013	80.2
Moor Lal Lal inflow	Lal Lal Reservoir	1/01/1968	30/06/2013	8,511.5
Lal Lal Ck	Lal Lal Reservoir	7/06/1977	30/06/2013	13,170.5
Woolen Ck	Lal Lal Reservoir	7/06/1977	30/06/2013	511.2

The historical data stream flow presented in Table 4.3 has been extended to cover a longer period using a calibrated hydrological model (SimHyd), information about the characteristics of catchments and long climate records as inputs. An overview of the waterways and catchment nodes representing the waterways used in the Systems Framework is provided in Figure 4.10.

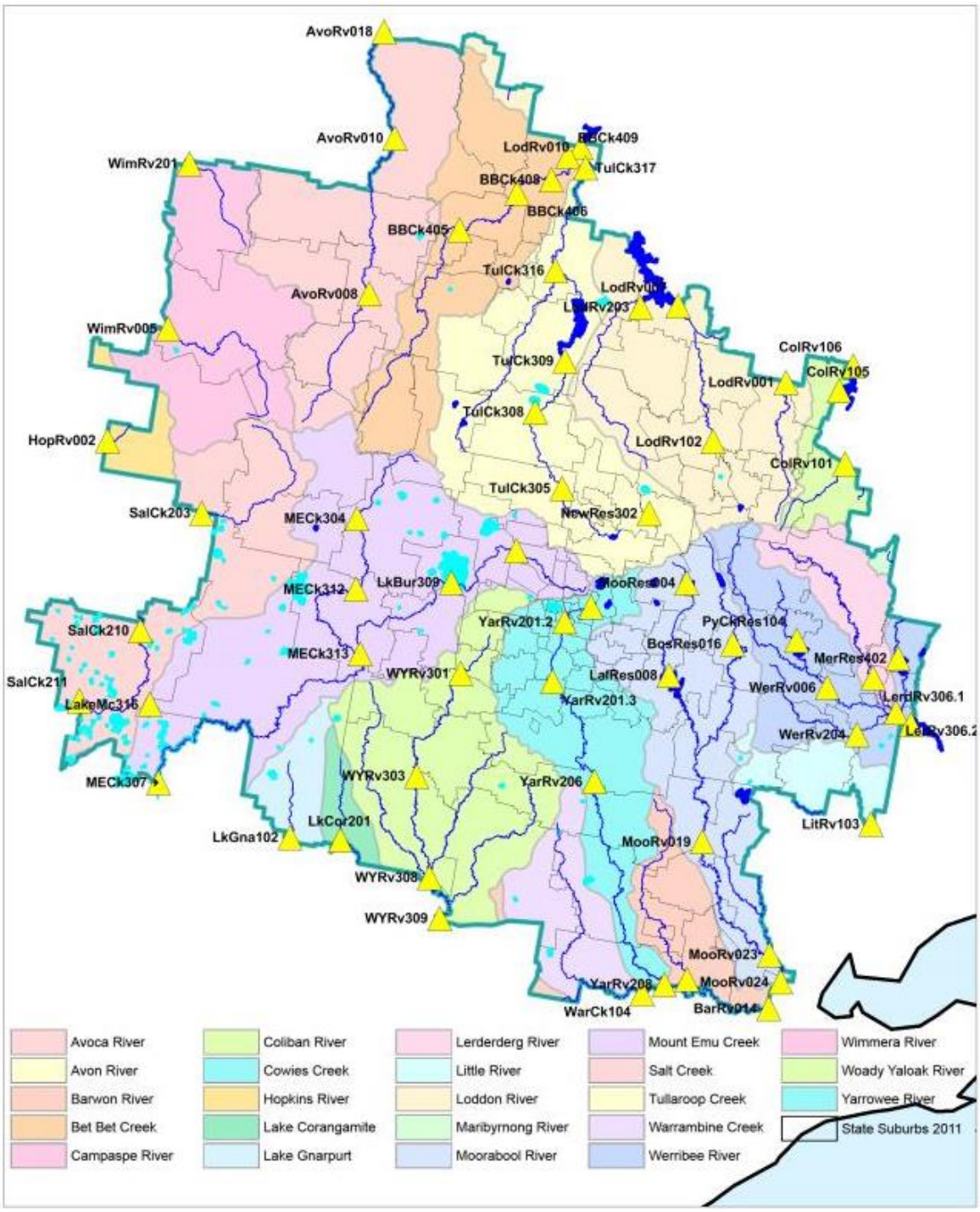

Figure 4.10: An overview of the waterways and catchment nodes

Figure 4.10 shows the waterways, catchment areas contributing to the water supply reservoirs and representation of the waterways as nodes in the Systems Framework. A detailed view of the representation in the Systems Framework of the Yarrowee River catchments with contributing suburbs or zones is provided in Figure 4.11. Note that the Yarrowee Catchment includes extractions of water to supply the Ballarat District (upstream of node YarRv201.1) and the impacts of urban development.

Figure 4.11: An overview of the Yarrowee River with contributing zones as represented in the Systems Framework

Clarkes, Fellmongers and Giles creeks merge into Yarrowee River upstream of the Western Highway (location YarRv201.1 in Figure 4.11) prior to flowing through the Ballarat CBD. It is noteworthy that 67% of the catchments upstream of the Western Highway discharge to these storages and the operation of these storages may impact on the flood risks in the Ballarat CBD. The upper reaches of the Yarrowee Catchment includes White Swan, Gong Gong, Pincotts and Kirks Reservoirs, and Clarkes Weir.

The details of reservoirs, catchments and inflows to reservoirs in the upper Yarrowee River systems are shown in Figure 4.11 and Table 4.4.

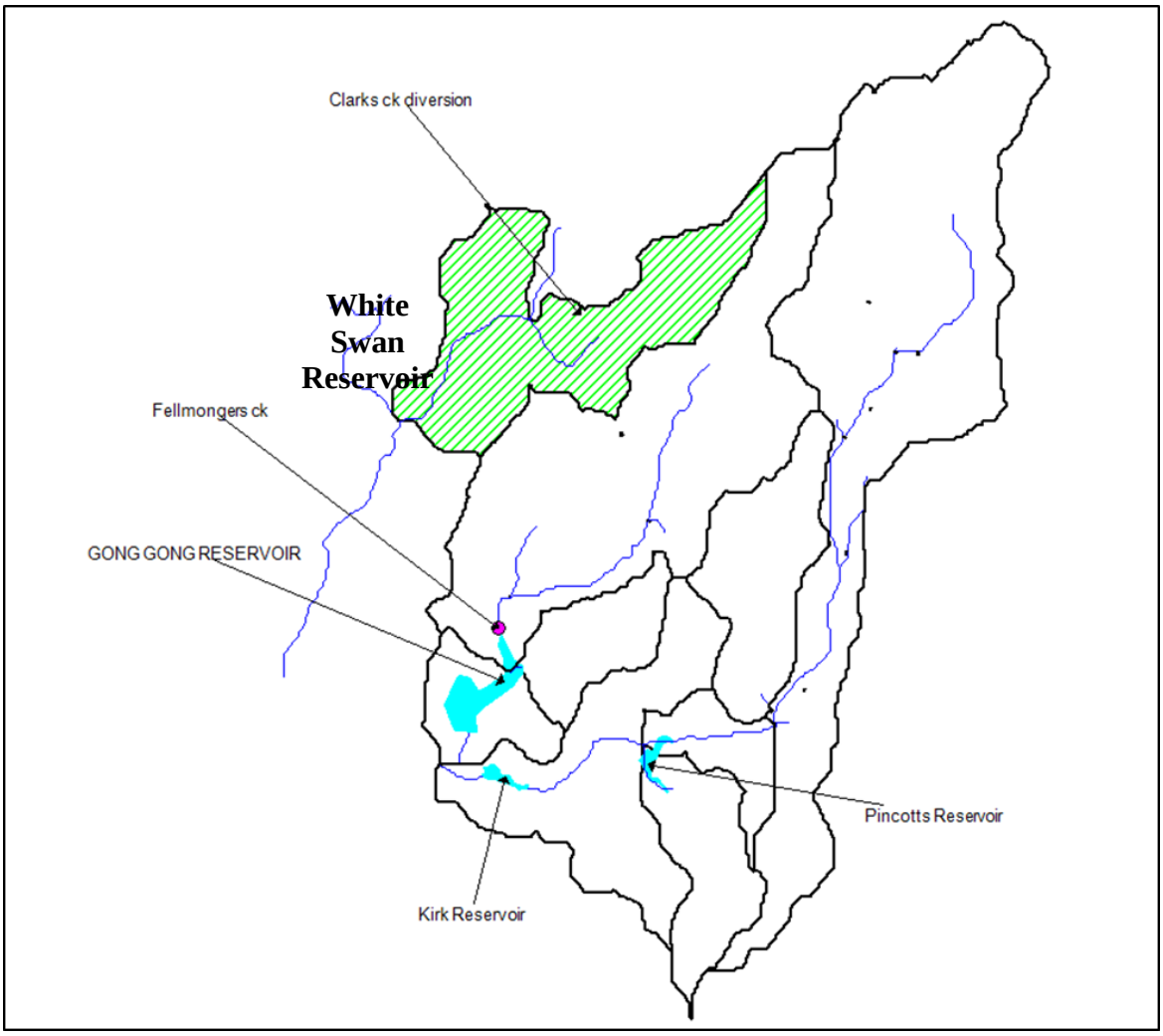

Figure 4.11: Upper Yarrowee River water supply catchments

Table 4.4: Reservoir, catchment area and inflow statistics

Waterway	Reservoir or weir	Reservoir volume (ML)	Catchment area (km^2)	Average annual inflow (ML/year)
-	White Swan	14,107	-	-
Giles Creek	Kirks	400	11.02	1,351
-	Pincotts	218	9.55	-
Fellmongers Creek	Gong Gong	1,902	15.98	722
Clarkes Creek	Clarkes Weir	-	11.17	755

The stream flows to reservoirs and rainfall in the upper Yarrowee River Catchments are shown in Figure 4.12.

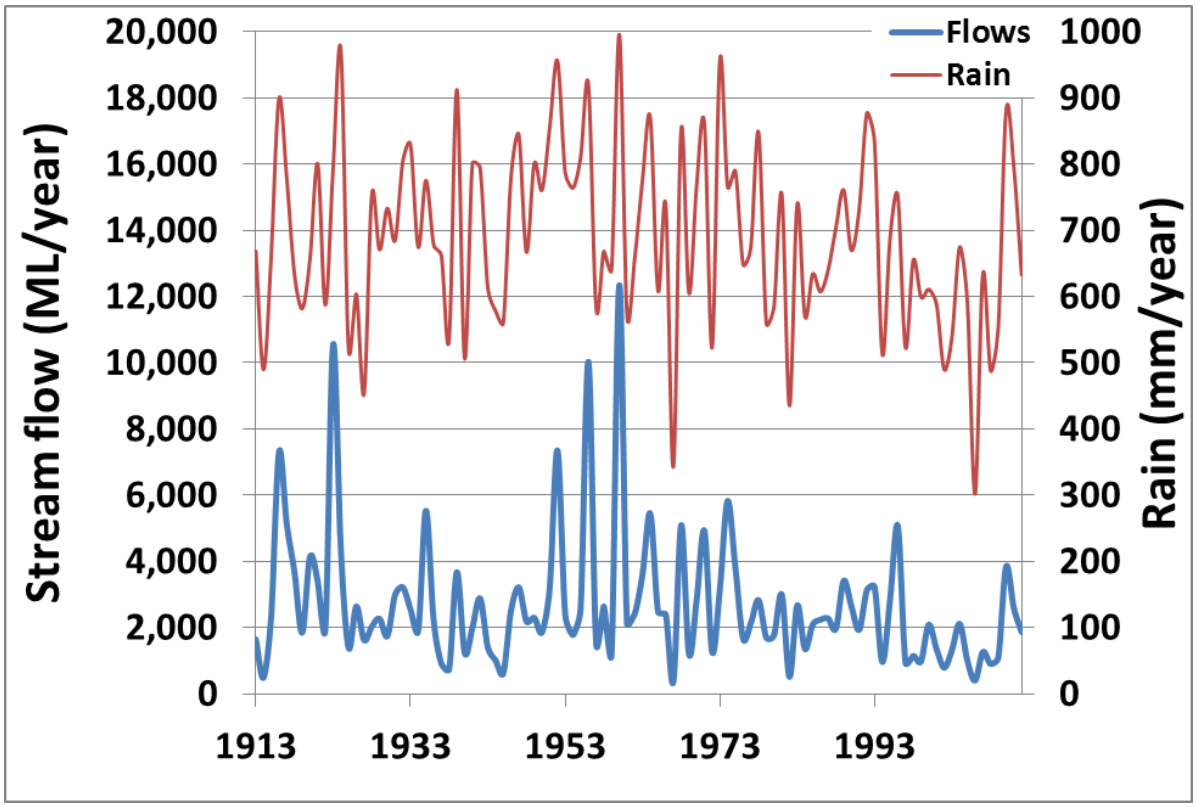

Figure 2.13: Stream flow into water supply systems

The water demands, and environmental releases or spills from reservoirs in the upper Yarrowee catchment into the lower catchment are presented in Table 4.5. Note that 67% of the upper catchment flows into reservoirs and weirs which presents an opportunity for additional stormwater management upstream for the City of Ballarat.

Table 4.5: Upper Yarrowee water balance

System	Water demand (ML/year)	Environmental flow/spills (ML/year)
Clarkes	431	334 Environmental releases and spills
Gong Gong and Kirks	1,064	1,009 Environmental releases and spills

The average annual water balance of flows in the Yarrowee River to the Boundary of the City of Ballarat (YarRv201.3) is provided in Figure 4.13. Note that this water balance includes extractions for water supply in the upper catchment, urban stormwater runoff from hard surfaces, stormwater harvesting and wastewater discharges from Ballarat South Wastewater treatment plant.

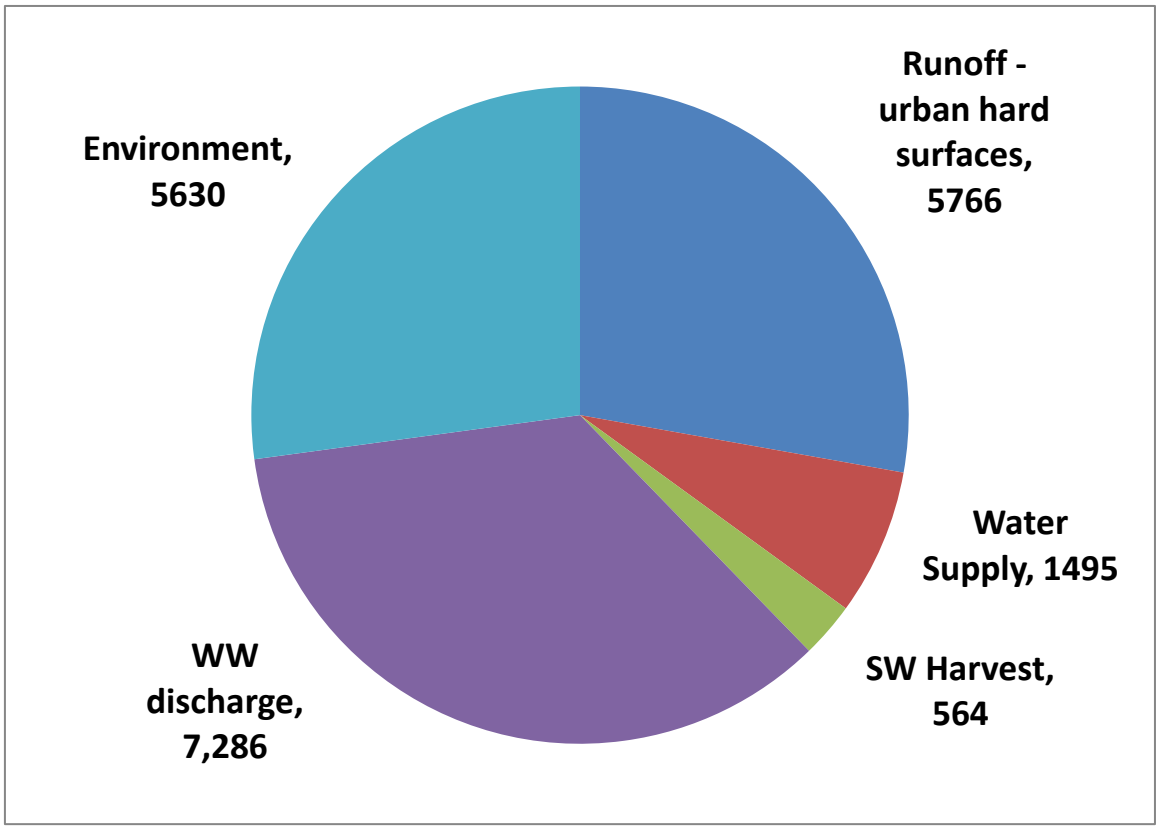

Figure 4.13: Water balance in the Yarrowee River at City of Ballarat boundary (circa 2012)

The West Moorabool River and Lal Lal catchments are adjacent to the upper Yarrowee Catchments. Devisl Creek and upper Moorabool River flow into the Moorabool Reservoir. The upper reaches of the Moorabool River Catchment also includes Whisky and Lal Lal Creeks. The upper catchment includes Moorabool, Wilson and Beales Reservoirs, and Whisky Weir. These storages ultimately overflow to the West Moorabool River and Lal Lal Reservoir in the lower catchment. A diagram of the Moorabool catchments is shown in Figure 4.14.

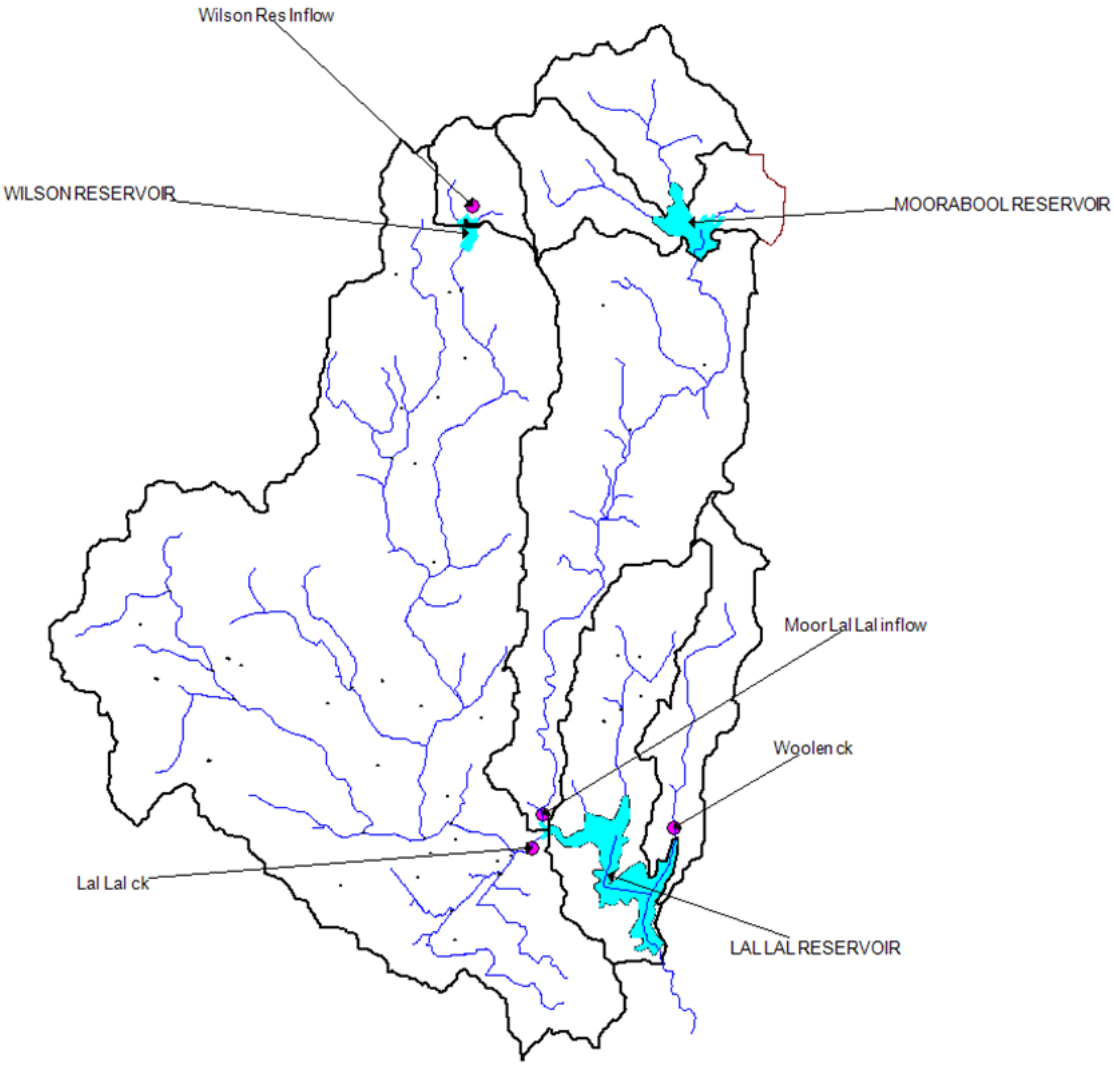

Figure 4.14: West Moorabool River Catchment

The details of reservoirs, catchments and inflows to reservoirs in the upper Yarrowee River systems are shown in Table 4.6.

Table 4.6: Reservoir, catchment area and inflow statistics

Waterway	**Reservoir or weir**	**Reservoir volume (ML)**	**Catchment area (km^2)**	**Average annual inflow (ML/year)**
Upper West Moorabool River	Moorabool Reservoir	6,732	30.26	3,392
Whisky Creek	Whisky weir	-	3.64	487
Upper Lal Lal Creek	Wilson Reservoir	1,103	8.41	767
Upper Lal Lal Creek	Beales Reservoir	415	6.81	621
Lower West Moorabool River	Lal Lal Reservoir	59,549	229.77	33,556

The stream flows to reservoirs and rainfall in the upper West Moorabool River Catchments are shown in Figure 4.15.

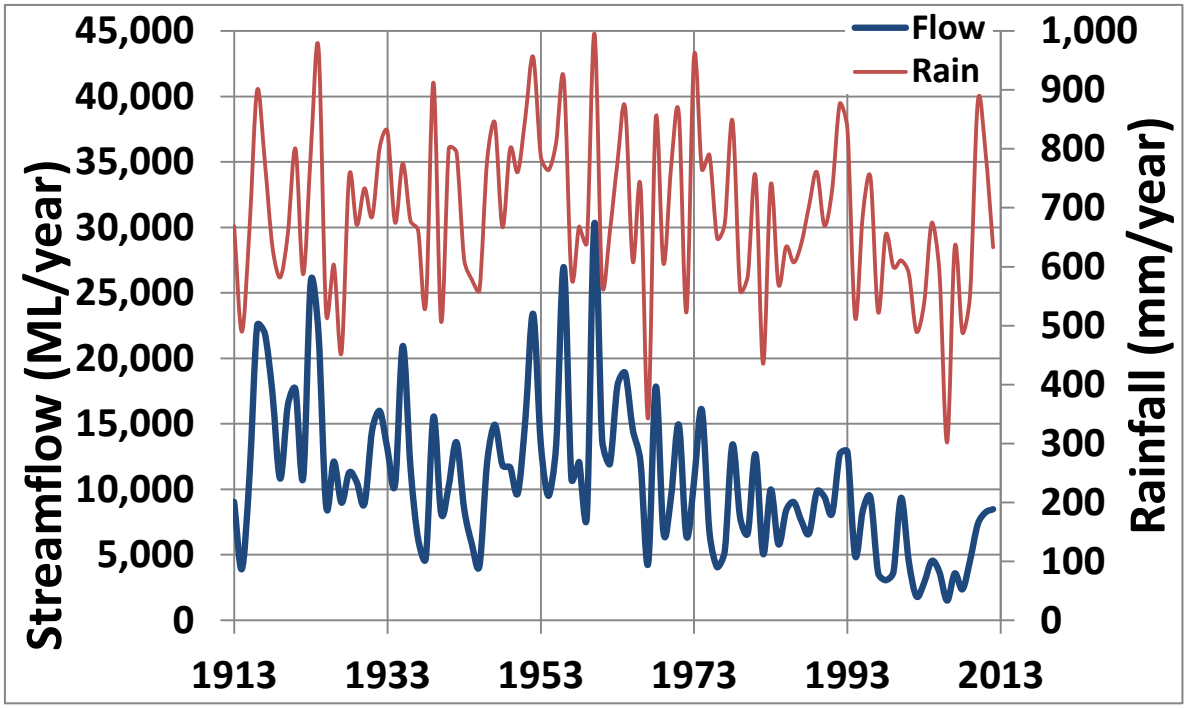

Figure 4.15: Stream flow into the Upper West Moorabool River water supply systems

The stream flows to reservoirs and rainfall in the Lower West Moorabool River Catchments are shown in Figure 4.15.

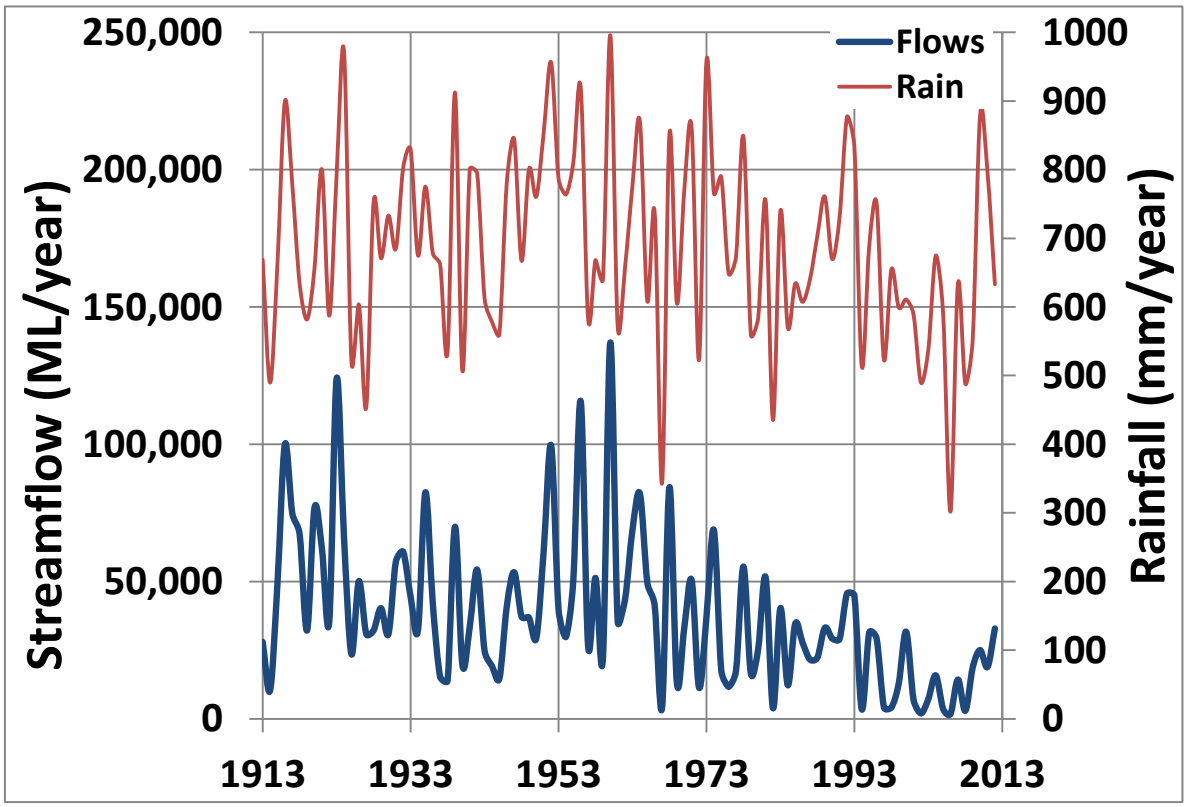

Figure 4.16: Stream flow into the Lower West Moorabool River water supply systems

The water balances in the upper and lower Moorabool River are provided in Table 4.7.

Table 4.7: Water balance

System	Water supply (ML/year)	Environmental flows/spills (ML/year)
Upper West Moorabool	3,710	470 bypass flows 230 irrigators 2 domestic and stock 814 evaporation
Lower West Moorabool	9,930	2,287 bypass flows 2,381 Barwon Water 284 environmental release 763 irrigators 9 domestic and stock 2,093 Evaporation

The average annual water balance in the upper and lower Moorabool River systems is shown in Figures 4.17 and 4.18 respectively.

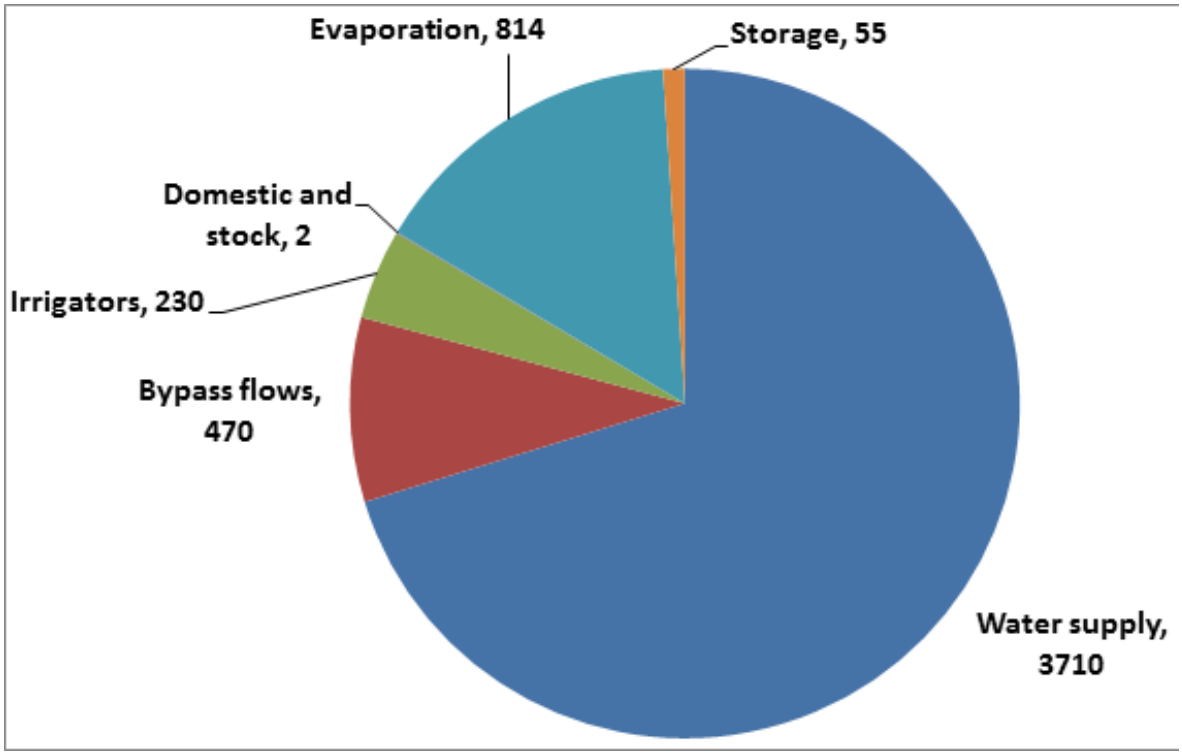

Figure 4.16: Water balance in the upper West Moorabool River (Circa 2012)

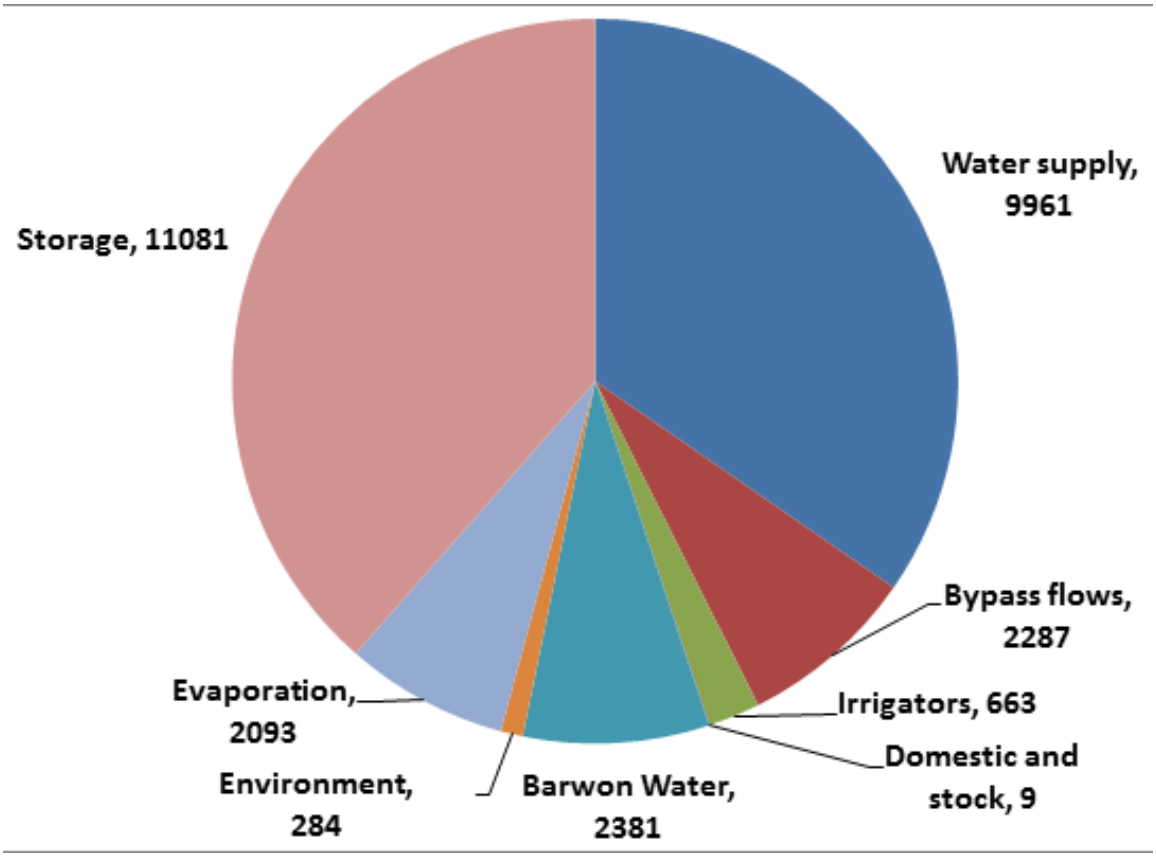

Figure 4.17: Water balance in the lower West Moorabool River (circa 2012)

Stoney Creek flows into Talbot Reservoir and McCallum's Creek flows into Evansford Reservoir. The Talbot and Evansford reservoirs in the upper reach of the McCallums Creek Catchment supplies the Maryborough Water District. The Stoney and McCallum's Creek catchment are shown in Figure 4.18 and summarised in Table 4.8.

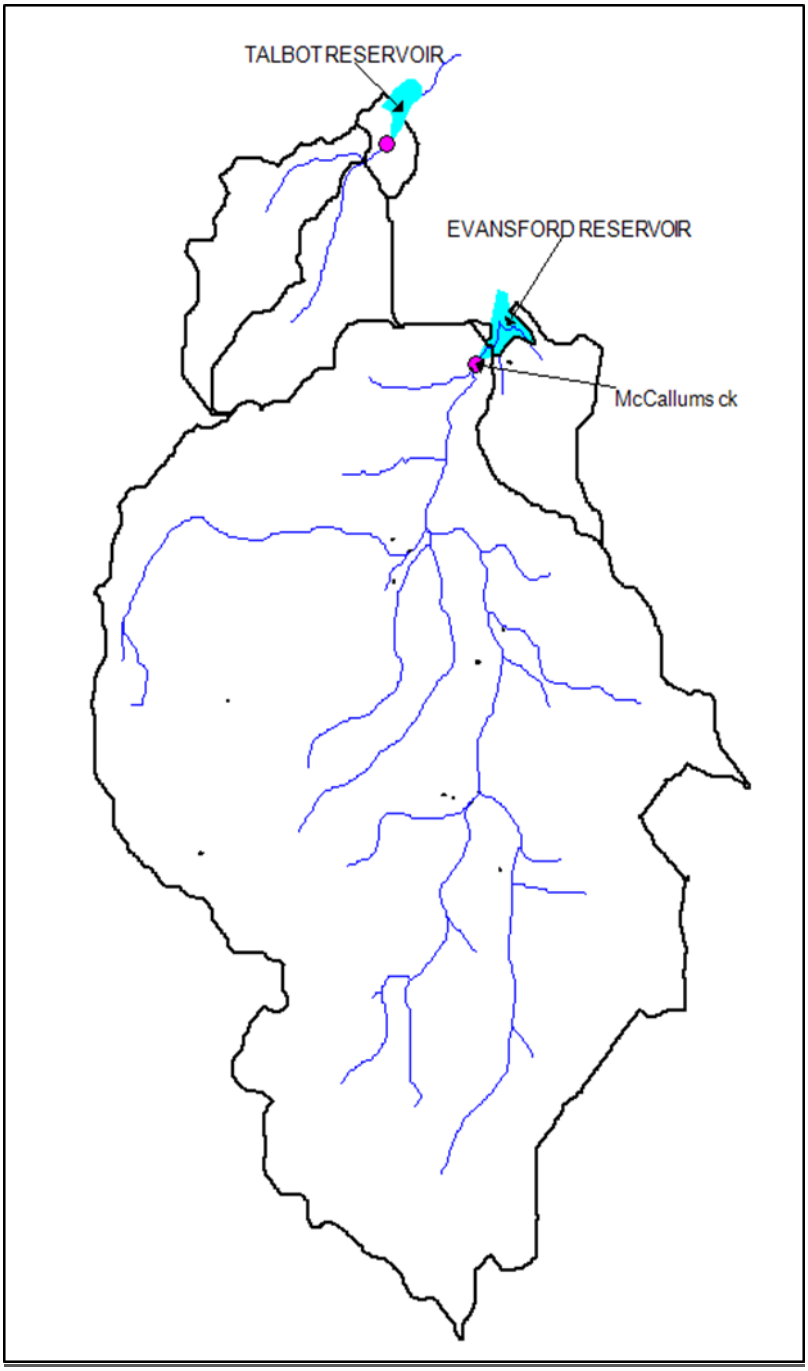

Figure 4.18: Stoney and McCallum's Creek catchments

Table 4.8: Waterway, catchment and reservoir details

Waterway	**Reservoir or weir**	**Reservoir volume (ML)**	**Catchment area (km^2)**	**Average annual inflow (ML/year)**
Stoney Creek	Talbot Reservoir	846	14.74	424
McCallum's Creek	Evansford Reservoir	1,351	172.88	3,650

The extended stream flows into the Talbot and Evansford Reservoirs are shown with rainfall from Maryborough in Figures 4.19 and 4.20 respectively.

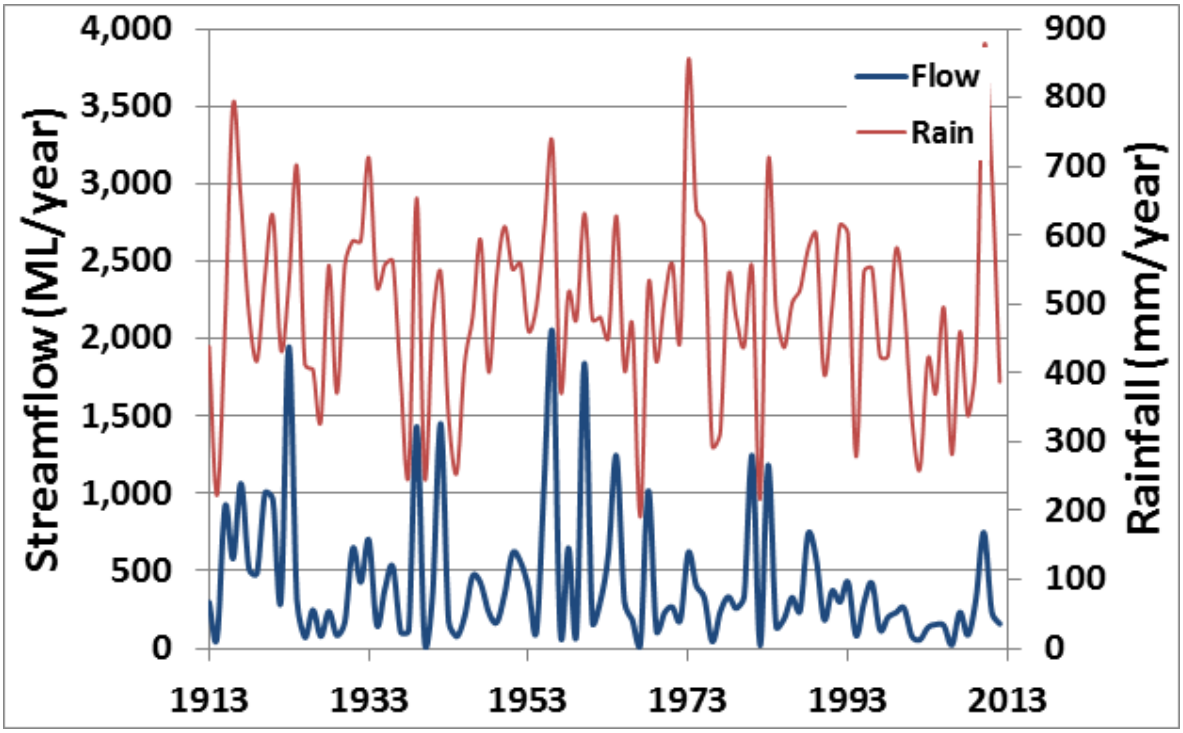

Figure 4.19: Inflows to Talbot Reservoir from Stoney Creek

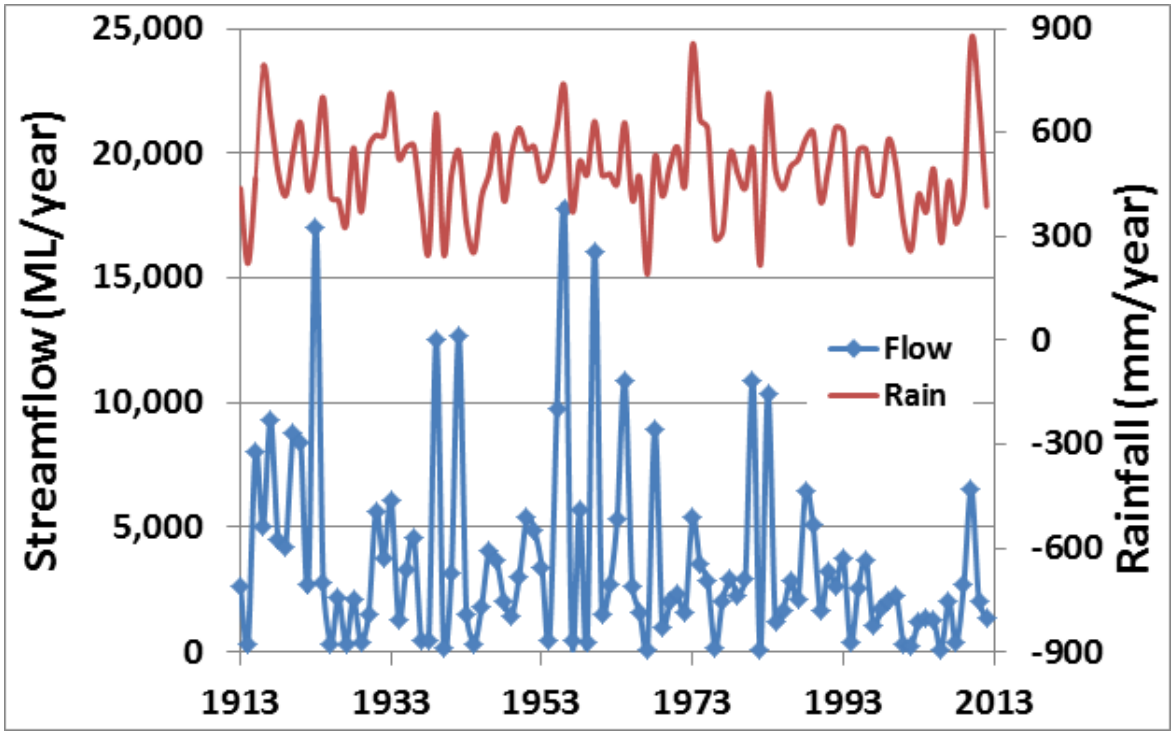

Figure 4.20: Inflows to Evansford Reservoir from McCallum's Creek

The water balances for Stoney and McCallum's Creeks are provided in Table 4.9.

Table 4.9: Water balance (circa 2012)

System	Water supply (ML/year)	Environmental flows/spills (ML/year)
Stoney Creek	216	Evaporation 223 Spill 31
McCallums Creek	356	Evaporation 337 Environmental release 203 Spill 923 Transfer to Talbot Res 173

The water balances for the Stoney and McCallum's Creeks are presented in Figures 4.21 and 4.22 respectively.

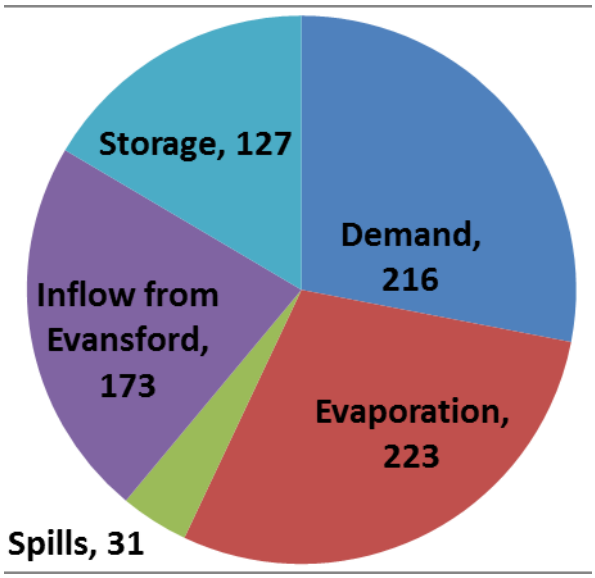

Figure 4.21: water balance in Stoney Creek at Talbot Reservoir (circa 2012)

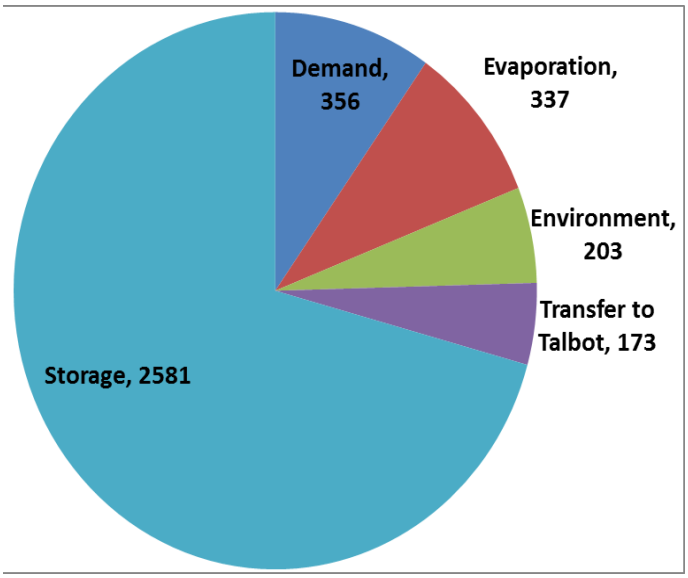

Figure 4.22: water balance in Stoney Creek at Evansford Reservoir (circa 2012)

An overview of the water supply and distribution system utilised in the Systems Framework is provided in Figure 4.23.

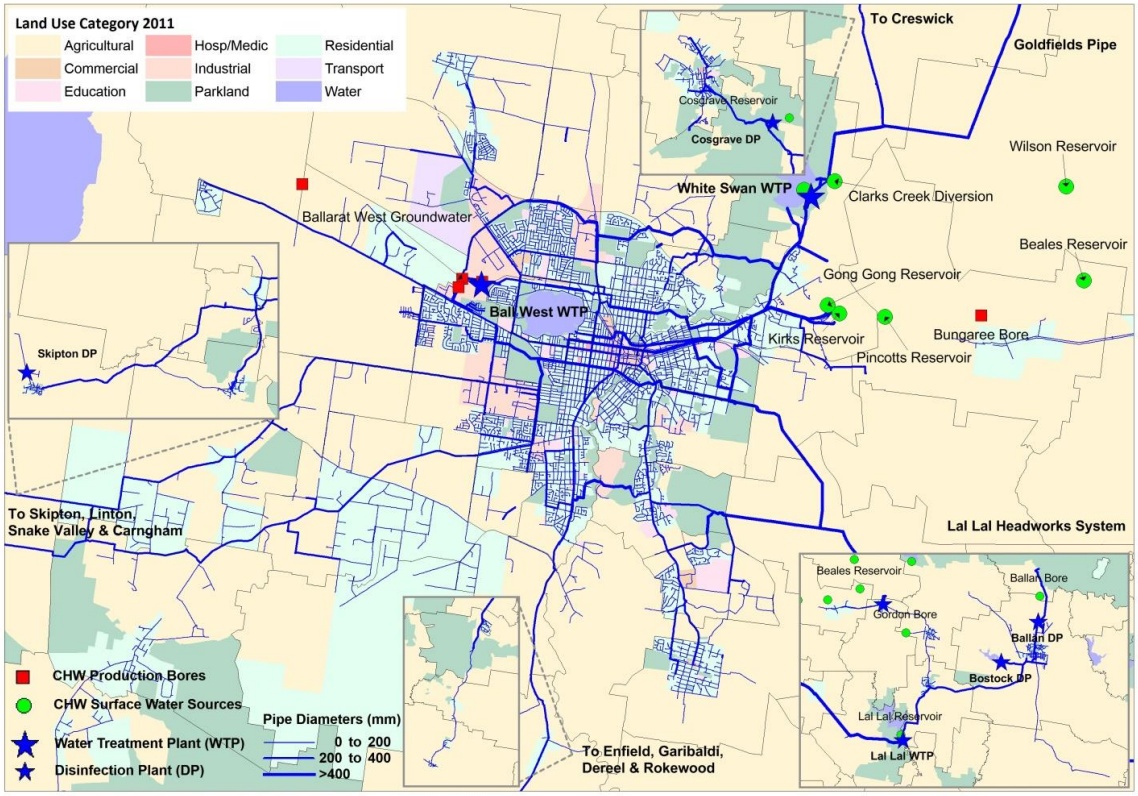

Figure 4.23: An overview of the water supply and distribution system for Ballarat used in the Systems Framework

The characteristics of the wastewater disposal systems for the Ballarat District that were included in the Systems Framework are provided in Figure 4.24.

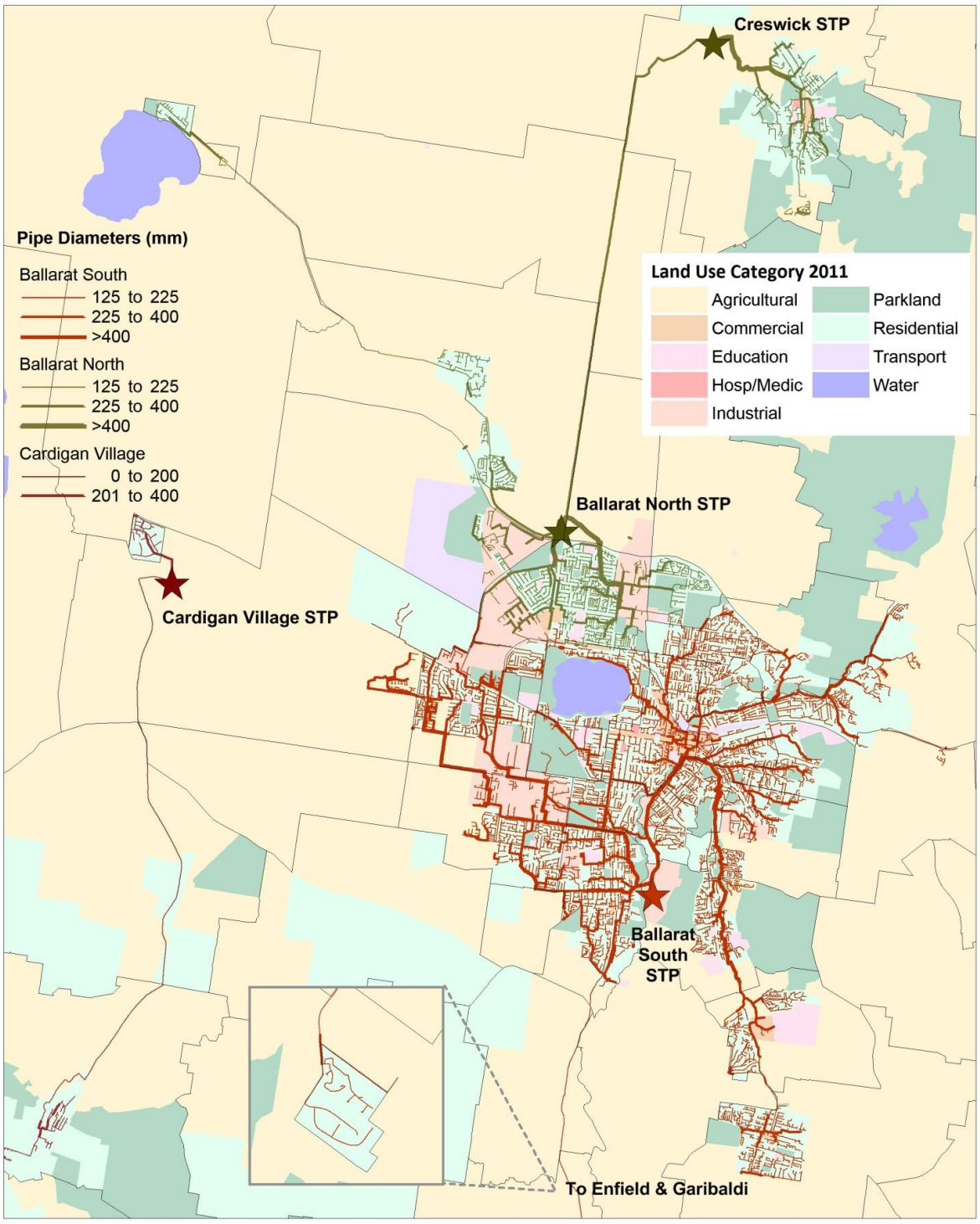

Figure 4.24: Overview of the wastewater system for the Ballarat district used in the Systems Framework

The details of the water supply and distribution system for Maryborough used in the Systems Framework are presented in Figure 4.25.

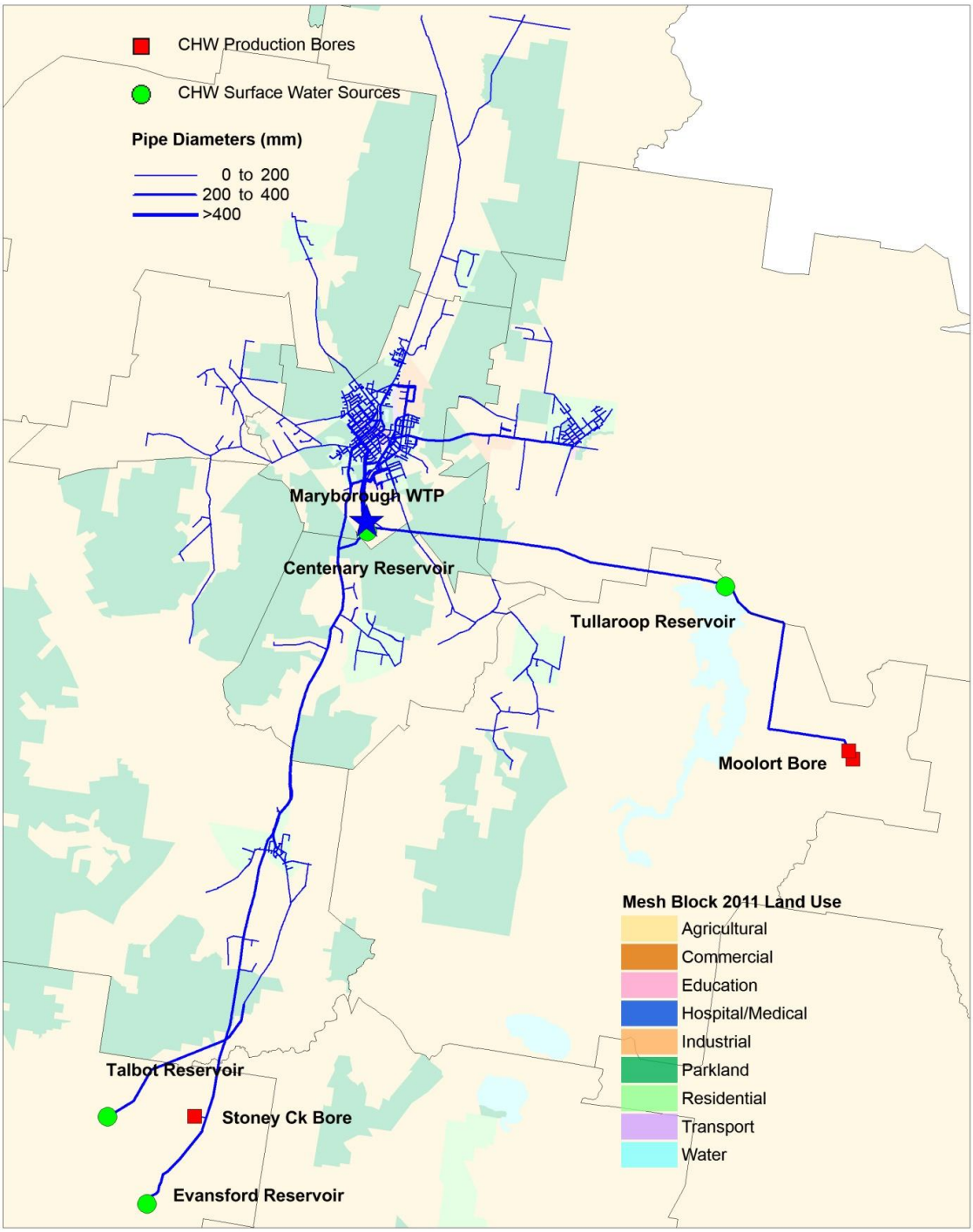

Figure 4.26 Overview of the water supply system for the Maryborough District used in the Systems Framework

An overview of the wastewater system for the Maryborough District is provided in Figure 4.27.

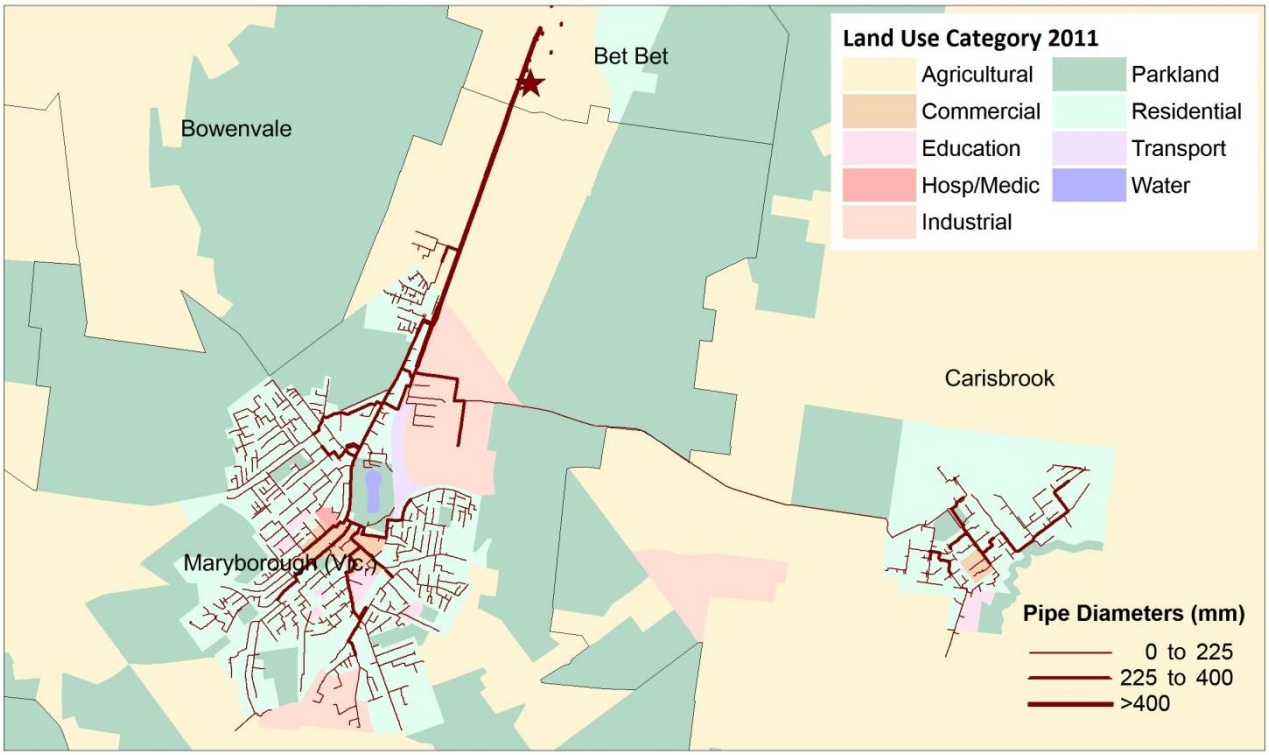

Figure 4.27: Overview of the wastewater system for the Maryborough district used in the Systems Framework

5 Hind Casting, Calibration and Validation

Hind casting is a process of using the Systems Framework to simulate the behaviour of water cycles throughout a period in history where behaviours are known. Daily sequences of water demand, wastewater, stormwater runoff and water flows generated by the Systems Framework are linked to nodes in the networks within the model.

This process utilises historical climate data for inputs to the systems analysis and allows comparison of the results of the analysis to observed water cycle behaviours. A hind casting process also provides a transparent mechanism for interaction with stakeholders around known data, revealing the historical behaviour of systems, validating and agreeing on assumptions, and calibration of models.

The Strategy Development Team for the Living Ballarat project includes staff from Central Highlands Water and City of Ballarat that informed the hind casting process, provided clarification of the local operation of systems and enhanced the data used in the Systems Framework. This ongoing collaborative process that commenced during March 2013 provided regular opportunities for discussion of inputs to and the structure of water cycle systems throughout the region.

A hind casting period from 2000 to 2012 was chosen for the project that best represented the availability of observed data (water use and water levels in reservoirs) to test the efficacy of the systems analysis. An overview of key insights provided by the hind casting process is provided for the Ballarat and Maryborough water districts in this Section.

The System Framework uses sequences of daily water uses as inputs to the network analysis and applies water restrictions that alter water use to create water demands. In addition, the Systems Framework also includes losses of water from infrastructure via leaks and unmetered water use to determine the supply of water to the region.

Ballarat

The water supply system for Ballarat and surrounds provides reticulated water supply to a population of approximately 97,000 people.

Water Demand

The growth projections and calibrated sequences of water use from each land use from each zone were combined in the Systems Framework to produce total water use for the Ballarat water supply district. The total of water use inputs to the Systems Framework for Ballarat are compared to the total observed water use derived from water billing data in Figure 5.1. Note that the water demands derived from water billing data include the impacts of water restrictions.

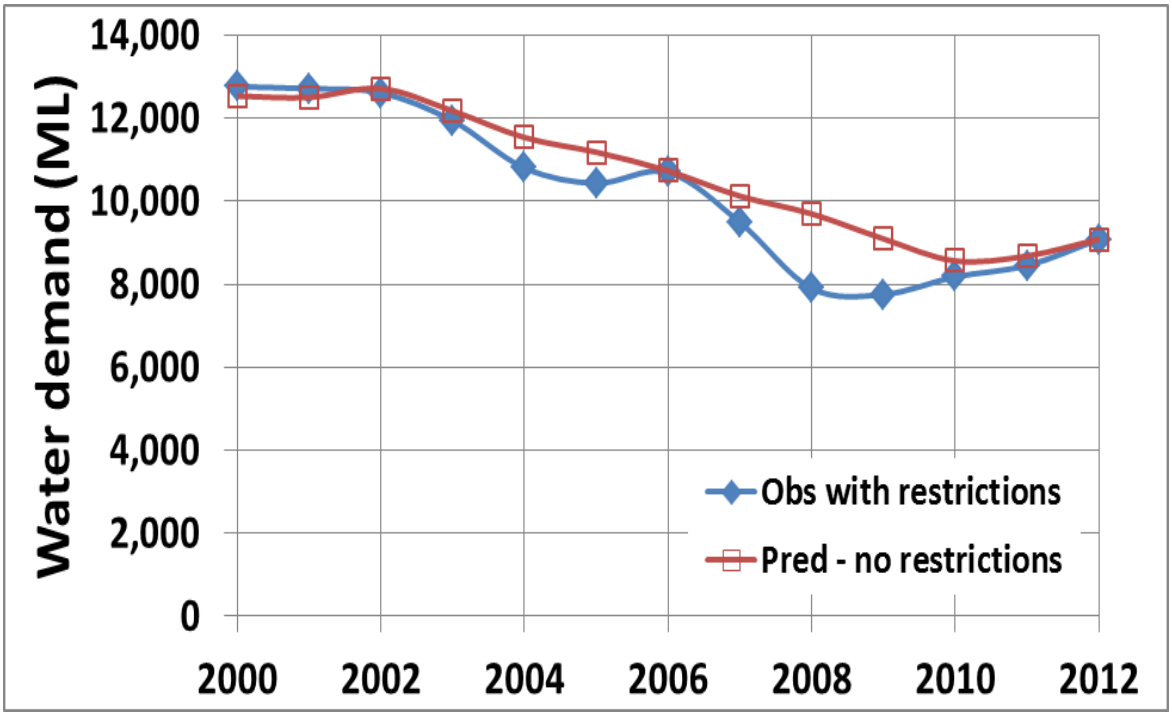

Figure 5.1: Predicted water use versus observed water demands

Figure 5.1 demonstrates that the calibration of the trajectory of water use is consistent with the observed trends for increased water efficiency throughout the Ballarat water district. The calibration results indicate that 6.3% of existing buildings and all new buildings in each year included a higher level of water efficiency between 2002 and 2010. The details of the calibration are:

- Existing buildings:
  - 3.3% of existing buildings/annum include water efficient appliances and practices
  - 1.5% of existing buildings/annum include rainwater harvesting for outdoor uses with water efficient appliances and practices
  - 1.5% of existing buildings/annum include rainwater harvesting for indoor and outdoor uses with water efficient appliances and practices
- New buildings:
  - 70% of new buildings include water efficient appliances and practices
  - 15% of new buildings include rainwater harvesting for outdoor uses with water efficient appliances and practices
  - 15% of new buildings include rainwater harvesting for indoor and outdoor uses with water efficient appliances and practices

This result indicates that over 86% of building stock in the Ballarat water district included water efficiency measures during the last decade to produce a substantial reduction in water use. As a consequence of these actions, the characteristics of water use behaviours throughout the district have changed dramatically over the last decade. Two key insights are derived from this analysis:

1. It is important that efforts to include water efficiency (such as water efficient appliances and practices, rainwater harvesting) in buildings is continued

2. The impact of water efficiency on mitigating population driven increases in water demand will diminish in the future unless additional building scale water efficiency initiatives are implemented.

The calibration of water restriction rules for the water use within the Systems Framework has produced the predicted water demands for the period 2000 to 2012. The predicted and observed water demands are presented in Figure 5.2.

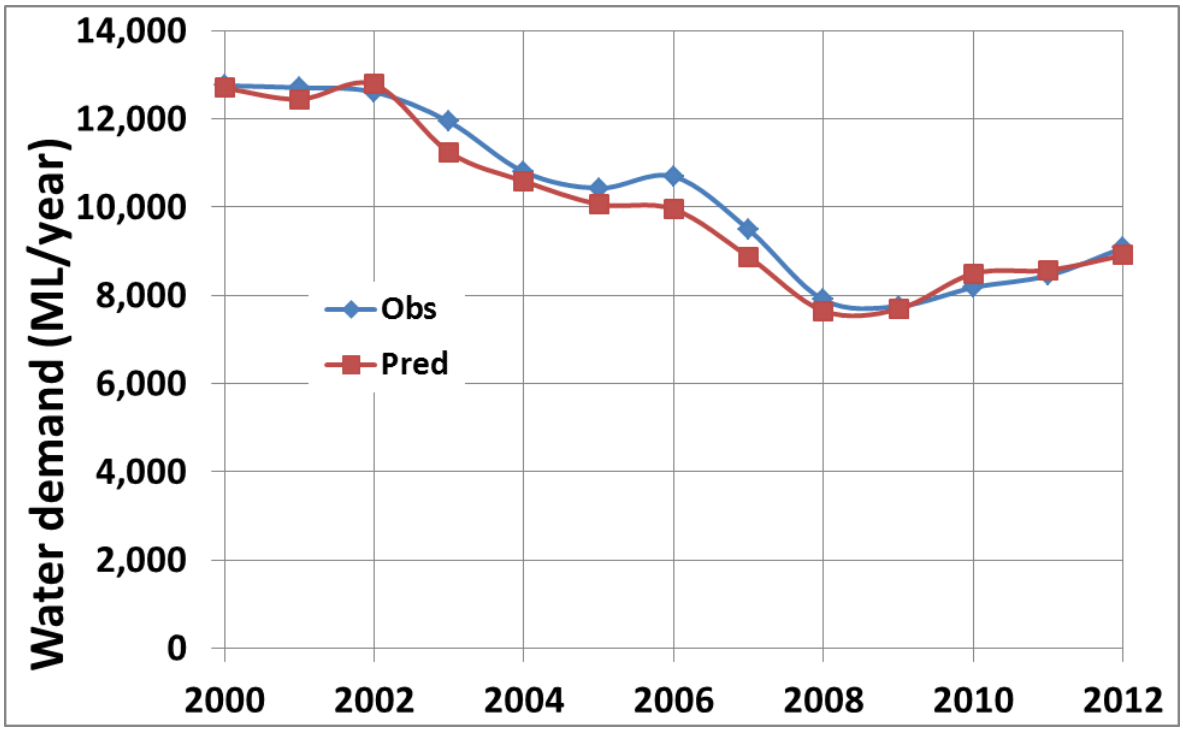

Figure 5.2: Predicted water demands versus observed water demands

Figure 5.2 demonstrates that the Systems Framework has reproduced the trajectory and patterns of water demands for the Ballarat water district. This was achieved by implementing water restriction rules as a function of the combined water storage in the Moorabool, White Swan, Lal lal, Kirks, Gong Gong, Pincotts, Beals and Wilson Reservoirs as shown in Table 5.1.

Table 5.1: Water restriction rules used in the Systems Framework

Stage	**1**		**2**		**3**		**4+**	
Total storage (%)	30	19	19	9	9	6	6	0
Reduction in demand (%)	5		8		10		24	

Table 5.1 shows the calibrated reduction in water demands for given total water storage for each stage of water restrictions. The water restrictions rules presented in Table 5.1 were derived for use in the Systems Framework and the resulting reductions in water use in response to restrictions for the period 2000 to 2012 are presented in Figure 5.3.

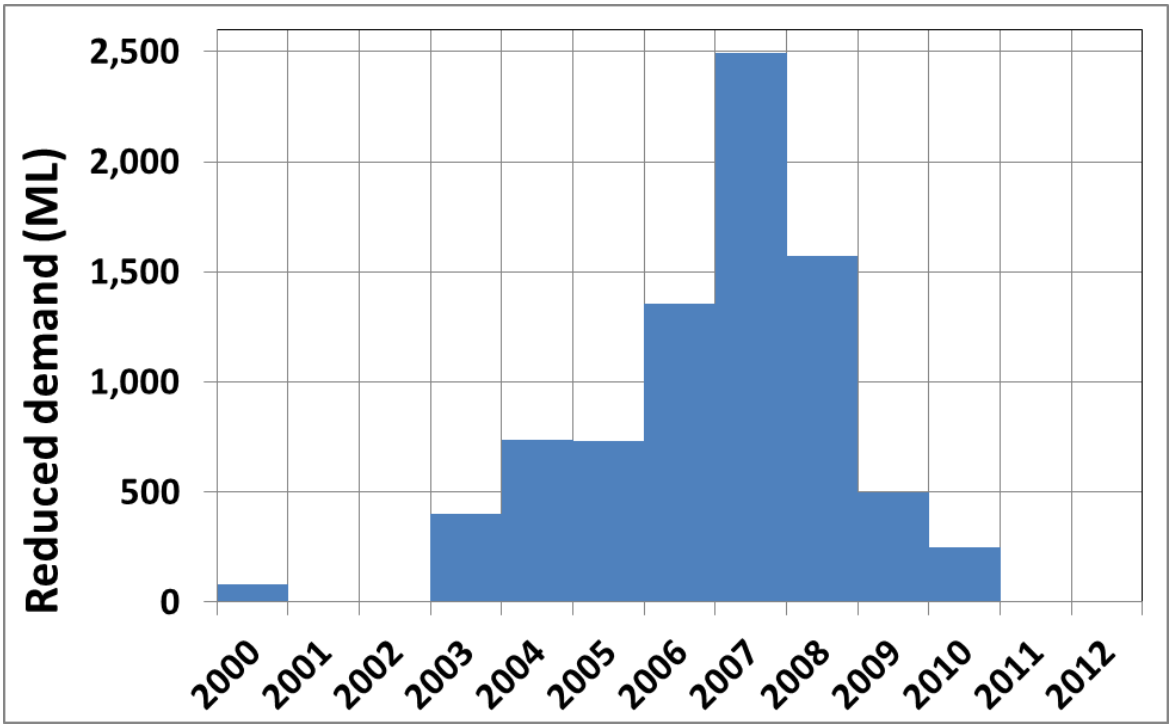

Figure 5.3: Predicted reductions in water demand in response to restrictions for the hind casting period

Figure 5.3 indicates that the predicted levels of water savings were reasonable consistent with the application of water restrictions during the period 2000 to 2012 that commenced with Stage 1 restrictions in 2000 and included greater than level 4 restrictions during the period 2006 to 2009.

It was also necessary to understand the magnitude of losses from the water supply system. The reported annual losses from the Ballarat water supply system have diminished from 2,171 ML in 2006 to 918 ML in 2011.[14] The annual volumes of observed water demands and supply were compared to derive the proportional losses for incorporation in the water distribution system within the Systems Framework as presented in Figure 5.4.

[14] Central Highlands Water (2012). Ballarat and District Water Supply System Strategic Plan 2011 – 2060.

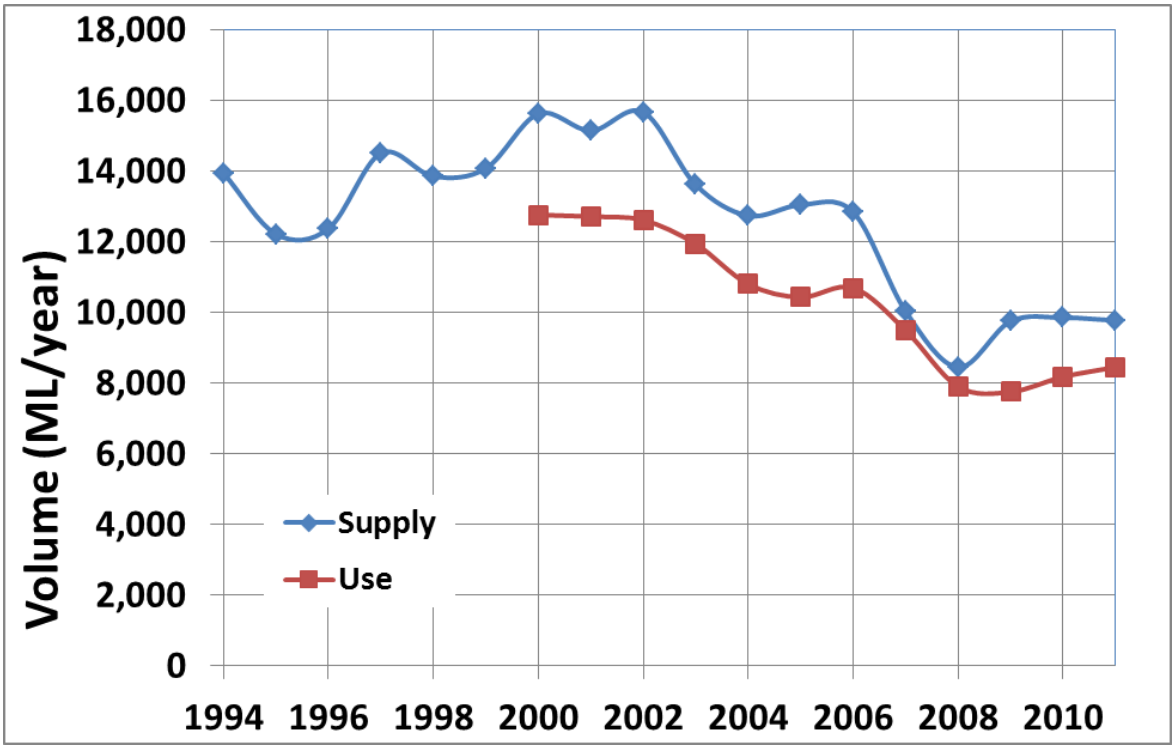

Figure 5.4: Comparison of observed water demands and supply for the Ballarat water district

Figure 5.4 reveals that supply of water to meet demands in the Ballarat water district is subject to water losses or unaccounted for water consumptions ranging from 20% to 5% (average: 15%) during the hind casting period. An average value for water losses or unaccounted for water consumption of 12% of water demand was applied to water infrastructure in the Systems Framework that is consistent with current observations by Central Highlands Water.

The hind casting process revealed a range of actions driven by the recent drought and the unique characteristics of the hydrology of the water supply systems for Ballarat. These actions included:

- Use of ground water from the Ballarat West bore field during the period 2007 to 2010. The hind casting process revealed that this action made a substantial contribution to maintaining the viability of water supply to Ballarat.
- Ongoing changes in the water efficiency of building stock and water use behaviours in the residential and business sectors. This action made a dominant contribution to the viability of water supply to Ballarat.
- Water restrictions also provided substantial reductions in water use that significantly contributed to the viability of water supply to Ballarat.
- Supply of water from the Campaspe and Goulburn Rivers via the "Goldfields Pipe" from early 2008 acted to finally alleviate a critical shortage of water supply to Ballarat.

A majority of the water head works systems consists of water storages or extractions in the upper reaches of river catchments where the characteristics of stream flow is ephemeral. As a consequence, inflows to reservoirs are highly variable and are better described by the daily time step utilised in the System Framework than use of monthly or annual periods of analysis. Water

extractions from the upper reaches of river catchments also generate significant impacts on the health of downstream waterways.

Water Supply

Water supply to the Ballarat water district is predominantly sourced from the Upper West Moorabool and Yarrowee River catchments situated to the east of Ballarat. This system includes three significant storages including Moorabool, Lal Lal and White Swan Reservoirs.

The hind casting process allowed a more detailed review of the operation of the Moorabool Reservoir which captures inflows from Devils Creek and the West Moorabool River, up to 3 ML/day of stream flow bypasses the reservoir as environmental flows and water is extracted via a pipeline (capacity of 12 ML/day) and directed towards White Swan reservoir for water supply.[15] In addition, review of existing regional analysis using REALM with monthly time steps by Central Highlands Water and Department of Environment and Primary Industries (DEPI) allowed inclusion of irrigators in the upper catchment in the Systems Framework.

The daily sequences of water volumes in the Moorabool Reservoir generated by the Systems Framework are compared to observed reservoir volumes in Figure 5.5.

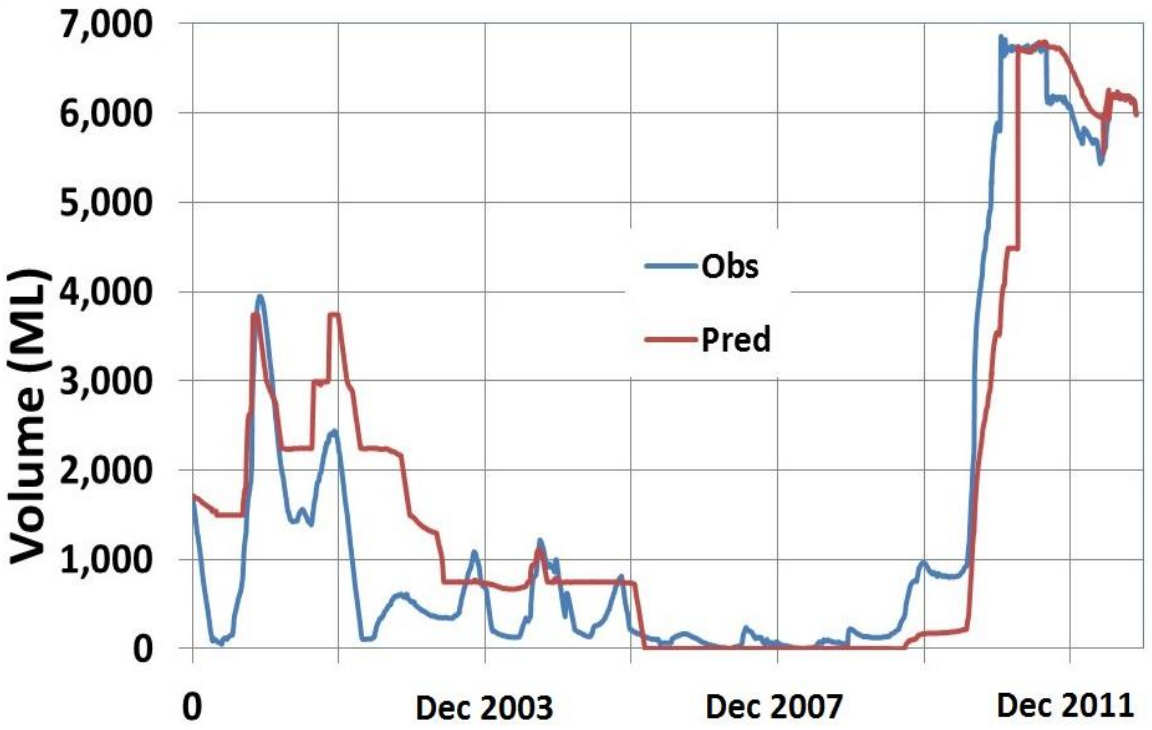

Figure 5.5: Observed and predicted water storage in Moorabool Reservoir

Figure 5.5 demonstrates that the Systems Framework was able to replicate the historical behaviour of the Moorabool Reservoir. This result indicates that complex interaction between stream flows, water demands, water restrictions, evaporation, irrigators and local operating decisions has been reproduced by the systems analysis.

[15] Central Highlands Water (2012). Ballarat and District Water Supply System Strategic Plan 2011 – 2060.

An important insight from the hind casting process was the understanding of the priorities for extraction of water from the Moorabool Reservoir and the small ephemeral streams Whisky, Lal Lal, Giles and Fellmongers Creeks that also contribute to the inflows to White Swan Reservoir. During storm events that generate higher sub-daily stream flows in the small creeks, priority was assigned to extracting water from the Creeks. Alternatively, water supply from Moorabool reservoir is utilised when stream flow is insignificant in the creeks. The daily time step utilised by the Systems Framework allowed understanding of this process of optimisation.

The Lal Lal Reservoir captures inflows from the West Moorabool River, and Black, Woolen and Lal Lal Creeks. Up to 20 ML/day of stream flow bypasses the reservoir as environmental flows and the river system also supplies rural water demands. Water is also released from the reservoir for water supply to the Barwon region and water is extracted to supply the Ballarat water district. The daily sequences of water volumes in Lal Lal Reservoir generated by the Systems Framework are compared to observed reservoir volumes in Figure 5.6.

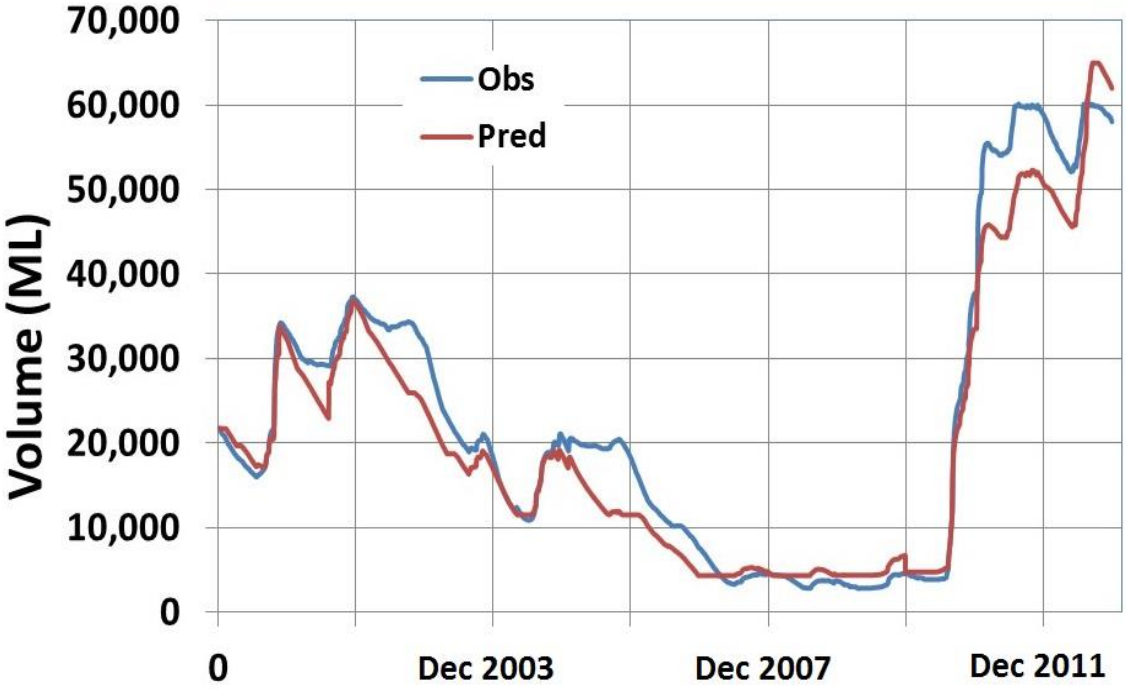

Figure 5.6: Observed and predicted water storage in Lal Lal Reservoir

Figure 5.6 reveals that the Systems Framework was able to replicate the historical behaviour of the Lal Lal Reservoir that indicating that the analysis was able to resolve a wide range of competing demands on the reservoir.

The hind casting process allowed a deeper understanding of the preferential relationship between the Moorabool, Lal Lal and White Swan reservoirs for supply of water to Ballarat. Water supply from White Swan Reservoir is preferred when storage volumes in the reservoir are greater than 50%.

Alternatively, water supply is preferred from Lal Lal reservoir when water storages in White Swan Reservoir are drawn down below 50%. These historical extraction behaviours require optimisation

of the operation of Moorabool Reservoir that partially supplies both White Swan and Lal Lal Reservoirs.

The addition of the Goldfields Pipe and groundwater sources to the supply system has potentially changed the optimisation process to maximising the benefits from the trade-off between the two "back up" bulk water supplies (Lal Lal Reservoir and Goldfields Pipe) as compared to local supply from small streams and ground water.

Whilst this new optimisation paradigm involves parameters across multiple temporal and spatial scales, the more detailed Systems Framework has allowed the capacity to further investigate further.

White Swan reservoir receives inflows from Newlyn, Cosgrove, Moorabool, Kirks, Gong Gong, Beals, Wilson and Pincotts reservoirs, and from Clarkes Creek and the Goldfields Pipe to supply water to the Ballarat district. This reservoir acts as a balancing storage for a range of water sources and dependent on operating decisions from all of these sources.

The daily sequences of water volumes in White Swan Reservoir generated by the Systems Framework are compared to the observed reservoir volumes in Figure 5.7.

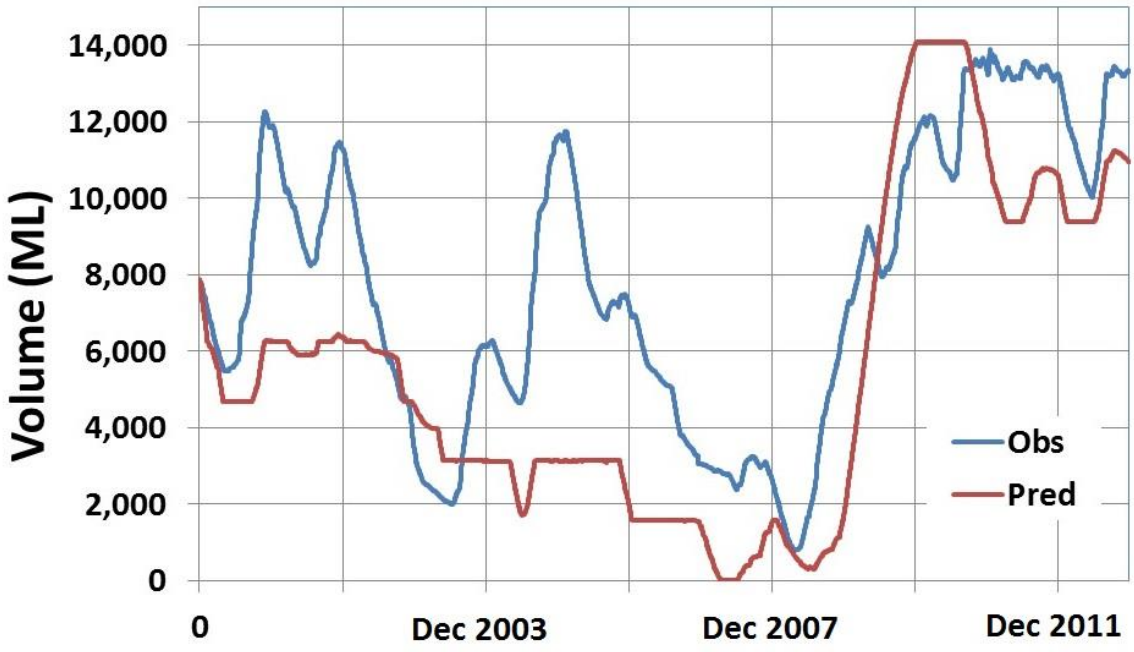

Figure 5.7: Observed and predicted water storage in White Swan Reservoir

Figure 5.7 reveals that the major patterns of changes in water volumes in White Swan reservoir has been reproduced by the Systems Framework. The pattern of refilling the reservoir early in the historical sequence was not fully replicated. However the low storage levels during the worst period of the drought and refilling of the reservoir due to the Goldfields Pipe in 2008 and from higher rainfalls has been reproduced.

The difference between the observed and predicted storage volumes in White Swan reservoir represents optimisation of water supply between Lal Lal and White Swan reservoirs – this

relationship is highly sensitive to assumptions around operating decisions and does not significantly change the water security of the water supply system as demonstrated by the similar collective volumes of stored water in the key reservoirs.

For example, establishing White Swan reservoir as higher priority storage for filling than Lal Lal reservoir in the Systems Framework results in a full reservoir from 2000 to 2005 and from 2010 – 2012 with low storage volumes during the peak of the drought (similar to Figure 5.6). However, this action diminishes the water storage in the Moorabool and Lal Lal reservoirs. In any event, the hind casting process has revealed that the response of the Ballarat water supply system is high sensitive to operating decisions. As a consequence there is substantial opportunity to further explore optimisation of water cycle operations using the additional spatial and temporal detail provided by the Systems Framework.

Construction of the Goldfields Pipe and commencement of operation during 2008 has allowed Central Highlands Water to access high security bulk water sources from the Goulburn River Basin via Warranga Basin and West Warranga irrigation channel. Similarly, the operation of the Goldfields Pipe has allowed access to low security bulk water sources from the Campaspe River Basin via Lake Eppalock.

Lake Eppalock also provides water to irrigators, and the Bendigo and Heathcote urban areas. The lake receives inflows from the Campaspe and Coliban Rivers, and Wild Duck and Mount Ida Creeks. Review of existing regional analysis using REALM provided by Department of Environment and Primary Industries (DEPI) allowed inclusion of irrigators dependent on the Campaspe and Goulburn River catchments. This information was supplemented by data from Goulburn Murray Water and Coliban Water.

The Campaspe River system is also subject to environmental flow requirements. The daily sequences of water volumes in Lake Eppalock generated by the Systems Framework are compared to observed storage volumes in Figure 5.8.

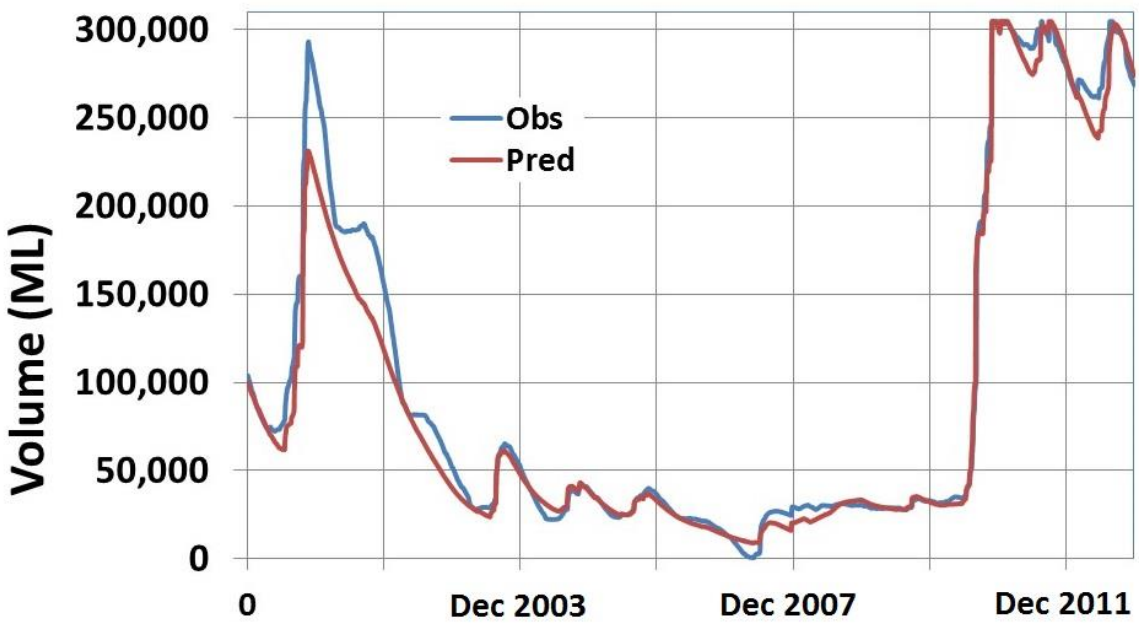

Figure 5.8: Observed and predicted water storage in Lake Eppalock

Figure 5.8 demonstrates that the Systems Framework was able to reproduce the behaviour of water storage in Lake Eppalock and the characteristics of the water systems dependent on the Lake. It is noteworthy that there were low levels of water storage in Lake Eppalock throughout the recent drought. The monthly sequences of predicted water volumes in Warranga Basin are compared to the observed storage volumes in Figure 5.9.

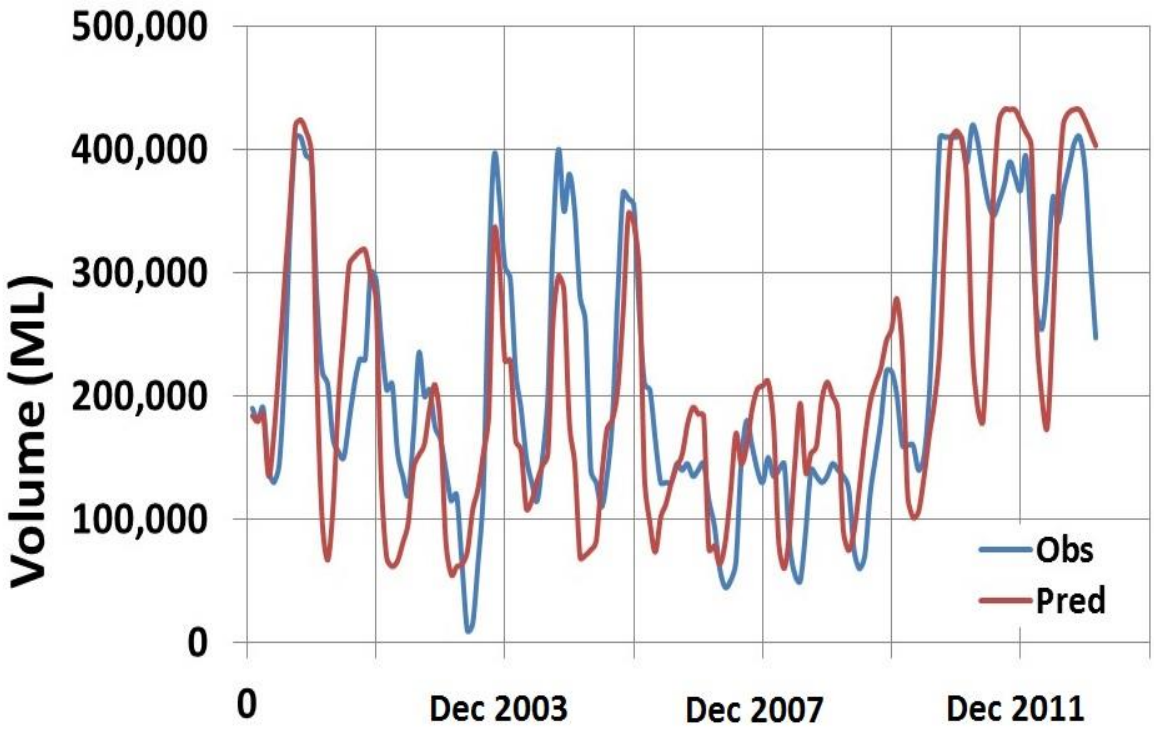

Figure 5.9: Observed and predicted water storage in Warranga Basin

Figure 5.9 shows that the Systems Framework was able to replicate the behaviour of the Warranga Basin and the dependent water systems. Similar to Lake Eppalock, the water storages in the Warranga Basin were substantially drawn down during the recent drought.

The substantial variation in water storages volumes in Warranga Basin is a consequence of the large and variable water demands supplied via the basin for irrigation districts and urban areas. Both Lake Eppalock and the Warranga Basin are also subject to high rates of evaporation. The Systems Framework successfully reproduced both low and high frequency dynamics of water storages across the region.

Examination of the behaviour of both storages during the recent drought indicates that water may not be consistently available from these storages to supplement water security in other regions. In any event, the ability of the Systems Framework to replicate the behaviour of these regional systems will allow robust exploration of the impacts of policies and strategies for future management of the regional water cycle.

Water Balance

The annual volumes of water demands, urban stormwater runoff and wastewater discharges to the Ballarat north and south wastewater treatment plants are presented in Figure 5.10 as a timeline of an "urban water balance" for the Ballarat district.

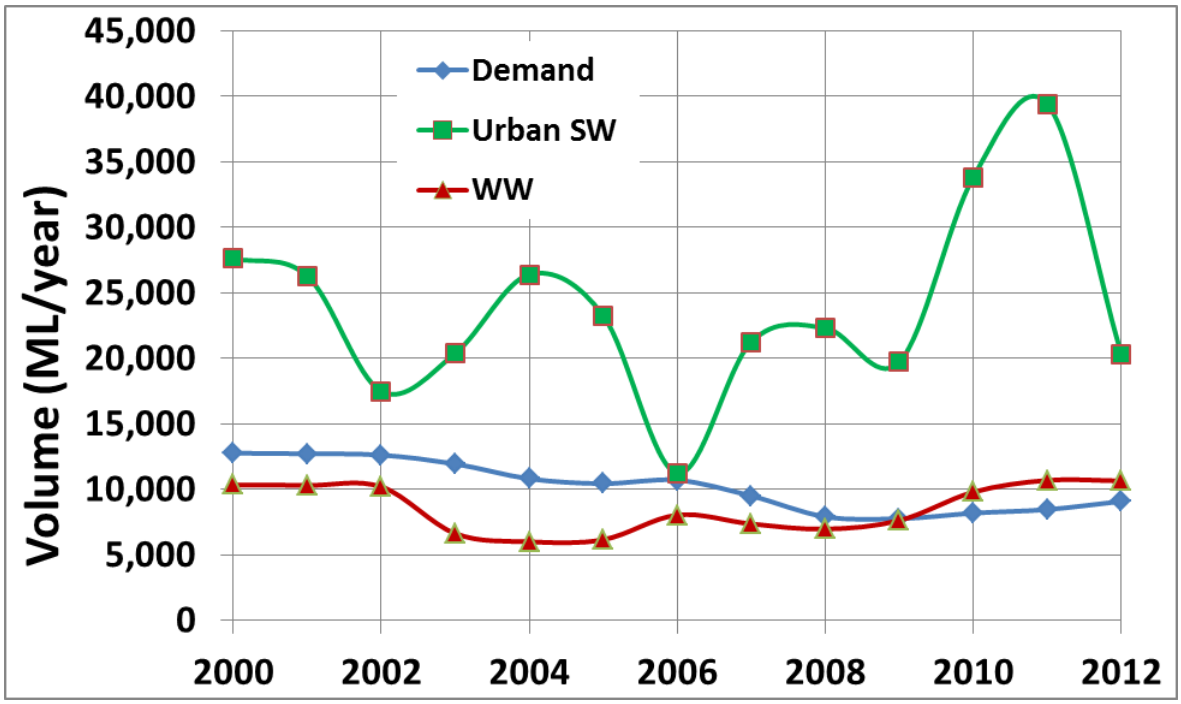

Figure 5.10: The "urban water balance" from the Ballarat district for the period 2000 to 2012

Figure 5.10 reveals that the urban areas within the Ballarat water district (including connected rural towns) generated substantially greater volumes of stormwater runoff than water demands for all years except 2006. During 2006, the Ballarat district experienced the lowest annual rainfall on record. Nevertheless, the volume of urban stormwater runoff during 2006 was similar to total water demands.

Note that urban stormwater runoff presented in Figure 5.10 was generated by surfaces in urban developments including road reserves, and residential, commercial, industrial, education, institution and public open space land uses.

The volumes of wastewater discharged to wastewater treatment plants was also simular to water demands throughout the 2000 to 2012 period. A combination of urban stormwater runoff and wastewater discharges to treatment plants provides volumes of local water that are a minimum of double the magnitude of water demands throughout the hind casting period and throughout the recent drought.

The Ballarat district generates more local water resources than water demands within the district which provides outstanding opportunities for the district to decrease reliance on water extractions from outside of the district.

A range of wastewater reuse and stormwater harvesting strategies were implemented in the Ballarat water district during the recent drought. These strategies included:

- Reuse of class A standard treated wastewater from Ballarat North treatment plant to top up Lake Wendouree and to supply irrigation demands for the Botanical Gardens and sporting precincts.
- Diversion of stormwater from Brown Hill to top up Lake Wendouree
- Diversion of stormwater from Pauls Wetland to Lake Wendouree and for irrigation
- Diversion from the Redan Wetland to Lake Wendouree
- Diversion from the Wendouree West detention basin to Lake Wendouree
- Diversion from Coghills Creek via Morton's cutting to Lake Learmonth

The locations of these projects are presented in Figure 5.11.

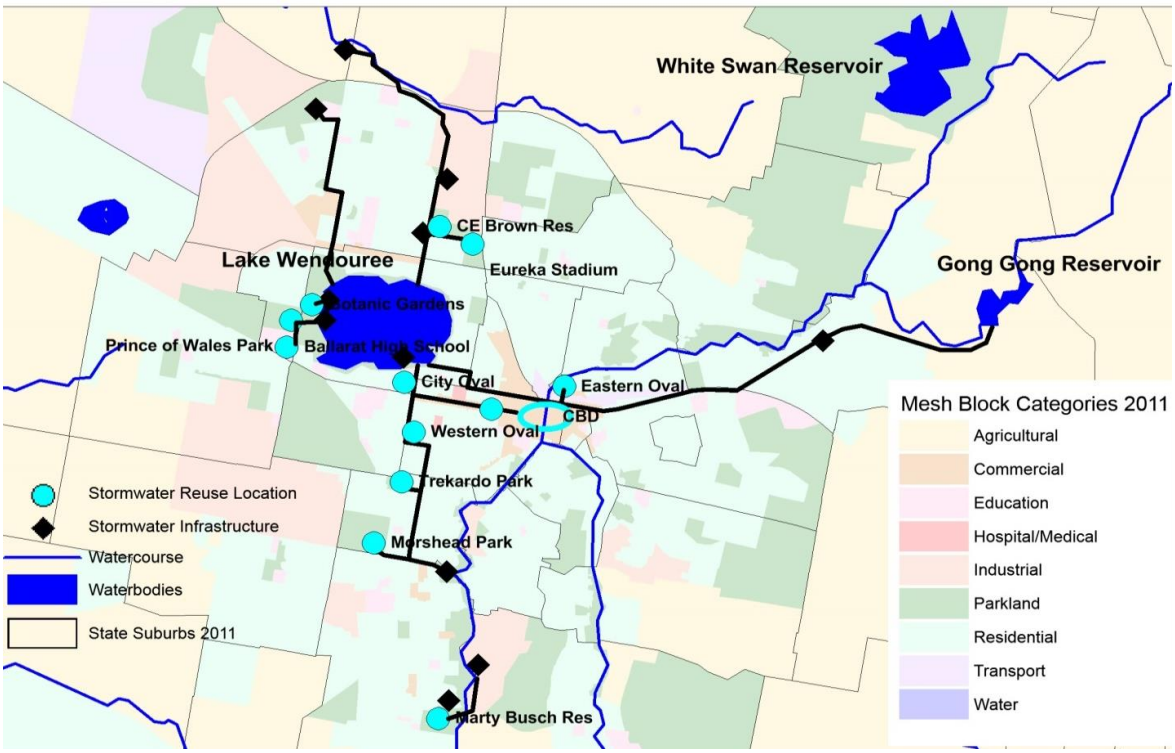

Figure 5.11: Location of various stormwater harvesting and wastewater reuse projects

The simulated impact of wastewater reuse, use of ground water from the Ballarat West bore field and stormwater harvesting on water volumes in Lake Wendouree is provided in Figure 5.12.

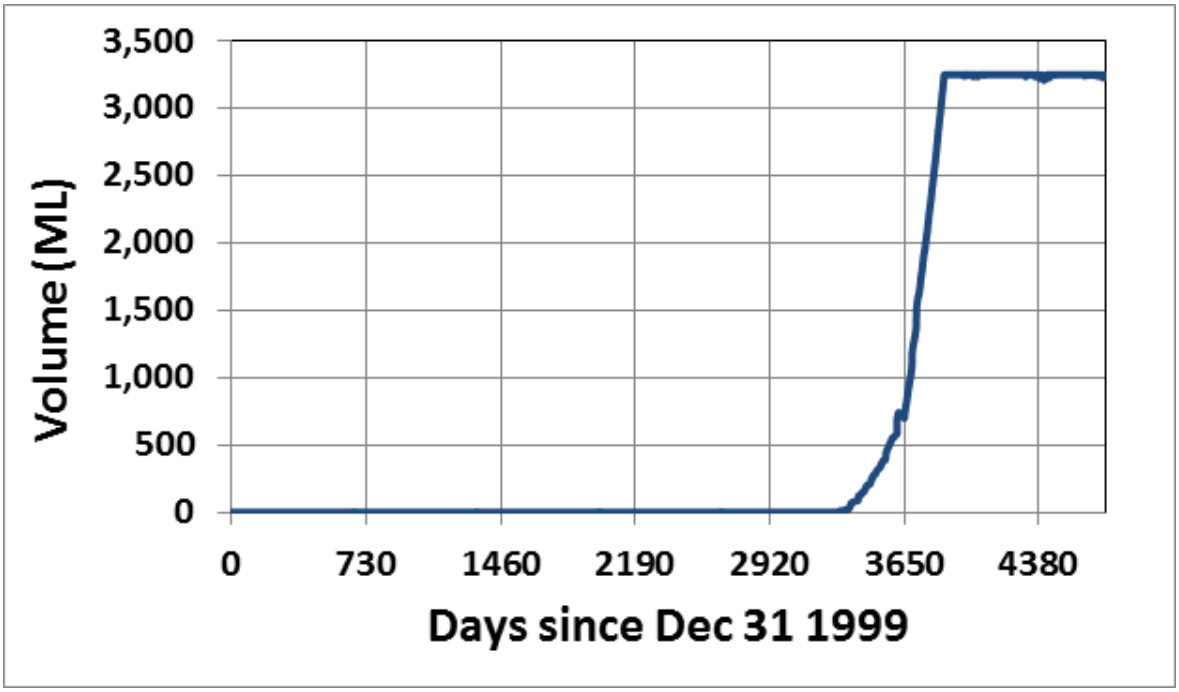

Figure 5.12: Water volumes in Lake Wendouree

Figure 5.12 shows that Lake Wendouree was refilled by flooding rains, and topped up by stormwater harvesting and wastewater reuse.

Maryborough

The water supply system for Maryborough and surrounds provides reticulated water supply to a population of approximately 10,500 people.

Water Demand

The calibrated behavioural water use algorithms in the Systems Framework reproduced the observed trends for increased water efficiency in the Maryborough district. These results indicate that 7.7% of existing buildings and all new buildings in each year between 2002 and 2010 included a higher level of water efficiency.

This result indicates that greater than 90% of buildings in the Maryborough district include water efficient appliances and practices. The calibration process also derived the water restriction rules for use in the analysis. The predicted and observed water demands in response to water restrictions for the Maryborough district are presented in Figure 5.13.

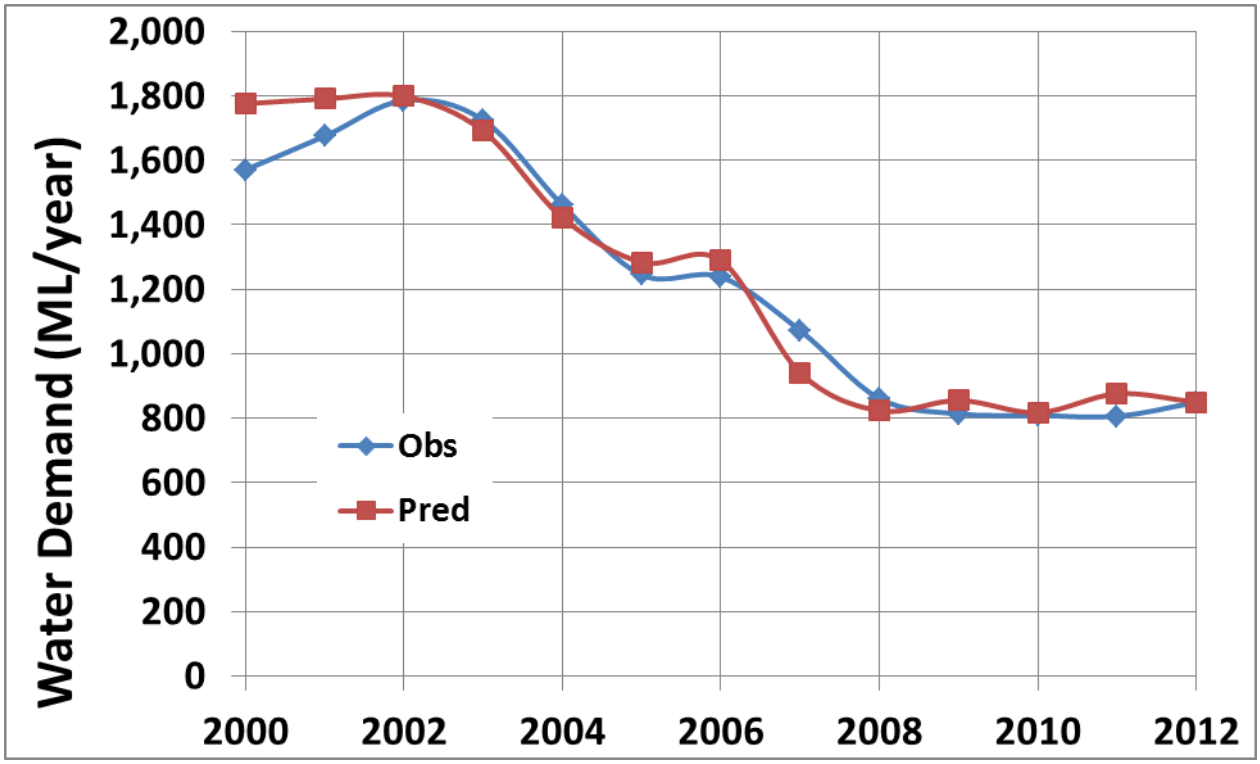

Figure 5.13: Predicted water demands versus observed water demands for the Maryborough district

Figure 5.13 demonstrates that the Systems Framework has reproduced the water demand behaviour for the Maryborough district including prediction of water use and water restrictions. These results highlight that the Maryborough district has experienced a dramatic change in water use behaviour during the last decade that has produced a halving of water demand. This outcome included the implementation of water restriction rules as a function of the combined water storage in the Evansford, Talbot and Tullaroop Reservoirs as shown in Table 5.2.

Table 5.2: Water restriction rules used in the Systems Framework

Stage	1		2		3		4+	
Total storage (%)	50	40	40	30	30	20	20	0
Reduction in demand (%)	5		8		12		20	

The water restrictions rules presented in Table 5.2 were derived for use in the Systems Framework. The resulting reductions in water use in response to restrictions for the period 2000 to 2012 are presented in Figure 5.14.

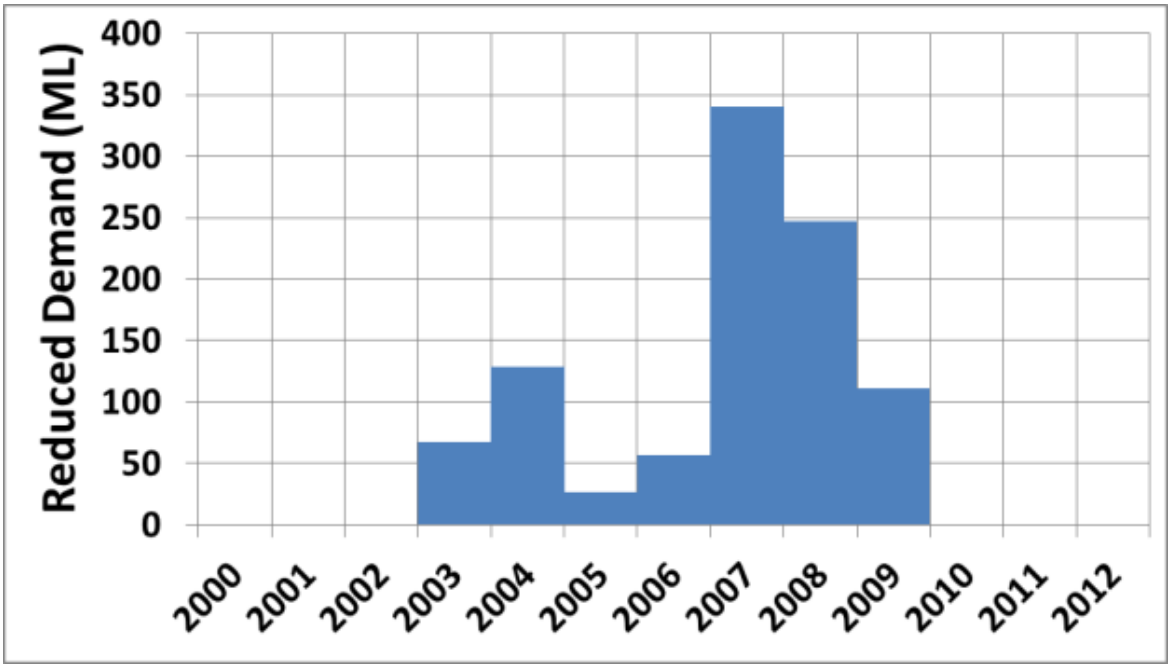

Figure 5.14: Predicted reductions in water demand generated by water restrictions

Figure 5.14 indicates that the predicted levels of water savings were reasonable consistent with the observed application of water restrictions during the period 2000 to 2012 that commenced with Stage 1 restrictions at the end of 2002 and included greater than level 4 restrictions during the period 2006 to 2009.

The reported annual losses from leakage and unaccounted for water consumption from the Maryborough water supply system of 24% were included in the Systems framework.[16]

Water Supply

The water head works system for Maryborough includes water storages in the upper reaches of the Stony and McCallum Creek catchments. Inflows to these reservoirs are highly variable and are better described by the daily time step utilised in the System Framework. Water supply is also drawn from the Tullarook reservoir situated on Tullarook creek and from the Moolort and Stony Creek borefields.

The hind casting process allowed a detailed review of the operation of the Evansford Reservoir which captures inflows from McCallums Creek, up to 2 ML/day of stream flow bypasses the reservoir as environmental flows and water is extracted via a pipeline (capacity of 6 ML/day) and directed towards Centenary Reservoir for water supply.[17] The daily sequences of water volumes in the Evansford Reservoir generated by the Systems Framework are compared to the observed reservoir volumes in Figure 5.15.

[16] Central Highlands Water (2012). Maryborough and District Water Supply System Strategic Plan 2011 – 2060.
[17] Central Highlands Water (2012). Maryborough and District Water Supply System Strategic Plan 2011 – 2060.

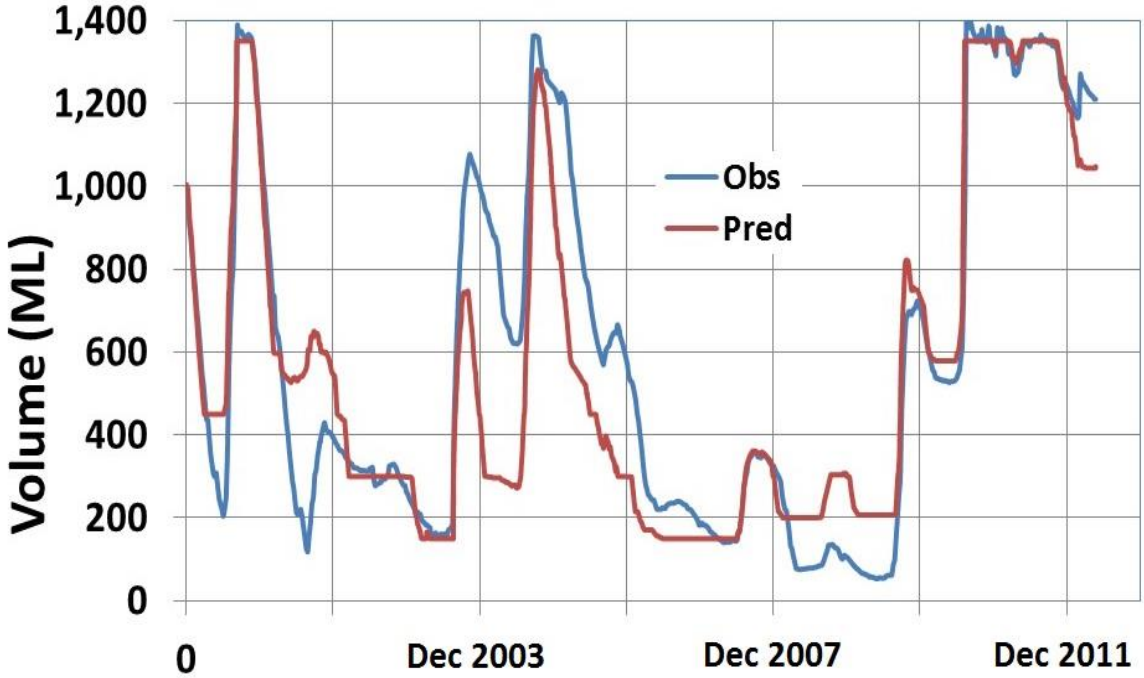

Figure 5.15: Observed and predicted water storage in Evansford Reservoir

Figure 5.15 demonstrates that the Systems Framework has replicated the behaviour of the Evansford Reservoir and the linked water systems. The Talbot Reservoir captures flows from Stony Creek and diversions from McCallums Creek when Evansford Reservoir is spilling. Talbot Reservoir supplies up to 2 ML/day to the Maryborough district. The daily sequences of water volumes in the Talbot Reservoir generated by the Systems Framework are compared to the observed reservoir volumes in Figure 5.16.

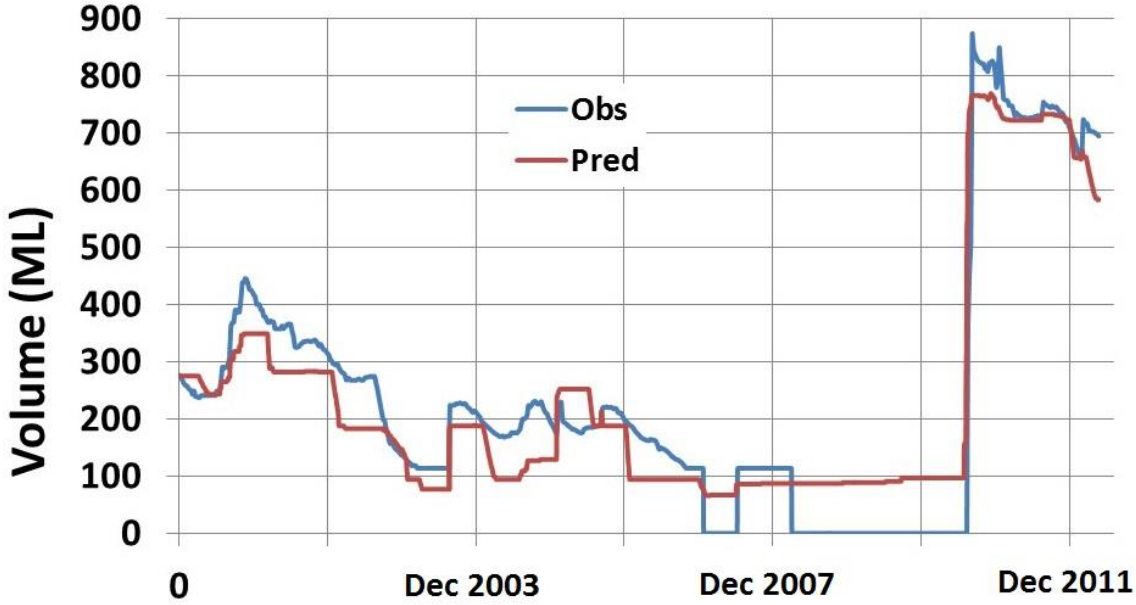

Figure 5.16: Observed and predicted water storage in Talbot Reservoir

Figure 5.16 reveals that that the Systems Framework has replicated the behaviour of the Talbot Reservoir. The behaviour of Evansford and Talbot reservoirs is characterised by periods of low water storage volumes during the last decade.

Tullaroop Reservoir captures stream flow in the lower reaches of Tullaroop Creek and provides water to meet rural demands in the Loddon Catchment. Central Highland Water holds a bulk entitlement to extract between 600 ML/year and 1,200 ML/year from the reservoir. The availability of water supply to the Maryborough district from Tullaroop reservoir is limited by Goulburn Murray Water's seasonal allocation of water, and from irrigation and evaporation demands on the reservoir.

Review of existing regional analysis using REALM provided by Department of Environment and Primary Industries (DEPI) allowed inclusion of irrigators dependent on the Loddon River catchment. This information was supplemented by data from Goulburn Murray Water and Central Highlands Water. The daily sequences of water volumes in the Tullaroop Reservoir generated by the Systems Framework are compared to the observed reservoir volumes in Figure 5.17.

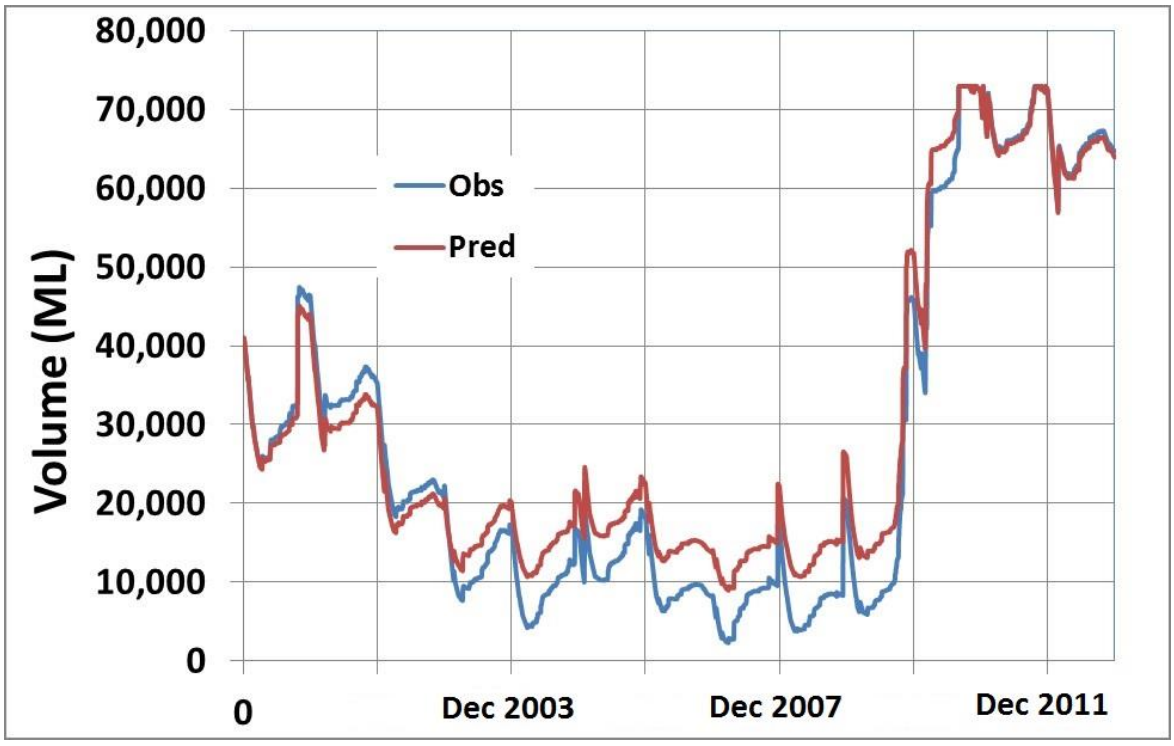

Figure 5.17: Observed and predicted water storage in Tullaroop Reservoir

Figure 5.17 shows that the Systems Framework was able to replicate the behaviour of the Tullaroop Reservoir and the dependent water systems. The water storages in the reservoir were substantially drawn down during the recent drought and throughout most of the last decade.

The substantial variation in water storages volumes in Tullaroop Reservoir is a consequence of the large and variable water demands supplied via the basin for irrigation districts and urban areas. In addition, the reservoir is also subject to high rates of evaporation.

Examination of the behaviour of Tullaroop Reservoir during the recent drought indicates that water may not be consistently available to supplement water security for the Maryborough District. However, the ability of the Systems Framework to replicate the behaviour of this regional system will allow robust exploration of the impacts of policies and strategies for future management of the regional water cycle.

Water Balance

The annual volumes of water demands, urban stormwater runoff and wastewater discharges to the Maryborough treatment plant are presented in Figure 5.18 as a timeline of an "urban water balance" for the Maryborough water district.

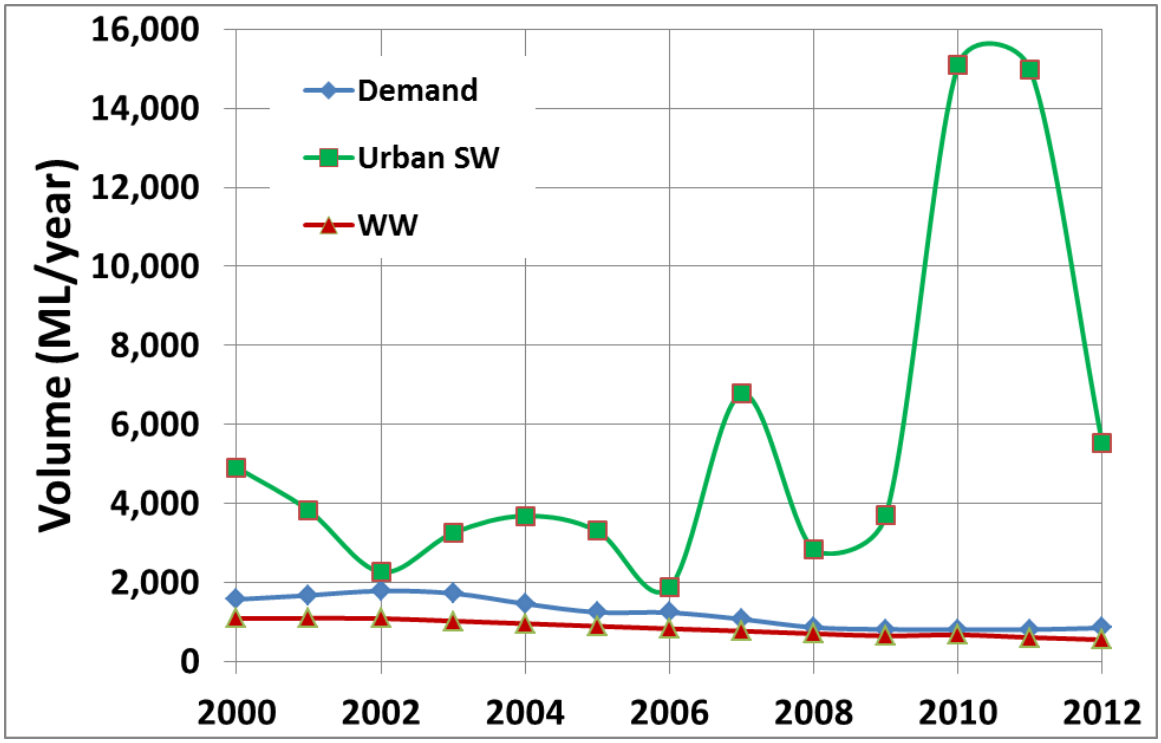

Figure 5.18: The "urban water balance" from the Maryborough district for the period 2000 to 2012

Figure 5.18 shows that the urban areas within the Maryborough district generated substantially greater volumes of stormwater runoff than water demands for all years except 2006 and 2002. Nevertheless, the volume of urban stormwater during 2002 and 2006 was greater than water demands.

The volumes of wastewater discharged to the wastewater treatment plant were also simular to water demands throughout the 2000 to 2012 period. A combination of urban stormwater runoff and wastewater discharges to the treatment plant provides volumes of local water that are a minimum of double the magnitude of water demands throughout the recent drought.

The Maryborough district generates more local water resources than water demands which provide outstanding opportunities for the district to decrease reliance on water extractions from external water resources shared with other communities and the environment.

6 Water Cycle Futures

A selection of results and associated insights from simulations of potential water cycle futures for the Ballarat region are presented in this Section with a focus on the Ballarat and Maryborough water districts. The region has significant interaction with surrounding regions including a reliance on water resources from the Campaspe and Goulburn River Basins for water security.

Regional climate

This investigation has utilised the longest available climate records to capture the spatial and temporal variability of the regions. Analysis of the rainfall sequences revealed substantial variations rainfall patterns and annual depths as shown in Figure 6.1.

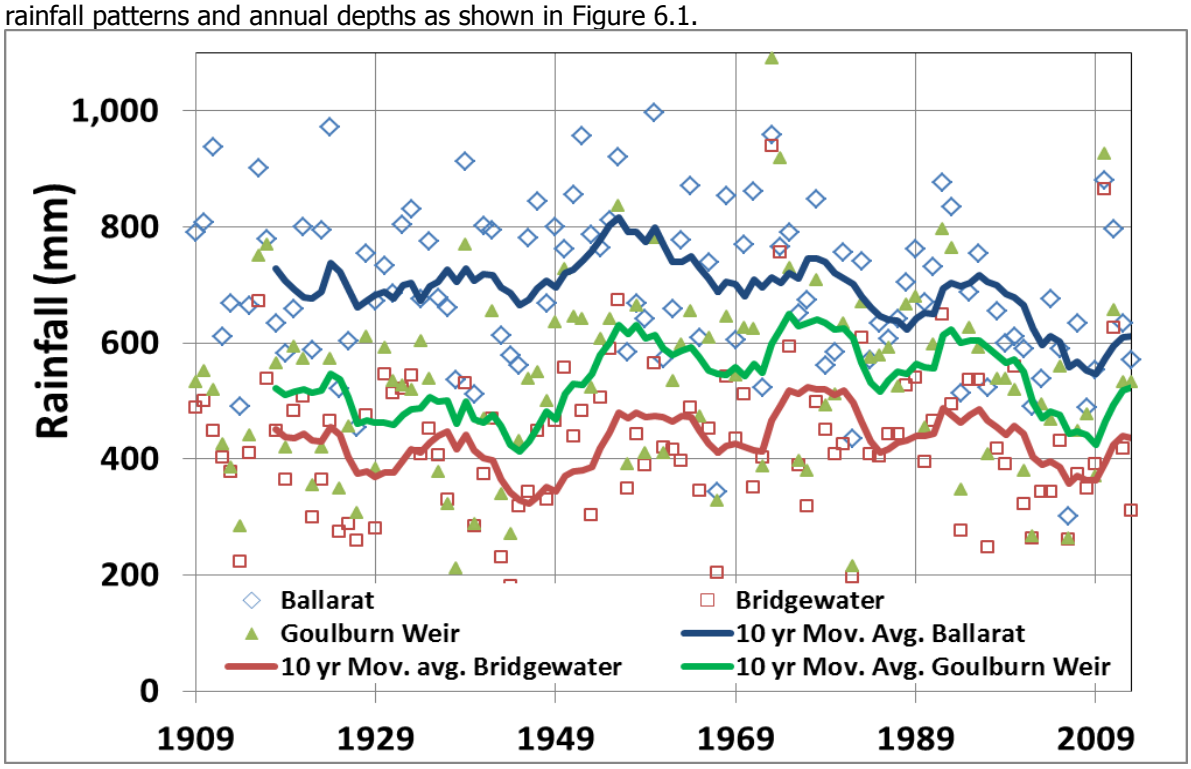

Figure 6.1: Annual rainfall sequences for Ballarat, Bridgewater and Goulburn Weir

Figure 6.1 shows that annual rainfall is highly variable across the regions involved in providing water security to the Ballarat region. These results indicate that the Ballarat region experiences consistently higher and less variable rainfall than the Goulburn and Bendigo (represented by Bridgewater) regions as demonstrated in Table 6.1.

Table 6.1: Statistics of regional annual rainfall

Location	Average (mm)	Minimum (mm)	Maximum (mm)
Ballarat Airport	694	301	996
Goulburn Weir	542	216	1090
Bridgewater (Bendigo)	433 (517)	170 (272)	938 (1060)

Table 6.1 highlights the greater resilience (relative reliability) of rainfall around the city of Ballarat that has a higher average annual rainfall depth and lesser variability. It is significant that during periods of low rainfall, typical of droughts, the rainfall experienced in the Goulburn and Bendigo areas is lower than Ballarat. In addition, this study has identified a high level of spatial variability in seasonal and daily climate processes that will substantially impact on the results of any analysis. These understandings indicate that the use of averages or monthly time steps in analysis of these combined regions may produce limited knowledge of regional water security or resilience.

This insight prompts a need to better understand the detail of the availability of regional water resources for the viability of the City of Ballarat and towns within the Ballarat region during droughts. Similarly, this enquiry also needs to consider the local availability of water resources within the Ballarat region. It is also essential to consider the downstream impacts of ensuring viability of regional towns using regional water resources such as Moorabool, Lal Lal and Tullaroop reservoirs that impact on the Moorabool and Loddon River Basins.

The experience of low water storage in Lake Eppalock, Warranga Basin and Lal Lal Reservoir during the last decade as presented in Section 5 of this report has indicated an uncertainty about shared water security across the regions and confirms a need to investigate these issues. This Section presented a selection of results from the analysis of the regions using a Systems Framework.

Figure 6.1 also reveals the cyclic nature of weather patterns across the region that includes persistent periods of wet and dry conditions. Analysis of average annual rain depths and rainfall frequency (days with rainfall) during wet and dry periods provides insight into the resilience of the region's water cycle. The wet period was defined as 1979 to 1993 and the dry period is defined as 1994 to 2009. Changes in average annual rainfall depth and rainfall frequency between wet and dry periods are presented in Figure 6.1a and 6.1b respectively.

Figure 6.1a shows a spatially diverse difference in the changes to average annual rainfall depths. Whilst the region experiences severe reductions in rainfall, isolated areas, such as near Beaufort, experience small increases annual rainfall. Dryer areas have lesser reductions in rainfall than wetter areas that experience substantial reductions in rainfall.

Figure 6.1b also reveals a spatially diverse response in rainfall frequency to wet or dry periods. Some isolated areas, such as Trentham, experienced increases in rainfall frequency during dry periods. The pattern of reduced rainfall frequency during dry periods is different to the pattern of reduced rainfall depth.

This insight highlights that the spatial patterns of weather are substantially different across the region during wet and dry periods. The patterns of rainfall are influenced by topography of the region and proximity to the ocean.

The spatial analysis of climate patterns also indicates that some catchments, such as the Yarrowee River, are more resilient to other catchments, such as the Upper Moorabool River.

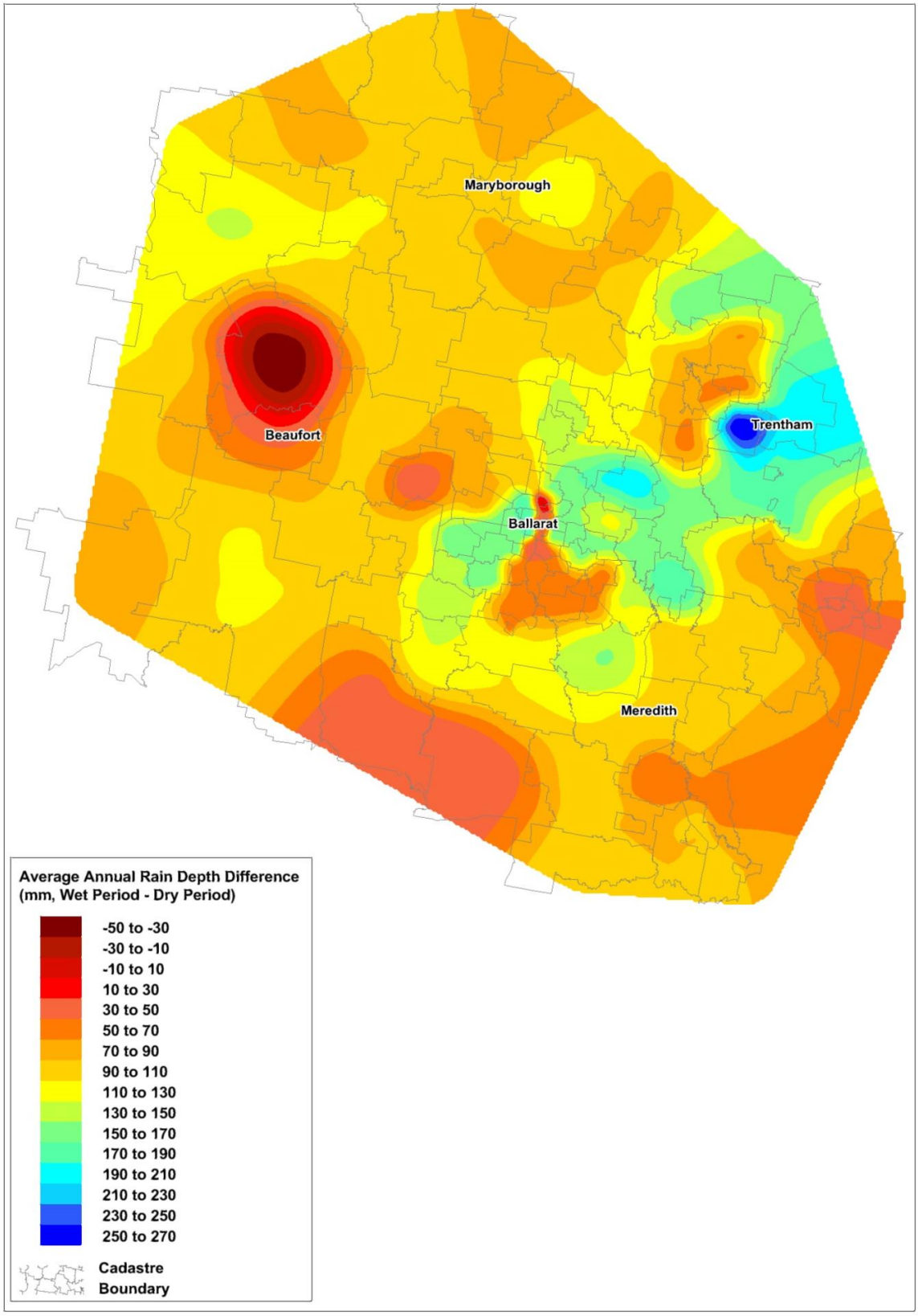

Figure 6.1a: Difference in average annual rainfall depth between wet and dry periods

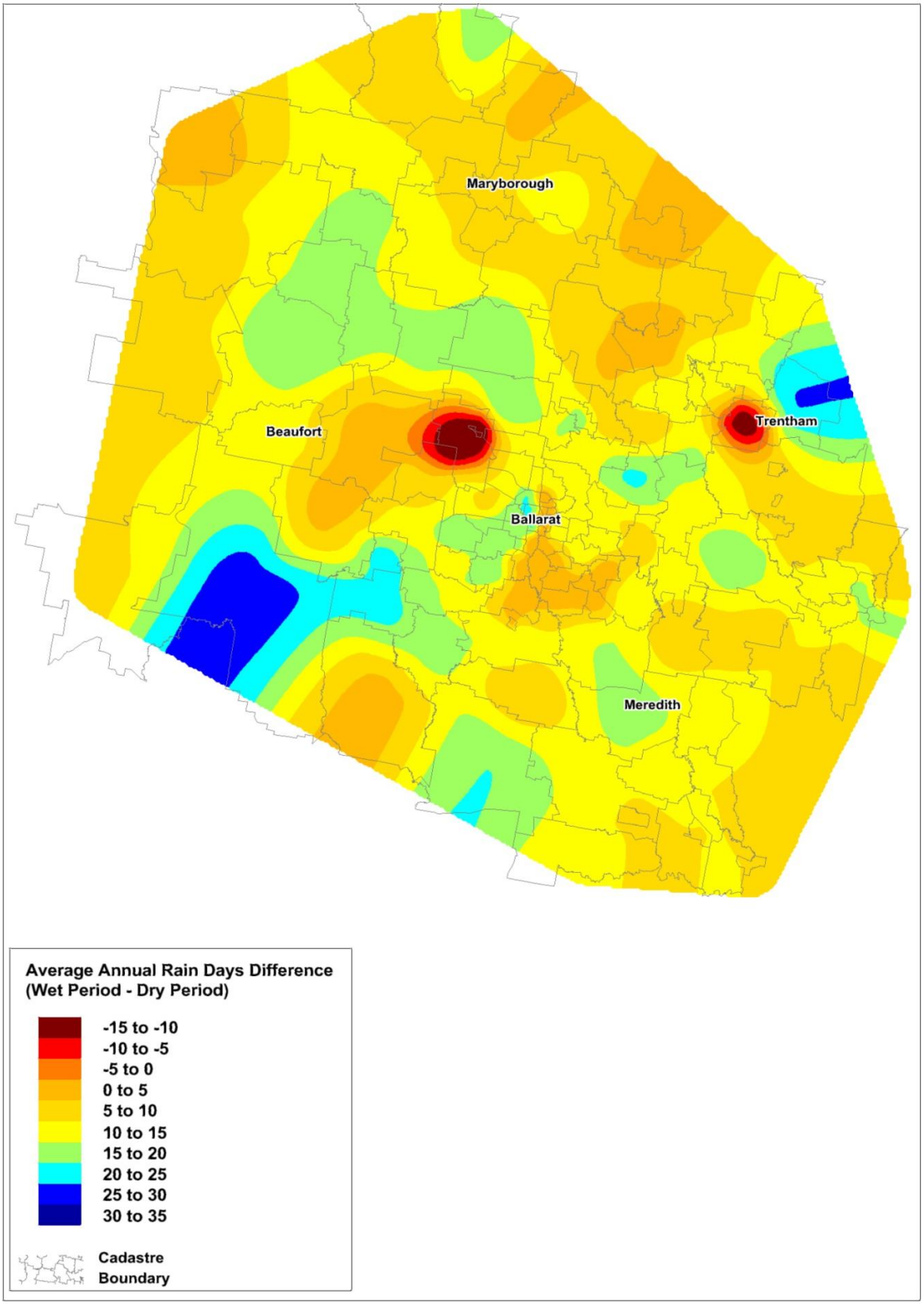

Figure 6.1b: Difference in average annual rainfall frequency (rain days) between wet and dry periods

Water Use

Water billing records (3 observations per year), distribution of household sizes and dwelling types, average weekly income and a range of climate parameters from 144 locations were used to derive local scale water demands that underpinned this investigation. The region is subject to substantial spatial and temporal variation of inputs and behaviours as demonstrated by the sample of observed household water use provided in Table 6.2.

Table 6.2: A sample of observed local average household water use that displays the spatial and temporal variation across the Ballarat region

Location	Residential water use in 2000 (L/day)	Residential water use in 2012 (L/day)	Reduction (%)
Ballarat Central	569	352	38
Maryborough	629	395	37
Clunes	653	370	43
Daylesford	472	323	32
Kingston	1,122	629	44
Mount Rowan	1,368	552	60

Table 6.2 highlights the spatial (location), temporal (2000 versus 2012) variation in water use behaviour throughout the Ballarat region. The spatial differences in residential water use behaviours across the region are highlighted by the maps of residential summer outdoor water demands versus average annual rainfall depths in Figure 6.2a.

Figure 6.2a shows that summer outdoor water use is higher in areas with lesser rainfall and lower elevations to the north, east and west of the dividing mountain ranges. These results indicate that the use of a single average household water use in analysis of water resources for the region may not capture the challenges or opportunities presented by a region. The Systems Framework has utilised all available spatial and temporal information to capture the spatial variation of behaviour of the water cycle across the region.

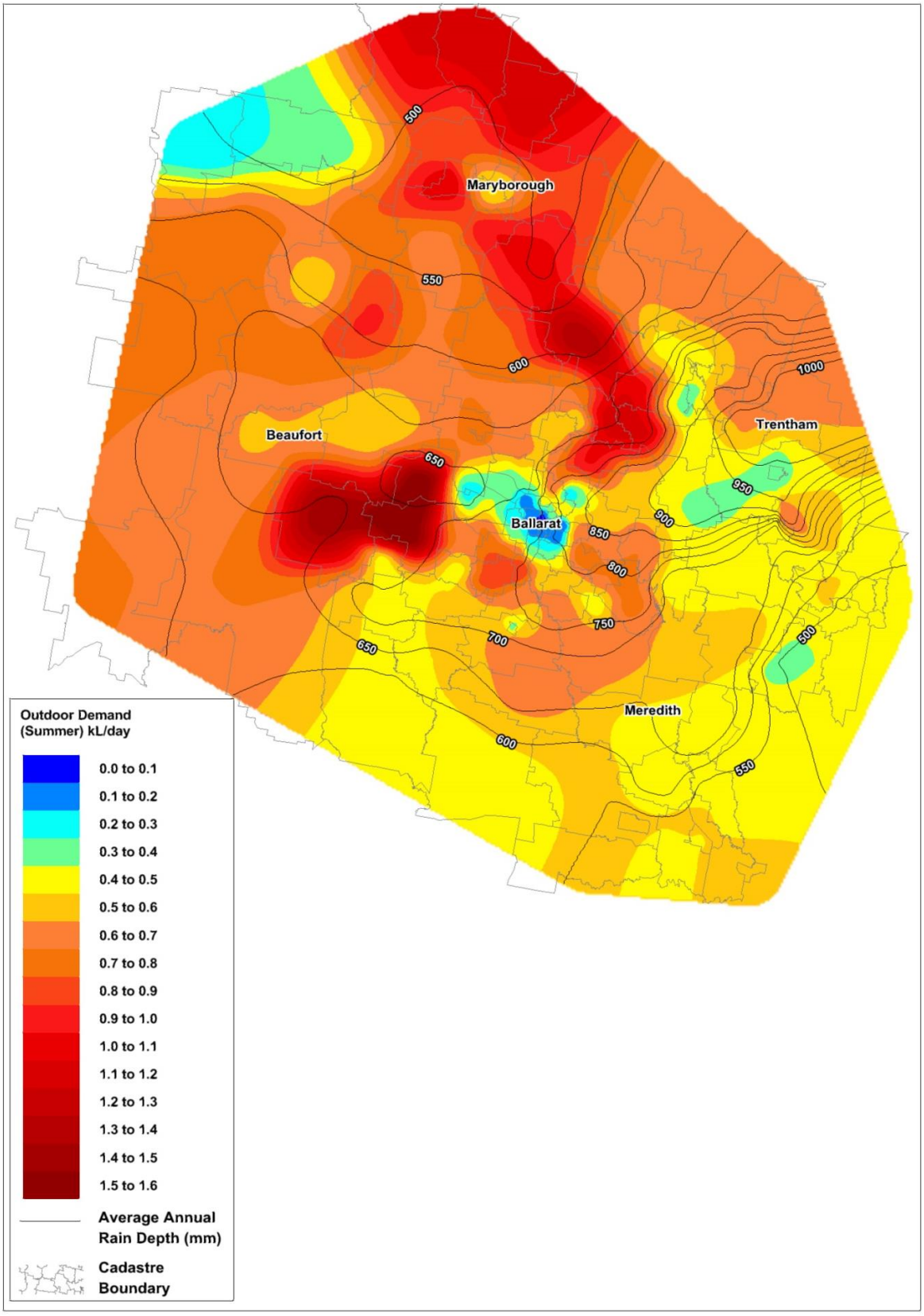

Figure 6.2a: Residential summer outdoor water uses versus average annual rainfall

Performance Criteria for Water Security

This investigation has used the performance criteria for the security of water supply in the Ballarat and Maryborough water districts as defined by Central Highlands Water to assess the security of water supplies. The assessment criteria are summarised in Table 6.3.

Table 6.3: Performance criteria for water security at Ballarat (B) and Maryborough (M)

Performance Criteria	Trigger level	Annual probability	Outcome
Aesthetic storage in White Swan Reservoir (B)	50%	5%	No more than 5 occurrences in 100 replicates
Stage 1 water restrictions (B & M)	See Tables 5.1 and 5.2	5%	No more than 5 occurrences in 100 replicates
Stage 3 water restrictions (B & M)	See Tables 5.1 and 5.2	0.1%	No simulated occurrence
Critical storage in White Swan reservoir (B)	20%	0.1%	No simulated occurrence
Critical storage in Lal Lal Reservoir (B)	20%	0.1%	No simulated occurrence
Water shortage (B & M)	Partial supply	0.1%	No simulated occurrence

Table 6.3 lists some of the criteria utilised to allow comparison of outcomes from this investigation with previous studies.

Ballarat

The Ballarat water supply district includes the City of Ballarat, a major regional centre of Victoria, and surrounding suburbs and outlying towns including Skipton, Enfield, Creswick and Ballan.

Water demands

Simulated water demands from this extensive district are presented in Figure 6.2.

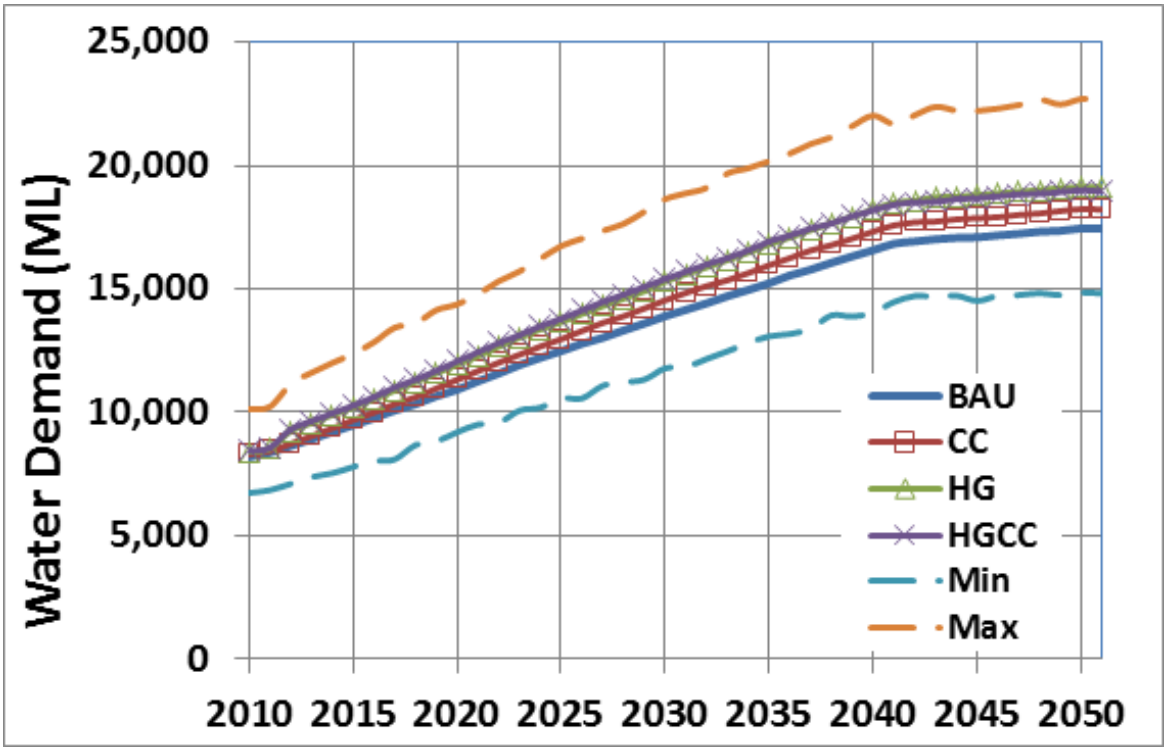

Figure 6.2: Simulated water demands from the Ballarat district for the scenarios

Figure 6.2 reveals that the Ballarat water district is expected to experience a substantial increase in annual water demands to 2051 that ranges from an increase of 9,214 ML for BAU (113%) to 10,959 ML for HGCC (130%). The future annual water demands for the district are also subject to considerable variation. For example, annual water demands range from a minimum of 14,816 ML to 22,727 ML in 2051. The scenarios with high population growth (HG) climate change (CC) produce higher water demands.

Note that the results presented in Figure 6.2 represent the summation of water demands from end users of water and the simulations include an additional 12% allowance for losses and unaccounted for water consumption. The total predicted water demands for the base scenario (BAU) are consistent with the water demands presented in Water Supply Demand Strategy by Central Highlands Water.

Water security

In response to the recent drought, water supplies to the Ballarat District were augmented by the addition of Ballarat West bore field connected to the Cardigan Aquifer during 2007, connection to the Bungaree Aquifer during 2007 and the Goldfields pipeline connected to the Campaspe and Goulburn Rivers during 2008. Cosgrove Reservoir (once water supply for Creswick) was also reconnected to the Ballarat system in 2006. Newlyn Reservoir was connected in 2008 (via the Newlyn Interconnector).

The Ballarat West bore field has not been utilised since 2010 and is now part of a demonstration project for Managed Aquifer Recharge (MAR) that is partially funded by the Living Victoria fund. This project aims to recharge the Cardigan Aquifer using treated stormwater to balance the extractions from the aquifer for water supply.

The project is currently planned to be reliant on the collection of roof runoff from the proposed Ballarat West Employment Precinct that is near Burrumbeet Creek as shown in Figure 6.3. Recharging the aquifer with excess stormwater runoff generated by urban development will balance the link between reducing water levels in the aquifer and low stream flows in waterways. The Ballarat West bore field has been included in the water supply portfolio for Ballarat considered in this investigation.

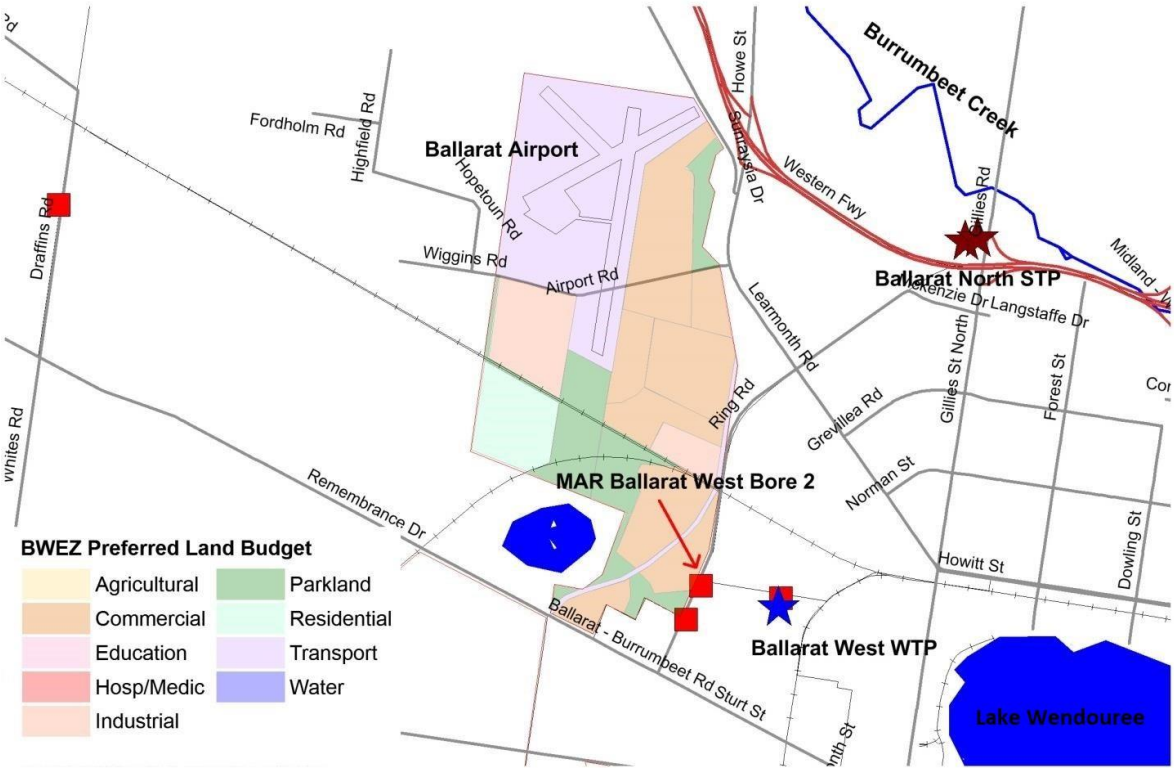

Figure 6.3: Ballarat West bore field and the Ballarat West Employment Precinct

Figure 6.3 shows the proposed location of the Ballarat West Employment Precinct is near the Ballarat West water treatment plant (WTP), the Ballarat North sewage treatment plant (STP), Lake Wendouree and Burrumbeet Creek. The Ballarat West bore field has been used to top up Lake Wendouree and can be used as a regular water supply solution provided that extractions from the bore field are balanced by annual recharge of the aquifer. This can be achieved using local stormwater harvesting from the proposed Ballarat West Employment zone or from stormwater harvesting in the Burrumbeet creek catchment.

The trigger for sourcing water from the Campaspe and Goulburn Rivers via the Goldfields pipeline was defined as less than 18% of the total storage volumes in local reservoirs (Lal Lal, White Swan, Moorabool, Wilsons, Beales, Gong Gong, Pincotts and Kirks Reservoirs) from previous studies.[18] Preliminary simulations during this investigation revealed that a trigger level of 40% of total storage for use of water from the Goldfields pipe was required. This outcome was a function of the high level of sensitivity to assumptions that was displayed for the Ballarat water supply. The results of this investigation are based on using a 40% of total storage volumes as a trigger for use of the Goldfields pipeline.

[18] Gilbert and Sutherland (2013). Level of service assessment water supply system Ballarat Vic.

This investigation has defined unacceptable water security as an annual probability of Stage 1 water restrictions that are greater than 5%. A requirement to augment the regional water supply system is triggered by an expected annual probability of water restrictions that are greater than 5% as shown in Table 6.4.

Note that the simulations for the base case have not included any of the proposed augmentation options. It is expected that these measures will be considered as Options during the next phase of this investigation.

Table 6.4: Summary of the timing of water supply augmentation

Scenario	Timing
Base case (BAU)	>2051
Climate change (CC)	>2051
High growth (HG)	>2051
HG + CC	> 2051

Table 6.4 highlights that a requirement to augment water supply to the Ballarat district may not be required within the planning horizon for all scenarios. These results are substantially more optimistic than previous estimates in the Water Supply Demand Strategy that indicate that augmentation will be required in 2050 for the base case and in 2040 for a return to dry climate situation.[19] Note that this analysis has partially optimised the operating rules and triggers for utilising different water resources throughout the Ballarat water district which has revealed improvement performance.

The differences between this analysis using a Systems framework and the previous estimates of water security outcomes are primarily attributed to the greater spatial and temporal details, and processes utilised within the Systems Framework. Whilst it is always difficult to compare the results of using stochastic to historical based simulations using traditional yield analysis [20], comparison to a time based systems analysis process (used in this study) that is underpinned by simulations of the local physics of all inputs requires additional consideration.[21] Indeed, previous analysis has resulted in recommendations that analysis of regional water resources for cities use spatially and temporally explicit methods of systems analysis to better understand the security of urban water supplies.[22] Otherwise, the full potential of alternative water management options including WSUD or IWCM approaches may not be understood.

It is noteworthy that the "Yield Analysis" methods specified by the former Department of Sustainability and Environment (DSE) for assessment of Water Supply Demand Strategies (WSDS) and the stochastic or "level of service" (LOS) based "Yield Analysis" are static (independent of time and space) methods of estimating the water available from a reservoir or water supply system.

This process derives a static "yield" from a water system that is then compared to a separate analysis, using whole of system average inputs (eg; average households), of water demands. The

[19] Central Highlands Water (2012). Ballarat and District Water Supply System Strategic Plan 2011 – 2060.
[20] Gilbert and Sutherland (2013). Level of service assessment water supply system Ballarat Vic.
[21] Coombes P.J., (2013) Integrated Systems Analysis to Create Evidence Based Policies for Water Cycle Reform in Greater Melbourne. *34th Hydrology and Water Resources Symposium*, Engineers Australia, Sydney, NSW.
[22] Coombes P.J., and M.E. Barry (2012). The impact of spatial and temporal averages on prediction of water security using systems analysis – towards the true potential of WSUD. 7th International WSUD Conference. Engineers Australia. Melbourne

simulation of water supply behaviour is not linked to water demands. In addition, a static "yield" of a water supply system is dependent on time and space for links with external systems and for the internal components of a water system. It is unlikely that "static yields" derived in this manner can be successfully added to yields or allocations from adjoining systems.

All inputs to the Systems Framework are based on the linked spatially and temporally dependent sequences of behaviour throughout the region. The application of operational rules (such as triggers for water restrictions and preferential supply from a particular water source – for example Lal Lal reservoir versus White Swan reservoir) respond differently to various assessment methods. The more detailed timelines of inputs used in this investigation reveal a greater range of challenges and opportunities for the management of a system.

In addition, analysis using regional averages, access to bulk allocations regardless of the biophysical limitations of catchments (water may not be available at the time it is required) and use of a monthly or annual time periods can have the effect of obscuring or hiding the behaviour of systems that respond at a daily (or shorter time scale).[23] A major proportion of the Ballarat water supply system includes storages and extractions from the ephemeral upper catchments of waterways that produce highly variable responses at short timescales (see Section 5 for additional discussion).

The limited length of available hydrological records in combination with the high level of spatial and temporal variation across the regions also provides the impression that our results maybe conservative or optimistic. Further analysis to extend the regional daily hydrology is almost complete and will confirm these results. It is noteworthy that this analysis already has supplemented the relatively short time series of daily hydrological data from the region with comprehensive data provided by the Department of Environment and Primary Industries (DEPI).

The uncertainty about water supply yields versus water demands for the Ballarat water districts are presented in Figure 6.3a. Note that the maximum water supply yield for Ballarat includes the full time use of the Ballarat West bore field.

[23] Coombes P.J., and M.E. Barry (2012). The impact of spatial and temporal averages on prediction of water security using systems analysis – towards understanding the true potential of WSUD. 7th International Conference on WSUD. Engineers Australia. Melbourne.

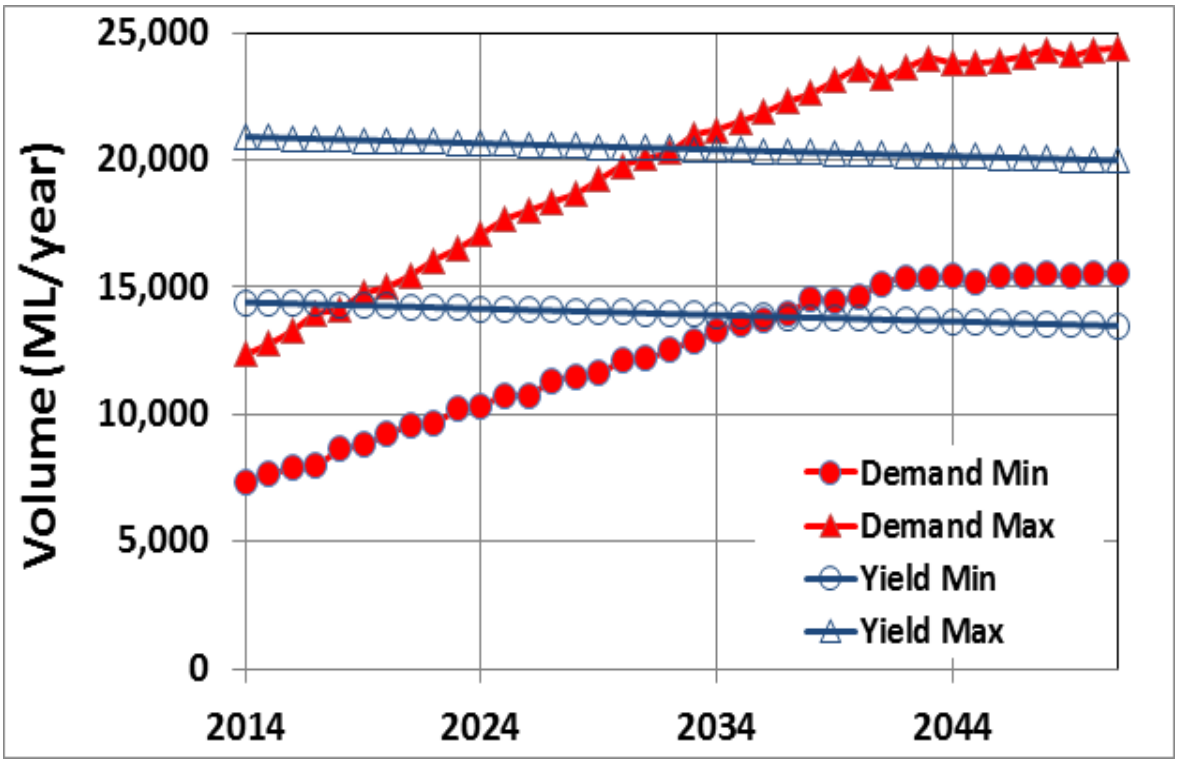

Figure 6.3a: Variation in water demands versus water supply yields for the Ballarat water district

Figure 6.3a reveals that the expected variability of water demands and water sources generates uncertainty about the future security of water supplies to the Ballarat water district. The timing of need to augment that water supply system ranges from 2020 to beyond the planning horizon. This insight highlights a requirement for a diverse portfolio of water supply strategies and for careful monitoring of the behaviour of regional systems. The significance of local ground sources and the viability bulk water sources is also highlighted by this diagram.

Bulk Water Sources

The simulated future requirement for bulk water supplies from the Goulburn and Campaspe River Basins via the Goldfields pipeline are presented in Figure 6.4.

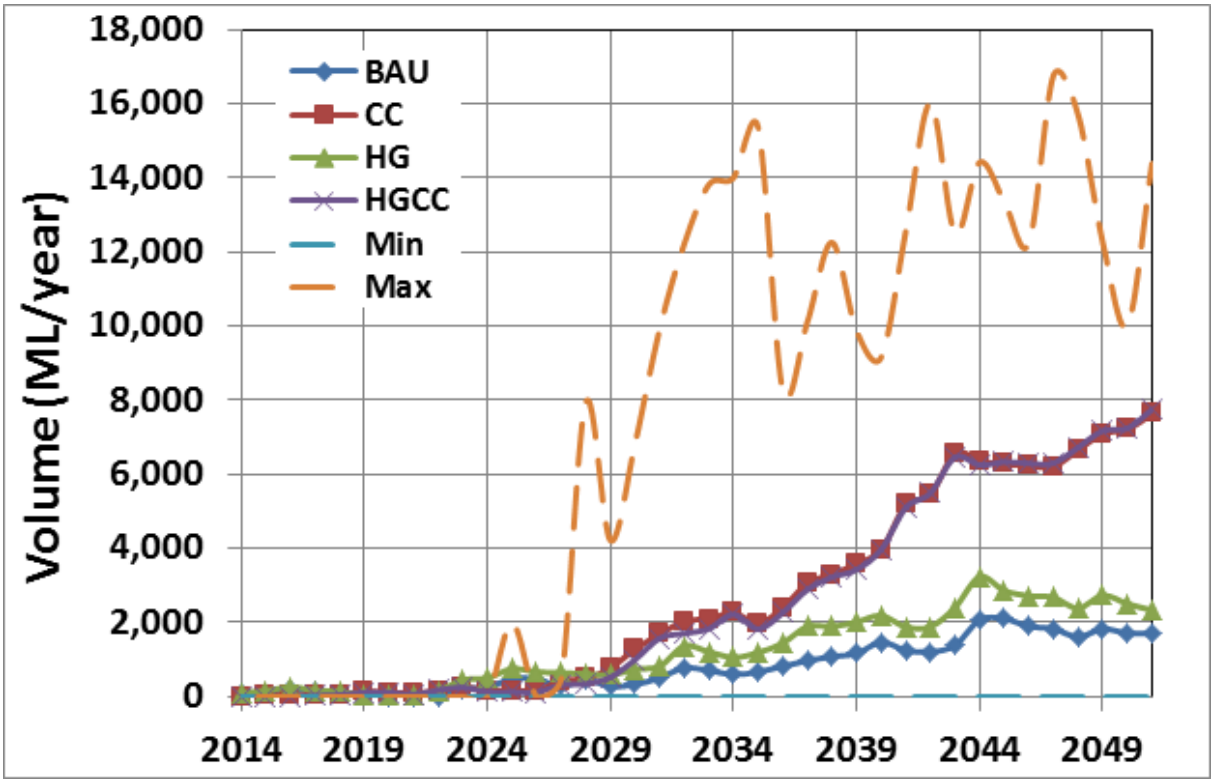

Figure 6.4: Bulk water extractions from the Goulburn and Campapse River Basins via the Goldfields Pipeline

Figure 6.4 implies a relatively low level of average utilisation of the bulk water transfers via the pipeline. A 10% probability of requiring bulk transfer in excess of capacity is not exceeded in the planning horizon to 2051. Closer inspection of the results also indicate periods of limited water available for transfer to the Ballarat region that was overcome by water from the Ballarat West bore field. These results, in part, drive the outcomes for water security and highlight that the use of averages can be misleading for understanding the probabilistic behaviour of water supply systems.

In addition, the transfer of bulk water supplies from the Campapse and Goulburn River basins is also subject to trade-offs with bulk water transfers from the Moorabool River Basin. The simulated bulk water extractions from Lal Lal Reservoir are presented in Figure 6.5.

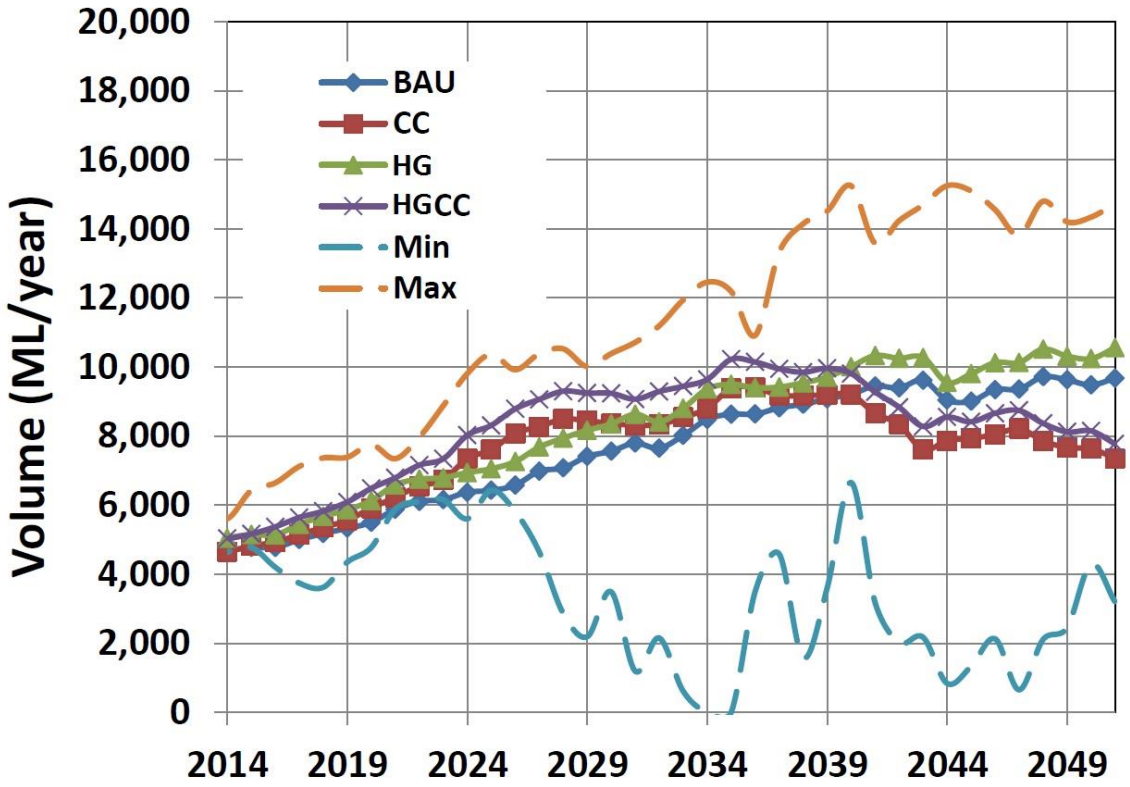

Figure 6.5: Bulk water extractions from Lal Lal Reservoir

Figure 6.5 reveals a relative high level of average water extractions from Lal Lal Reservoir were subject to substantial variation. Comparison to the current bulk allocation for Lal Lal Reservoir (up to 42,000 ML in any successive 3 year period) indicates that the average water extractions exceed the allocation from 2043 for high population growth with climate change (HGCC) and from 2044 for climate change (CC).

However a 10% probability of the allocation will be exceeded from 2039 for the high growth climate change (HGCC) scenario. The diminishing minimum extractions from Lal Lal reservoir from 2039 indicate the increasing probability that the reservoir has limited water storage available for water supply.

Analysis of the simulated water supply from White Swan Reservoir which indicates allocation from the Yarrowee, Upper West Moorabool and Goldfields pipe systems indicates that there is a 10% probability of the allocation will be exceeded from 2038. However, this allocation rule for the Yarrowee River system appears to be redundant due to inclusion of the Goldfields pipe.

In addition, extractions from the Ballarat West bore field exceeded the current allocation of 1,700 ML/annum from early in the simulations. This result indicates two insights – another simulation is required to optimise the contribution of the bore field and recharge of the aquifer should be considered as an option to increase the contribution of the Cardigan Aquifer to the Ballarat water district.

The simulated higher water extractions from Lal Lal reservoir and Ballarat West bore field relative to supply from the Goldfields pipe may be product of the sensitivity of the operating rules within the Ballarat water supply district that is reproduced by the Systems Analysis or a time based inability to source water for the Goldfields pipe from Lake Eppalock and Warranga Basin when

needed. This process has revealed the high level of sensitivity of the Ballarat district water systems to assumptions and the ability of the Systems Framework to reveal and simulate this sensitivity. This outcome indicates that the Systems Framework can be utilised to optimise a range of planned systems behaviours including operating rules, allocations and water restrictions.

This investigation has revealed that the security of the water supply for Ballarat is highly sensitive to changes in assumptions. The operating rules in the Systems Framework have been changed to optimise water extractions from Lal Lal Reservoir, the Goldfields pipeline and the Ballarat West bore field. Another simulation has been commenced to test this change in operating rules.

Water Balance

The components for fulfilling water demands for the Ballarat water district in 2051 are presented as a combination of the four scenarios in Figure 6.6.

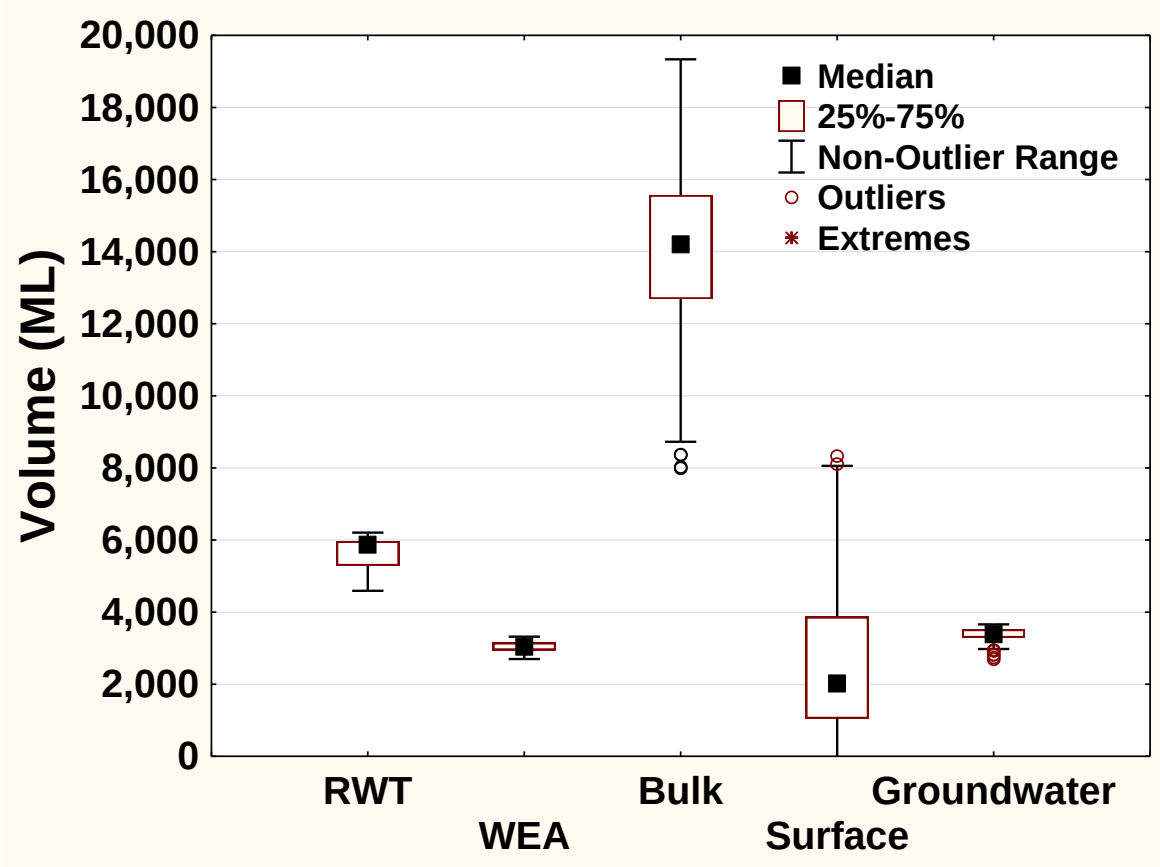

Figure 6.6: The components of fulfilling water demands of the Ballarat water district in 2051

Figure 6.6 demonstrates that water demands in 2051 for the Ballarat district are fulfilled using water supplies from bulk water (Bulk), local surface water (Surface), rain water (RWT) and ground water sources. Note that the water balance also includes water savings (WEA) from water efficient appliances and practices. Water supply or reductions in water use provided by water efficiency and rainwater harvesting represent the embedded reductions in local water use that have reduced the overall annual demands on the water supply system.

This Figure also highlights the relative magnitude and variability of the components of meeting

water demands for the BAU scenarios. The Ballarat district is highly dependent on bulk or external water sources (such as from the Goulburn and Campaspe Catchments via the Goldfields pipe and from the Moorabool Catchments via Lal lal Reservoir) and the supply this water is highly variable. The magnitude and variability of water supply from local surface water sources (Clarkes Creek, Whisky Creek, and Moorabool, Wilsons, Beales, Kirks, Gong Gong and Pincotts Reservoirs) is significantly less than supplies from bulk water sources.

A majority of centralised water supplies to the Ballarat district is represented by a combination of bulk and local surface water supplies with a substantial contribution of ground water from the Bungaree and Ballarat West bore fields. Over 70% of centralised water supplies and over 50% of the overall water balance for the Ballarat district in 2051 are provided by external bulk water sources. This is a substantial dependence on external water resources that are shared with other urban communities, the rural sector and ecosystems. There is a need to examine the availability of local water sources that will reduce dependency on external water sources. In addition, the analysis reveals that by 2051, the annual recharge rate for the Cardigan Aquifer (for example from stormwater harvesting) will need to be 3,500 ML.

The analysis also includes local water supply initiatives that were implemented during the recent drought that includes up to 52 ML/year from treated wastewater and up to 37 ML/year from stormwater harvesting that is used for irrigation of sporting precincts and the Botanical Gardens. Greater volumes of harvested stormwater of up to 1,420 ML/year and of treated wastewater of up to 600 ML/year are used to top up Lake Wendouree.

The availability of stormwater runoff generated by urban areas and wastewater discharges to the Ballarat North and South wastewater treatment plants in 2051 is presented in Figure 6.7.

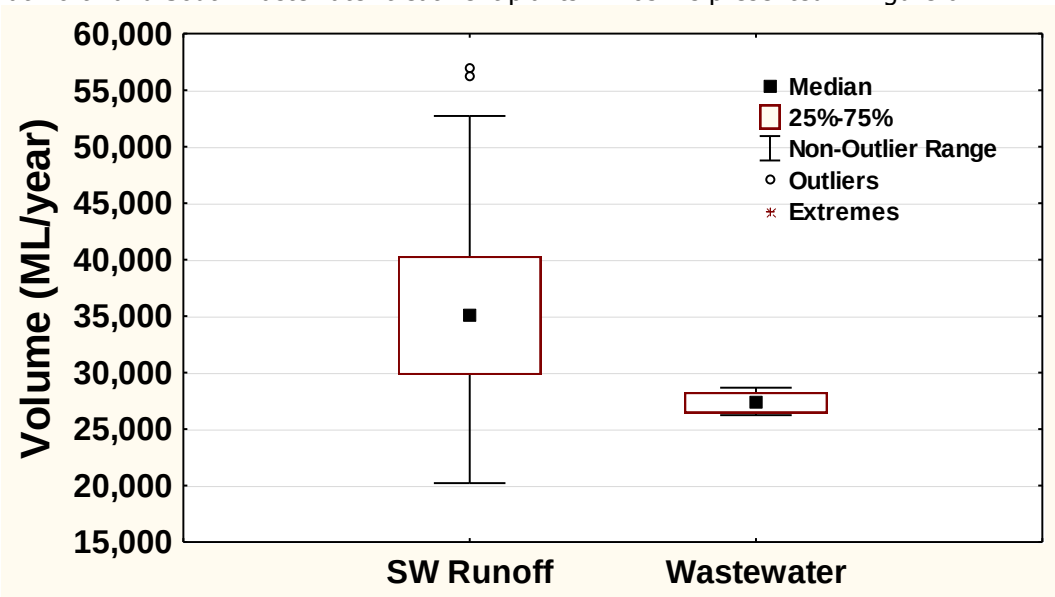

Figure 6.7: Urban stormwater runoff and wastewater discharges to treatment plants in the Ballarat district for 2051

Figure 6.7 shows that the stormwater runoff generated by urban areas within the Ballarat district is highly variable but substantially greater than water demands. Wastewater discharges from the urban areas that include infiltrated stormwater are a similar magnitude to water demands with a

similar variance. The Ballarat water district generates volumes of local water resources that are up to three times the magnitude of water demands.

Locally available water resources including urban stormwater runoff, wastewater, rainwater and groundwater provide substantial opportunities for the Ballarat district to reduce dependency on water resources from external sources. The addition of local water sources to the portfolio of water supply options will also improve the security of water supplies.

Waterways

The Systems Framework has also generated information about the linked behaviour of the major waterways throughout the Ballarat district. Some of these waterways including the Yarrowee River (Leigh River downstream of Ballarat) and Burrumbeet Creek within Ballarat have a history of poor water quality and algal blooms.

Much of the stream flow in the upper reaches of the Yarrowee River is diverted for water supply, a majority of summer flows downstream of the City of Ballarat is derived from the Ballarat South wastewater treatment plant and Ballarat Goldfields before passing through extensive areas of dry land grazing.[24]

Results from community water quality monitoring of the Yarrowee River have often been greater than the State Environmental Planning Policy (SEPP) guidelines for the catchment. However the instantaneous nature of this data in the upper part of the catchment was not sufficient to analyse against the guidelines. Biological monitoring of the Leigh River in 1997 near Mt Mercer also did not meet the SEPP guidelines, particularly Stream Invertebrate Grade Number – Average Level (SIGNAL level) for either riffles or edge habitats.

In 2009/10 research by the Victorian Centre for Aquatic Pollution Identification and Management (CAPIM) suggested that the Yarrowee River at the top of the catchment appeared to be a "pollution hotspot", including heavy metals and arsenic and pesticides, and recommended further investigation of many water quality and toxicity parameters to aid management responses.

The Burrumbeet Creek upstream of Lake Burrumbeet contains several urban stormwater catchments of Ballarat, Miners Rest and Learmonth, areas of dry land grazing and releases of treated wastewater from the Ballarat North wastewater treatment plant. The lake has been recognised as a high risk area for water quality and public health with a history of toxic outbreaks of Cyanobacteria (Blue Green Algae), particularly in the genus of Microcystis and Oscillatoria.[25]

Outbreaks of Cyanobacteria have resulted in the closure of the lake by the City of Ballarat with the most recent closure during January 2014.26 Modelling to support the Nutrient Management Plan estimated the yield for the Burrumbeet Creek to be high for Total Phosphorus (TP, 0.14 – 0.21 kg/ha/yr) and very high for Total Nitrogen (TN, 3.12 – 4.15 kg/ha/yr) which is likely a key contributing factor to the toxic outbreaks in the lake. The Glenelg Hopkins River Health Strategy 2004-2009 also reported the TP concentration of 0.325 mg/L (75th percentile) to be above the SEPP guidelines.

The Ballarat North and South wastewater treatment plants have been subject to considerable upgrades since the mid-1990s to manage increased wastewater discharges from urban growth and

[24] CCMA, 2006. Corangamite River Health Strategy 2006-2011
[25] GHCMA, 2001. Glenelg Hopkins Nutrient Management Plan 2001
[26] Ballarat Courier, 21 Jan 2014

to improve the quality of discharges to waterways. Both wastewater treatment plants are now configured to meet discharge objectives of total nitrogen concentrations less than 10 mg/L and total phosphorus less than 2 mg/L. The improved quality of effluent discharges will improve the historical impacts on waterways.

In addition, the Ballarat North wastewater treatment plant provides significant volumes of treated wastewater for reuse and to top up Lake Wendouree which will further mitigate impacts on waterways. The Ballarat South wastewater treatment plant also provides limited volumes of treated wastewater for reuse. The impact of the scenarios on cumulative stream flows in the Yarrowee River below City of Ballarat is presented in Figure 6.8.

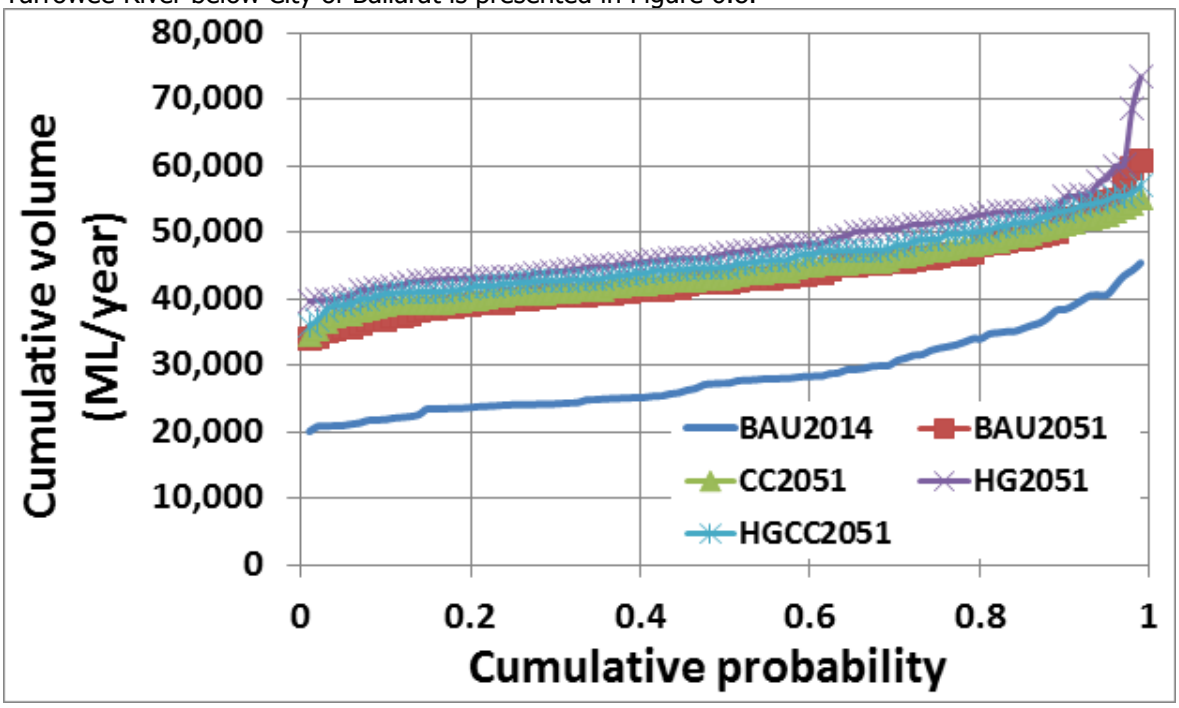

Figure 6.8: Annual stream cumulative flow volumes in the Yarrowee River below City of Ballarat

Figure 6.8 shows that the Yarrowee River in 2051 is subject to significant increases in annual stream flows as compared to stream flows in 2014. This outcome is generated by increased wastewater discharges from the Ballarat South wastewater treatment plant and increased volumes of stormwater runoff from urban development.

The expected increases in urban stormwater runoff and wastewater discharges created by new developments are greater than impact of the extraction of water to supply urban areas, and harvesting of rainwater and stormwater. The climate change scenarios produce generally lower stormwater annual runoff volumes with increased runoff volumes for infrequent events. The high population growth scenario produces greater frequent runoff volumes and lesser flows than 2014 flows more generally in response to increased extractions from the catchment for water supply and rainwater harvesting.

The impacts of the scenarios on average daily flows in the Yarrowee River are presented in Table 6.5

Table 6.5: Average daily stream flow in the Yarrowee River below the City of Ballarat

Scenario	Average daily flow (ML)	Change from 2014 (%)	Change from 2051 (%)
BAU 2014	79	-	-
BAU 2051	119	+ 51	-
CC	121	+ 53	+ 2
HG	131	+ 66	+ 10
HGCC	125	+ 58	+ 6

Table 6.5 shows that the Yarrowee River will experience substantial increases in flows by 2051 for all scenarios due to increases discharges of effluent from the Ballarat South wastewater treatment plant.

The impact of the scenarios on peak daily stream flows in the Yarrowee River below City of Ballarat is presented in Figure 6.9.

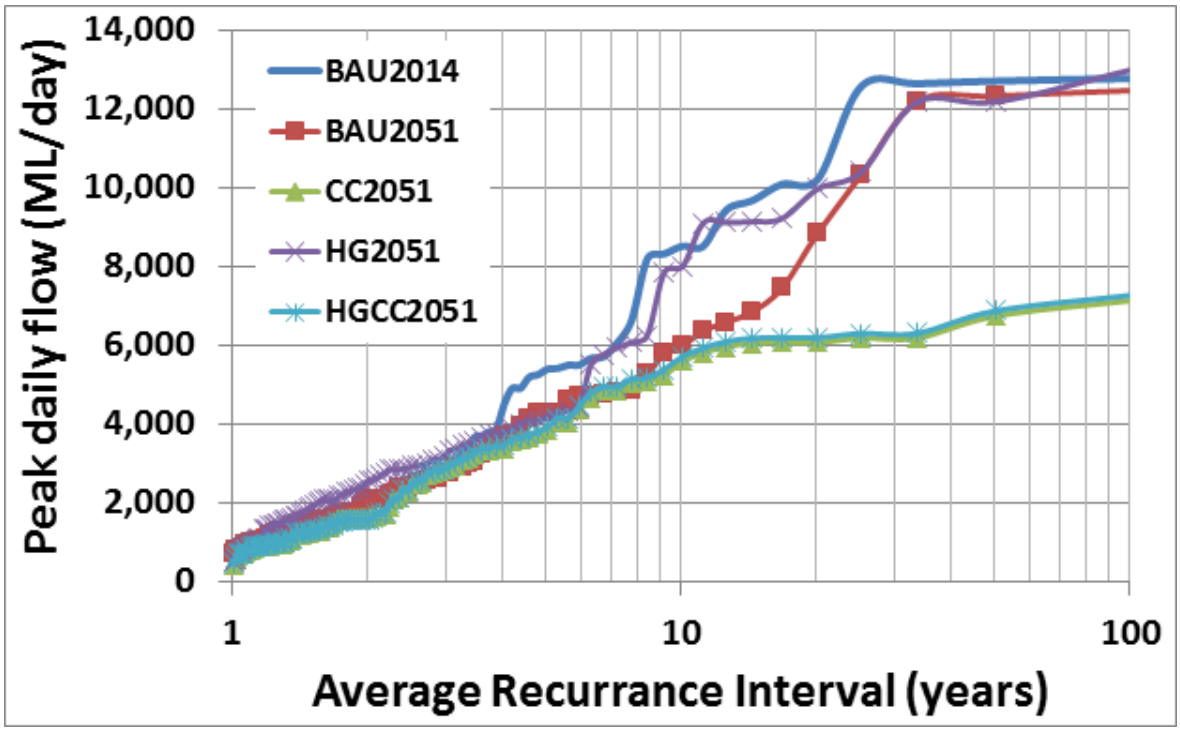

Figure 6.9: Peak daily flows in the Yarrowee River downstream from City of Ballarat

Figure 6.9 shows that the BAU and HG scenarios in 2051 are expected to produce similar peak daily flows as the BAU scenario in 2014. This impact is generated by the regular mode of the discharge of effluent to the river that has limited impact on peak discharges.

The climate change scenarios are expected to reduce daily peak discharges as a consequence of increased extractions from the waterway for water supply and decreased streamflows.

The impacts of the scenarios on the likelihood of flooding in the Yarrowee River Catchment within the City of Ballarat are presented as a proportion of current flood risks in Table 6.6.

Table 6.6: Estimated impacts on the likelihood of flooding in Yarrowee Catchment from 100 year ARI events

Scenario	Impacted properties (%)	Impacted buildings (%)	Change in impacted properties (%)	Change in impacted buildings (%)
BAU2014	2.2	1.4	-	-
BAU2051	2.16	1.37	- 2	- 2
CC2051	1.23	0.78	- 44	- 44
HG2051	2.58	1.64	+ 17	+ 17
HGCC2051	1.25	0.8	- 43	- 43

Table 6.6 reveals that the risk of flooding of properties and buildings in the Yarrowee River Catchment may decrease by 2051 due to increased demands on the Yarrowee River for water supply. The high growth scenarios generate increased flow risks due to greater urban stormwater runoff and the climate change scenarios produce reduced flood risks in response to reduced stream flows and increased water demands.

The flood risks in the City of Ballarat are shown for the Yarrowee River catchment in Figure 6.9a.

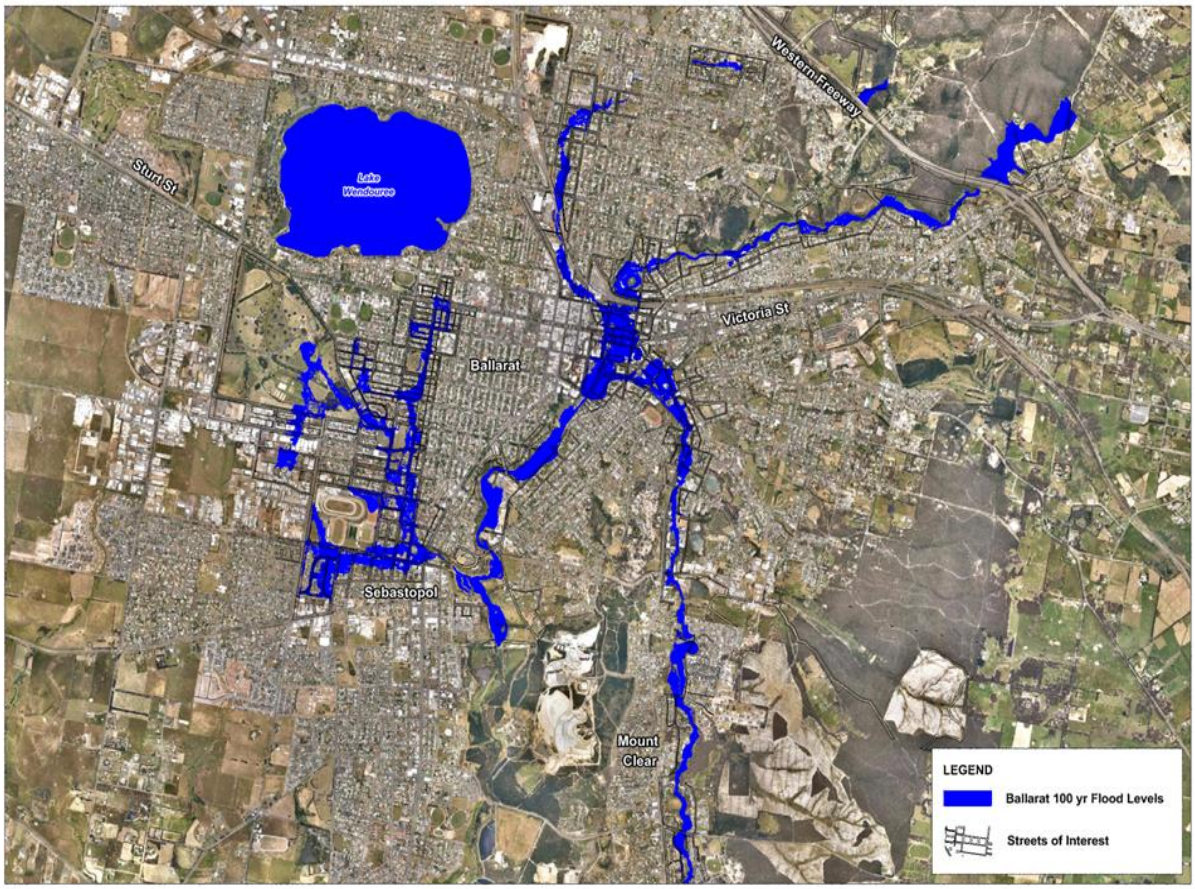

Figure 6.9a: Overlay of flood risks from 100 year ARI rain events in the Yarrowee Catchment within the jurisdiction of the City of Ballarat

The impacts of stormwater runoff from all land uses on water quality in the Yarrowee River just below City of Ballarat as indicated by annual loads of nitrogen are presented in Figure 6.10.

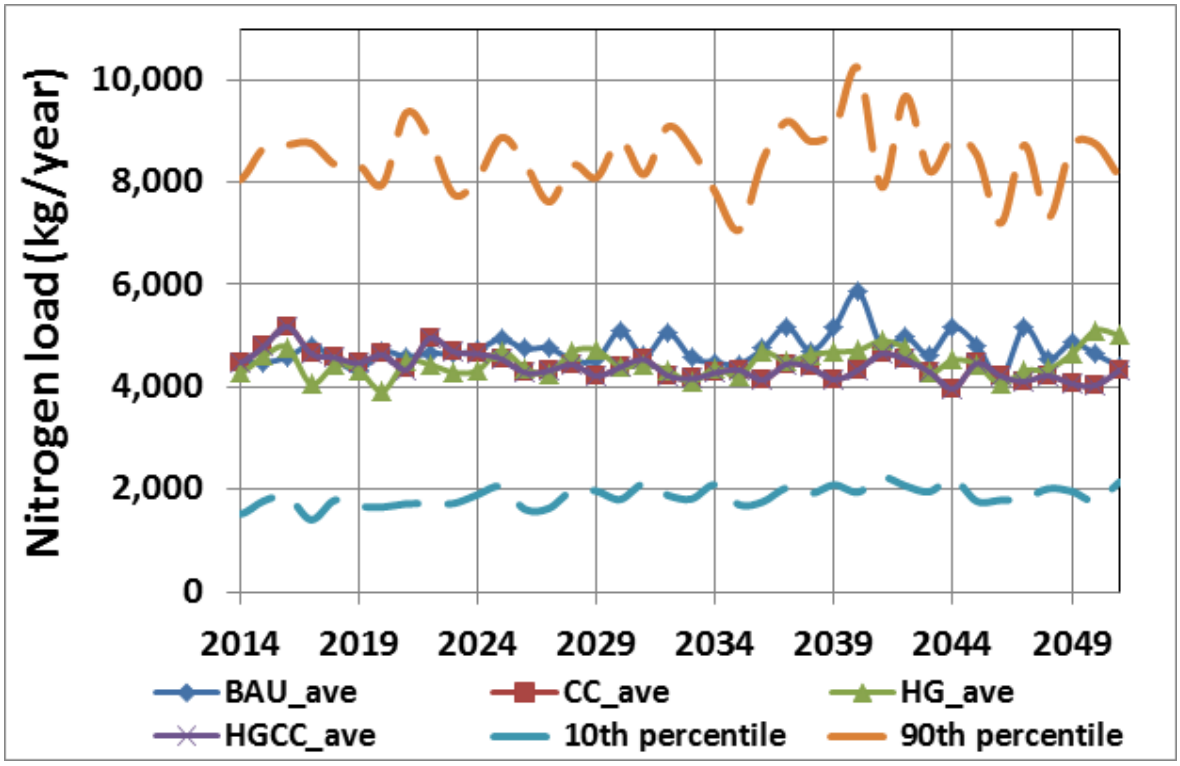

Figure 6.10: Annual nitrogen loads generated by stormwater runoff in the Yarrowee River below City of Ballarat

Figure 6.10 reveals that the average annual nitrogen loads generated by stormwater runoff in the Yarrowee River Catchment below City of Ballarat are expected to remain stable or slightly reduce during the planning horizon. This result is driven by three key factors:

- replacement of agricultural land uses with urban land uses decreases nitrogen loads in stormwater runoff,
- a growing proportion of the urban catchment includes rainwater harvesting on properties and the catchment also includes stormwater harvesting, and
- the climate change scenario reduces stream flows in the River.

These key factors also result in diminished loads of nitrogen in the river for the high growth and climate change scenarios. However, the Ballarat South wastewater treatment plant also discharges effluent that has been subject to tertiary treatment (assumed nitrogen content was 10 mg/L) to the Yarrowee River. The total annual nitrogen loads discharging to the Yarrowee River below City of Ballarat are provided in Figure 6.11.

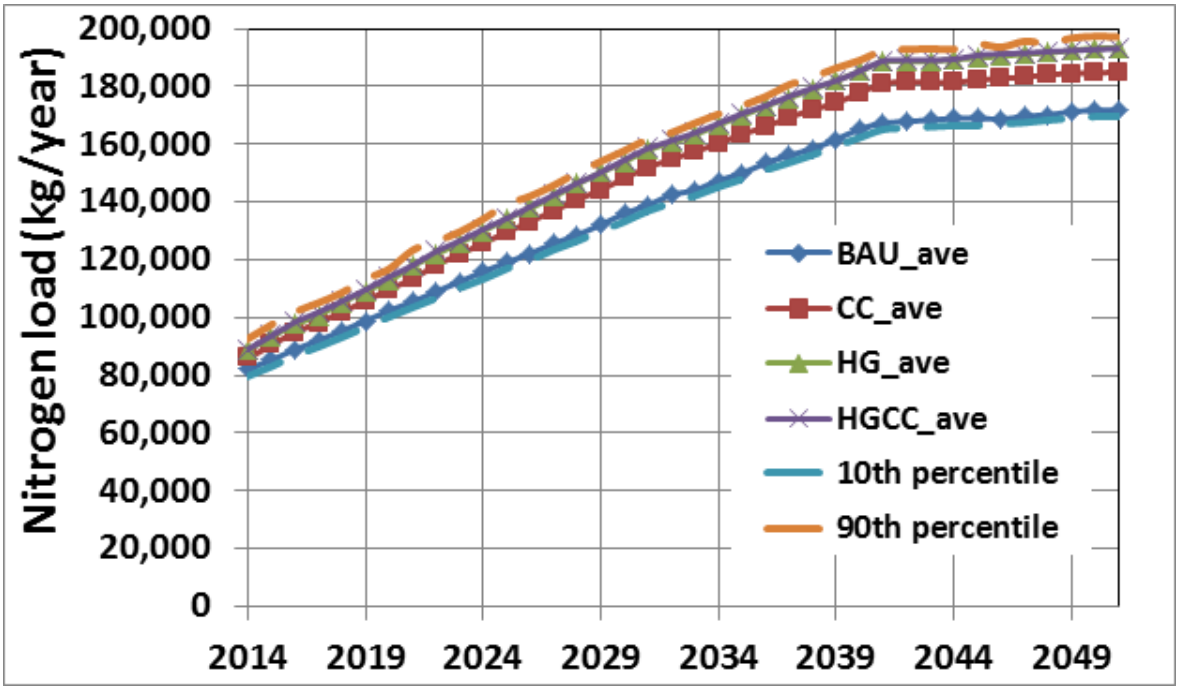

Figure 6.11: Total annual loads of nitrogen in the Yarrowee River below City of Ballarat

Figure 6.11 indicates that the discharges from the Ballarat South wastewater treatment plant dominate the water volumes and nitrogen loads in the Yarrowee River below the City of Ballarat.

These potential nitrogen loads may potentially diminish the health of the waterway and lead to increased risks of algae outbreaks. Similar impacts are expected for annual loads of phosphorus and suspended solids.

The annual loads of phosphorus generated by stormwater runoff in the Yarrowee River just below City of Ballarat are presented in Figure 6.12. The total annual phosphorus loads discharging to the Yarrowee River below City of Ballarat are presented in Figure 6.13.

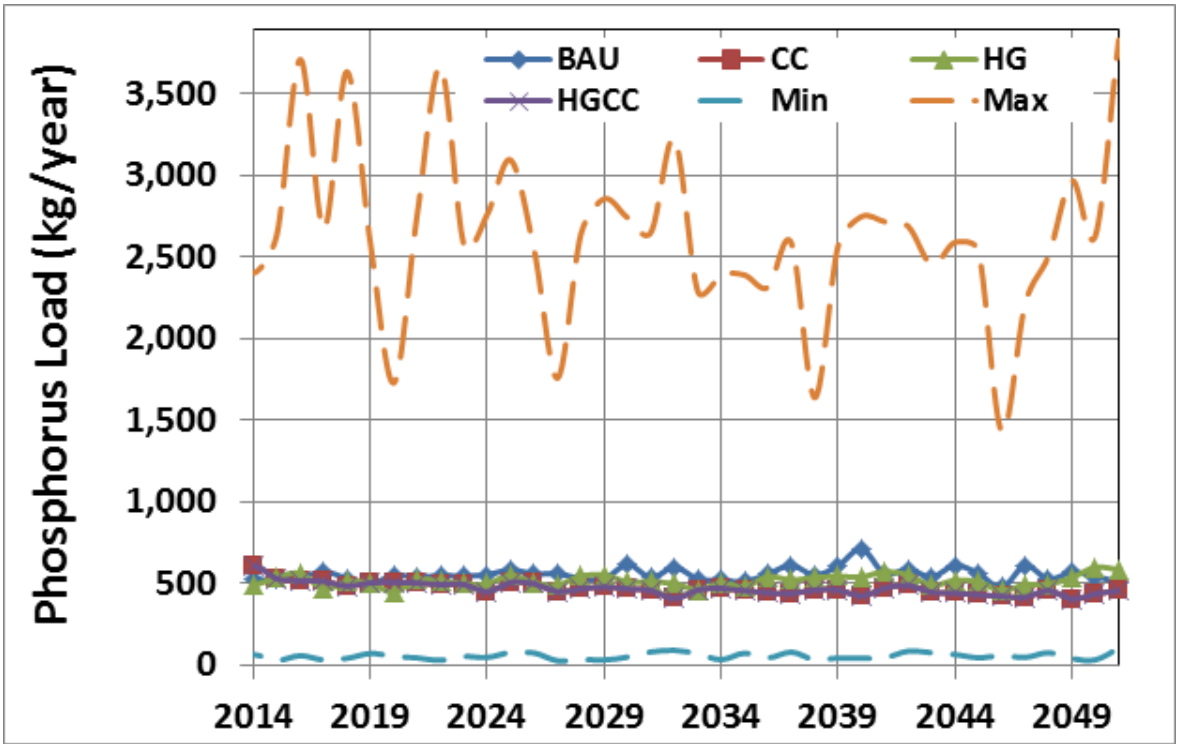

Figure 6.12: Annual phosphorus loads generated by stormwater runoff in the Yarrowee River below City of Ballarat

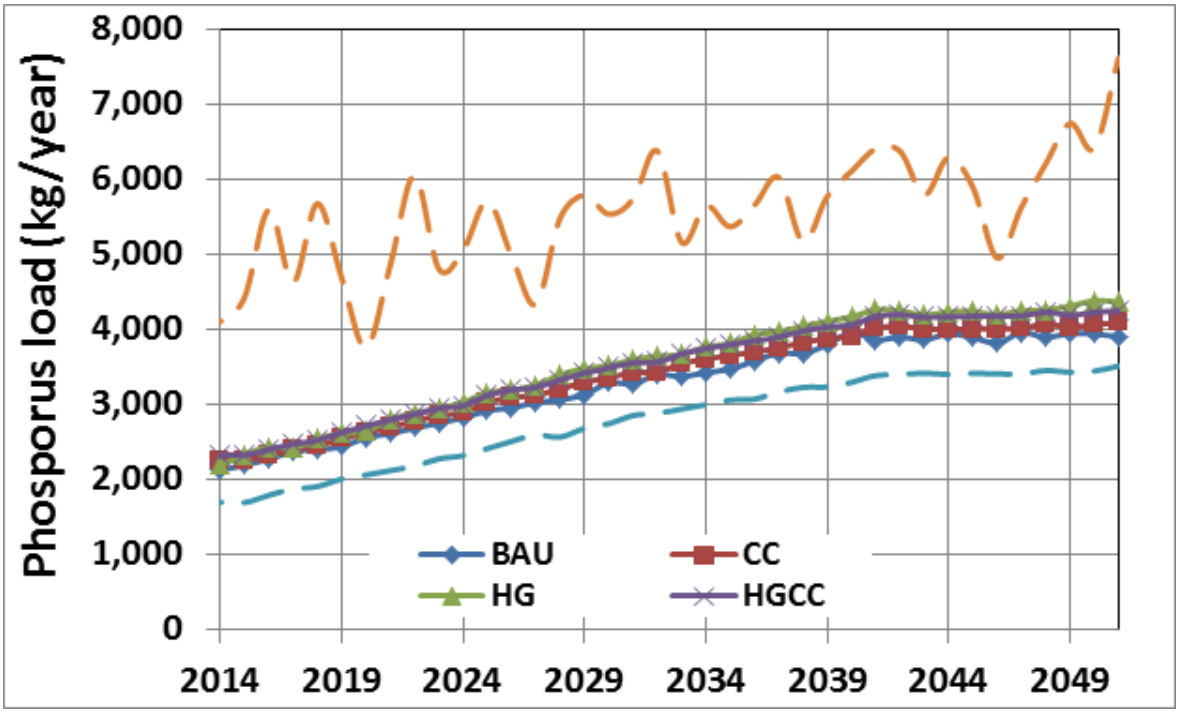

Figure 6.13: Total annual loads of phosphorus in the Yarrowee River below City of Ballarat

The annual loads of total suspended solids in the Yarrowee River just below City of Ballarat created by stormwater runoff are presented in Figure 6.14. The total annual total suspended solids loads discharging to the Yarrowee River below City of Ballarat are presented in Figure 6.15.

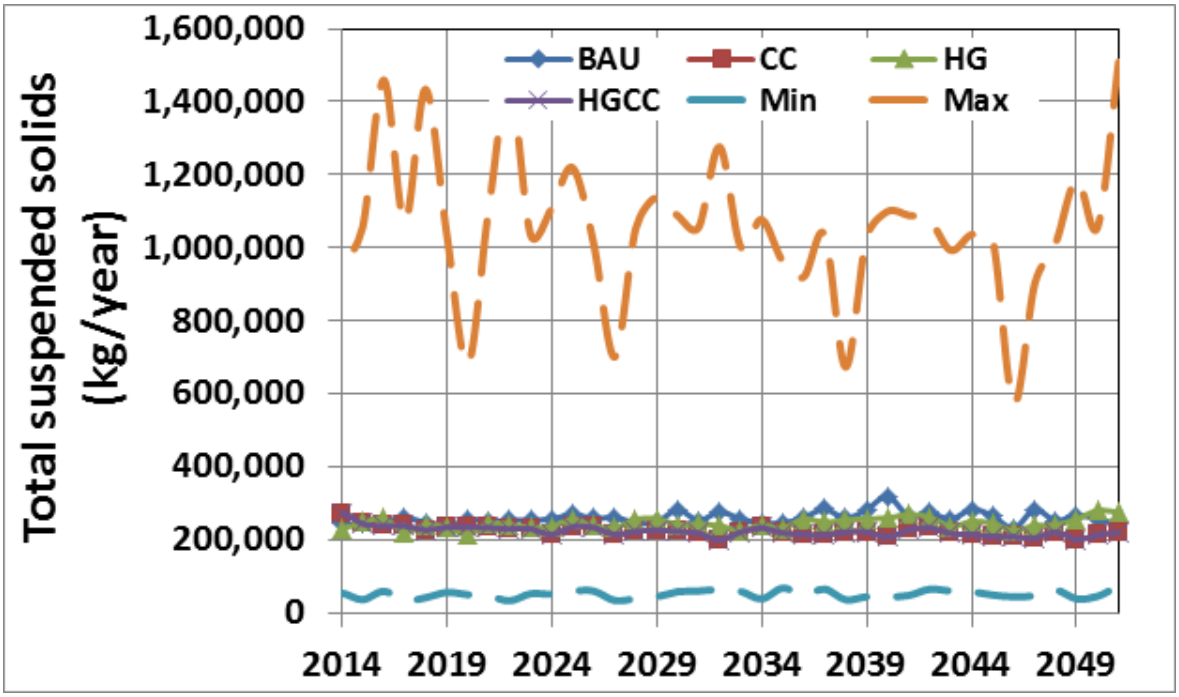

Figure 6.14: Annual total suspended solids loads generated by stormwater runoff in the Yarrowee River below City of Ballarat

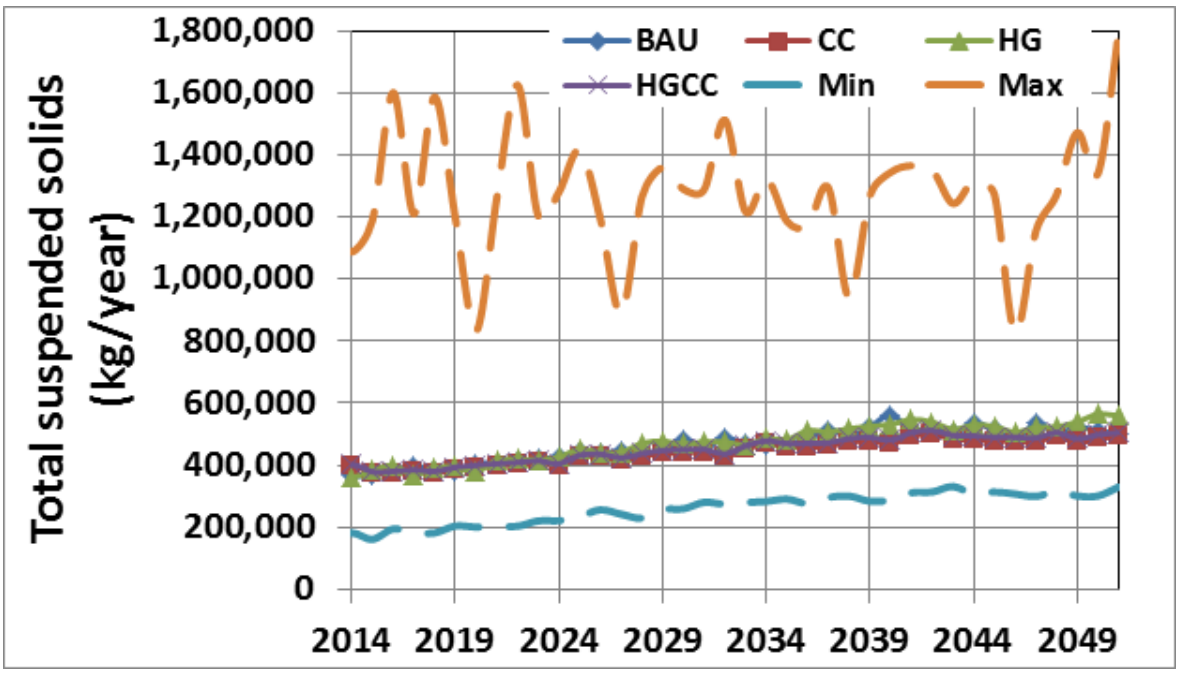

Figure 6.15: Total annual loads of total suspended solids in the Yarrowee River below City of Ballarat

Figures 6.10 to 6.15 indicate that effluent from the Ballarat South wastewater treatment plant has a substantial and increasing impact on the water quality in the Yarrowee River as indicated by loads of nitrogen, phosphorus and total suspended solids. These potential impacts on waterway health in the Yarrowee River highlight that waterways need to also been included in the trade-offs for water cycle futures – for example; wastewater reuse from Ballarat South wastewater treatment

plant will decrease the volumes of fresh water extracted from the river whilst decreasing the volumes of wastewater discharged to the river resulting in higher quality flows.

The impact of the scenarios on stream flows in Burrumbeet Creek below the Ballarat North wastewater treatment plant and upstream of the Sunraysia Highway (Node MECk307 in the Systems Framework) is presented in Figure 6.16. Note that Burrumbeet Creek is impacted by urban development, stormwater harvesting and wastewater discharges at this location but is not subject to extractions for water supply.

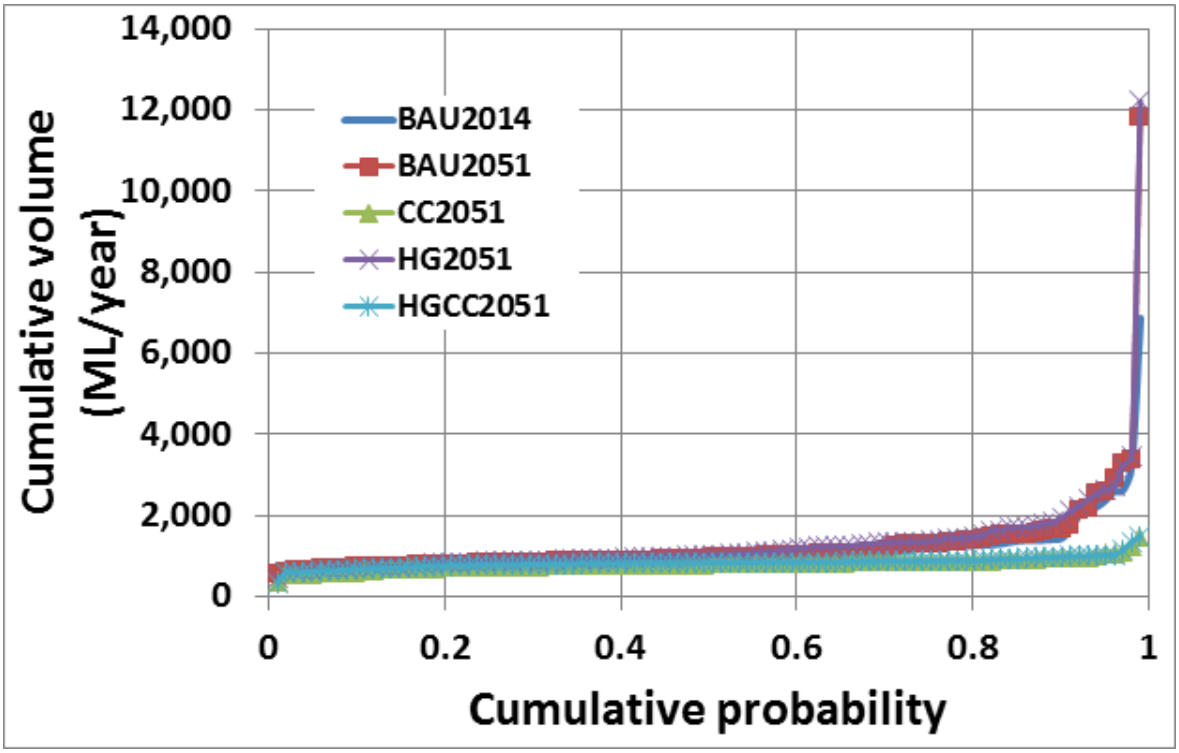

Figure 6.16: Annual cumulative flow volumes in Burrumbeet Creek upstream of Sunraysia Highway

Figure 6.16 reveals that Burrumbeet Creek may experience substantial increases in annual stream flows from BAU and HG scenarios and the climate change scenarios may substantially decrease annual stream flows.

The impacts of the scenarios on average daily flows in Burrumbeet Creek are presented in Table 6.7

Table 6.7: Average daily stream flow in Burrumbeet Creek upstream of Sunraysia Highway

Scenario	Average daily flow (ML)	Change from 2014 (%)	Change from 2051 (%)
BAU 2014	3.41	-	-
BAU 2051	3.36	- 1.5	-
CC	2.22	- 35	- 34
HG	3.58	+ 5	+ 6.5
HGCC	2.28	- 33	- 32

Table 6.7 shows that Burrumbeet Creek will experience greater average flows by 2051 for the high growth (HG) scenario due to increases discharges of effluent from the Ballarat North wastewater treatment plant and increased urban runoff. Reductions in average stream flows are expected for the BAU and climate change scenarios. The impact of the scenarios on peak daily stream flows in Burrumbeet Creek is presented in Figure 6.17.

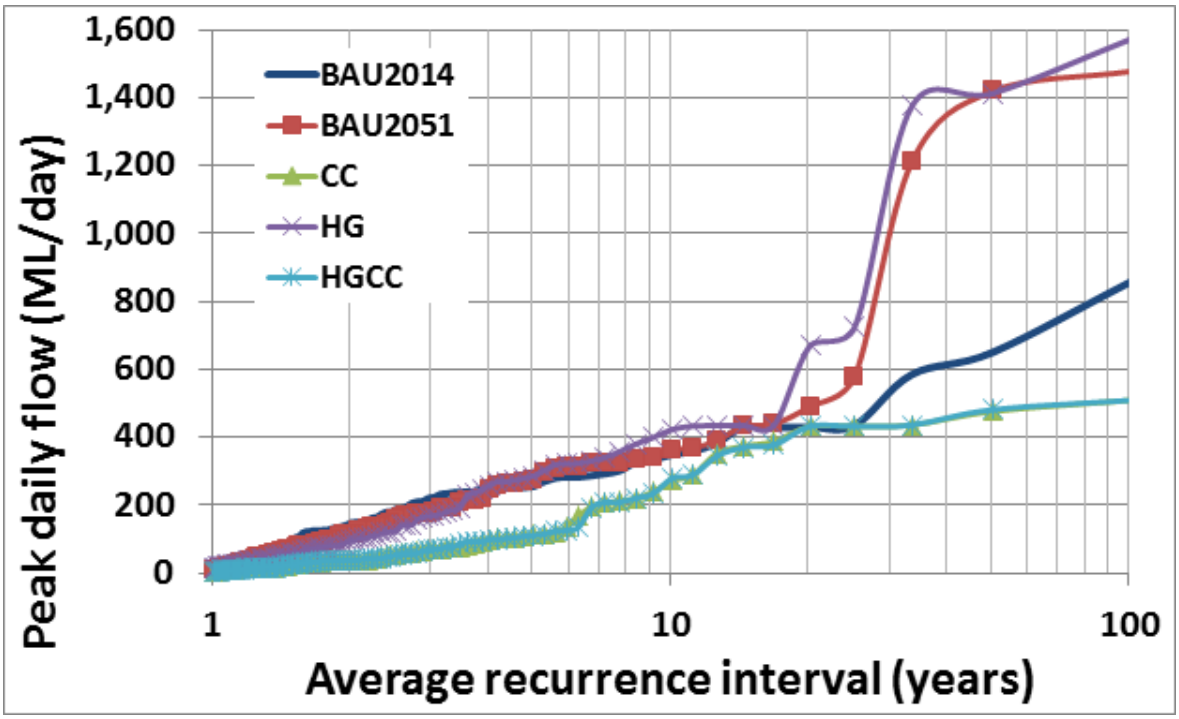

Figure 6.17: Peak daily flows in Burrumbeet Creek upstream of Sunraysia Highway

Figure 6.17 reveals that the BAU and high growth scenarios will generate increased peak daily flows in Burrumbeet Creek by 2051 for rainfall events with average recurrence intervals (ARI) greater than 20 years. This result indicates increased likelihood of flooding. However, the climate change scenarios reduce stream flows and increase demands for treated wastewater from Ballarat North wastewater treatment plant resulting substantial reductions in peak daily flows.

The impacts of the scenarios on the likelihood of flooding in the Burrumbeet Creek Catchment within the City of Ballarat are presented as a proportion of current flood risks in Table 6.8.

Table 6.8: Estimated impacts on likelihood of flooding in Burrumbeet Catchment from 100 year ARI events

Scenario	Impacted properties (%)	Impacted buildings (%)	Change in impacted properties (%)	Change in impacted buildings (%)
BAU2014	1.0	0.4	-	-
BAU2051	1.7	0.7	72.1	72.1
CC2051	0.6	0.3	-40.7	-40.7
HG2051	1.8	0.8	83.2	83.2
HGCC2051	0.6	0.3	-40.7	-40.7

Table 6.8 shows that the risk of flooding of properties and buildings in the Burrumbeet Creek Catchment may increase by 2051 due to increased urban growth within the catchment. A spatial overview of flood risks from 100 year ARI rain events is presented in Figure 6.17a.

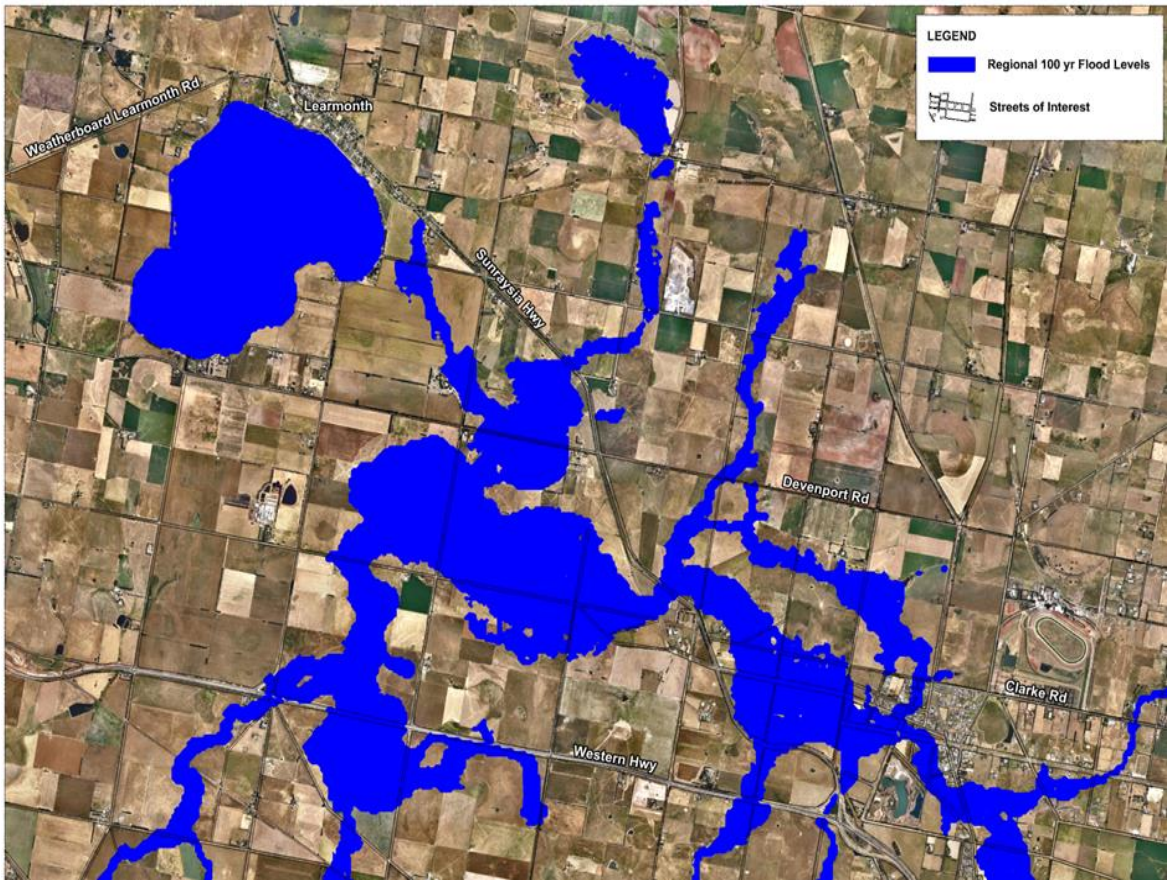

Figure 6.17a: Overlay of flood risks from 100 year ARI rain events in the Burrumbeet Creek Catchment within the jurisdiction of the City of Ballarat

The impacts of stormwater runoff from all land uses on water quality in Burrumbeet Creek just below City of Ballarat as indicated by annual loads of nitrogen are presented in Figure 6.18.

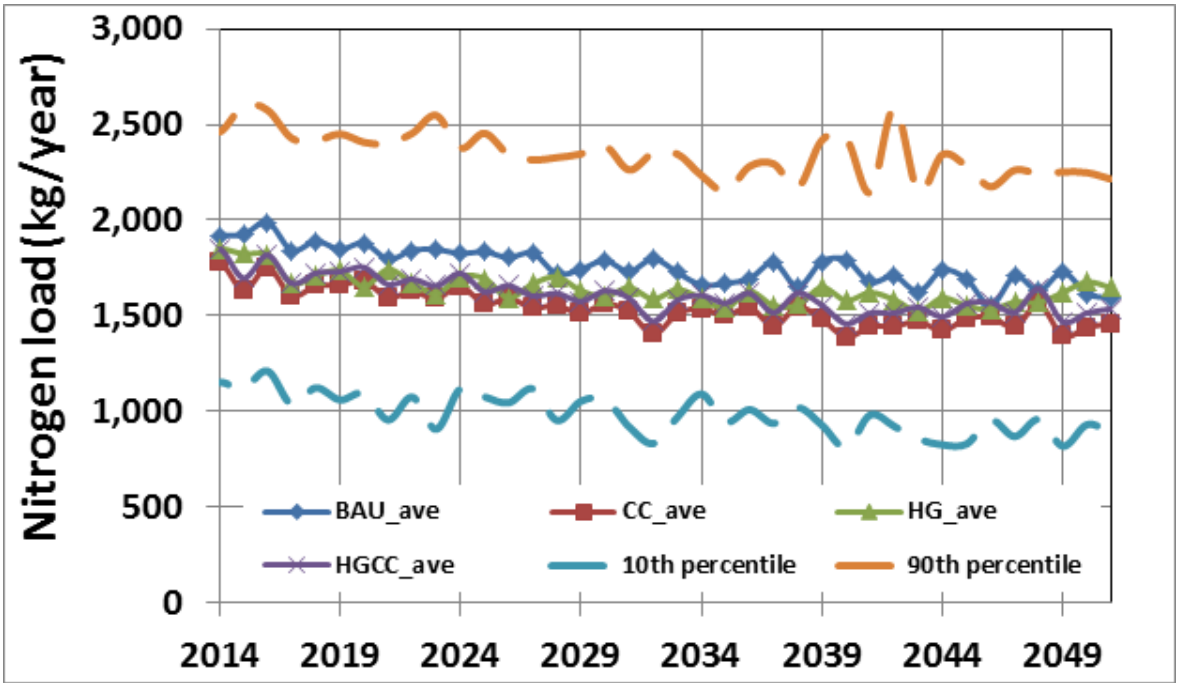

Figure 6.18: Annual nitrogen loads generated by stormwater runoff in the Burrumbeet Creek below City of Ballarat

Figure 6.18 shows that replacing agricultural land uses with urban land uses reduced average annual loads of nitrogen generated by stormwater runoff to the waterway. The lower volumes of stream flows and higher rates of urban development in the climate change and high growth scenarios has generated further reductions in average annual loads of nitrogen. These results are highly variable.

The Ballarat North wastewater treatment plant also discharges effluent that has been subject to tertiary treatment (assumed nitrogen content was 10 mg/L) to the Burrumbeet Creek. A substantial proportion of the treated wastewater from the wastewater treatment plant is utilised to supply irrigation demands and to top up Lake Wendouree which reduces discharges of effluent to Burrumbeet Creek.

The total annual nitrogen loads discharging to the Burrumbeet Creek below City of Ballarat are provided in Figure 6.19.

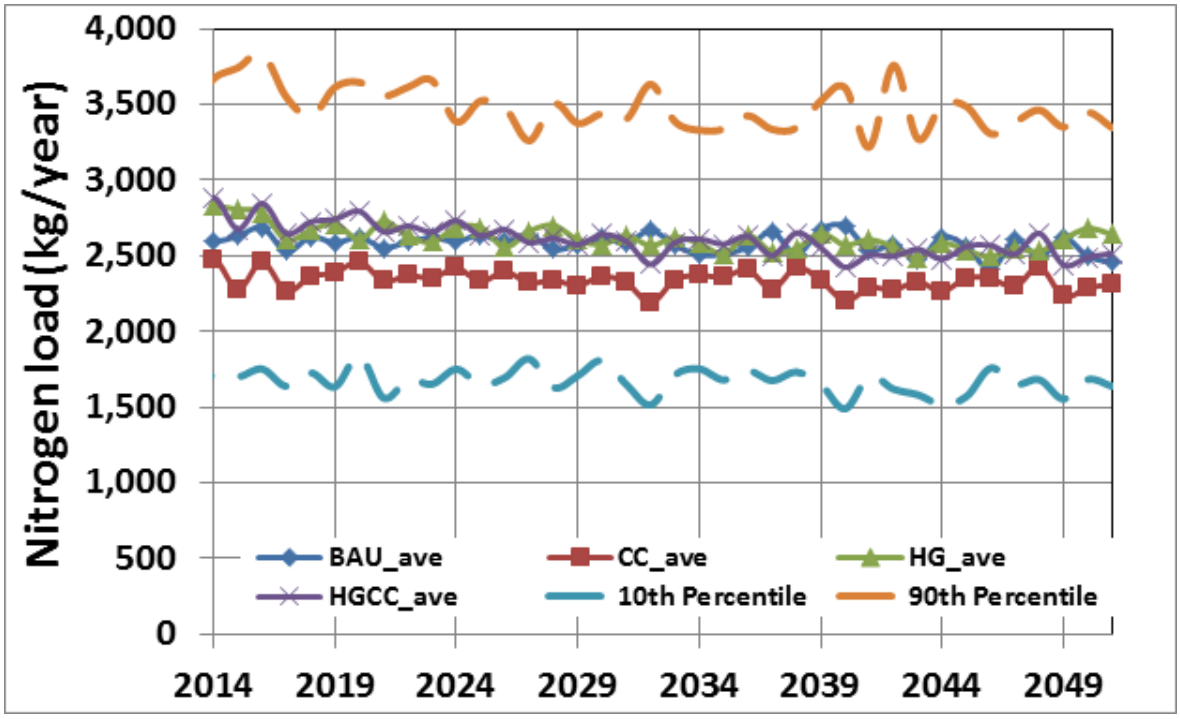

Figure 6.19: Total annual loads of nitrogen in Burrumbeet Creek upstream of Sunraysia Highway

Figure 6.19 highlights that effluent discharges from the Ballarat North wastewater treatment plant has increased annual loads of nitrogen in Burrumbeet Creek. However, the upgrades to the treatment plant and reuse of treated wastewater has provided substantial improvements in nitrogen loads in comparison to previously reported annual loads of 48,000 kg/year (prior to the upgrades).

Similar results are expected for the loads of phosphorus and total suspended solids in the waterway.

The annual loads of phosphorus generated by stormwater runoff in the Burrumbeet Creek upstream of Sunraysia Highway are presented in Figure 6.20. The total annual phosphorus loads discharging to the Burrumbeet Creek are presented in Figure 6.21.

The annual loads of total suspended solids generated by stormwater runoff in the Burrumbeet Creek upstream of Sunraysia Highway are presented in Figure 6.22. The total annual total suspended solids loads discharging to the Burrumbeet Creek are presented in Figure 6.23.

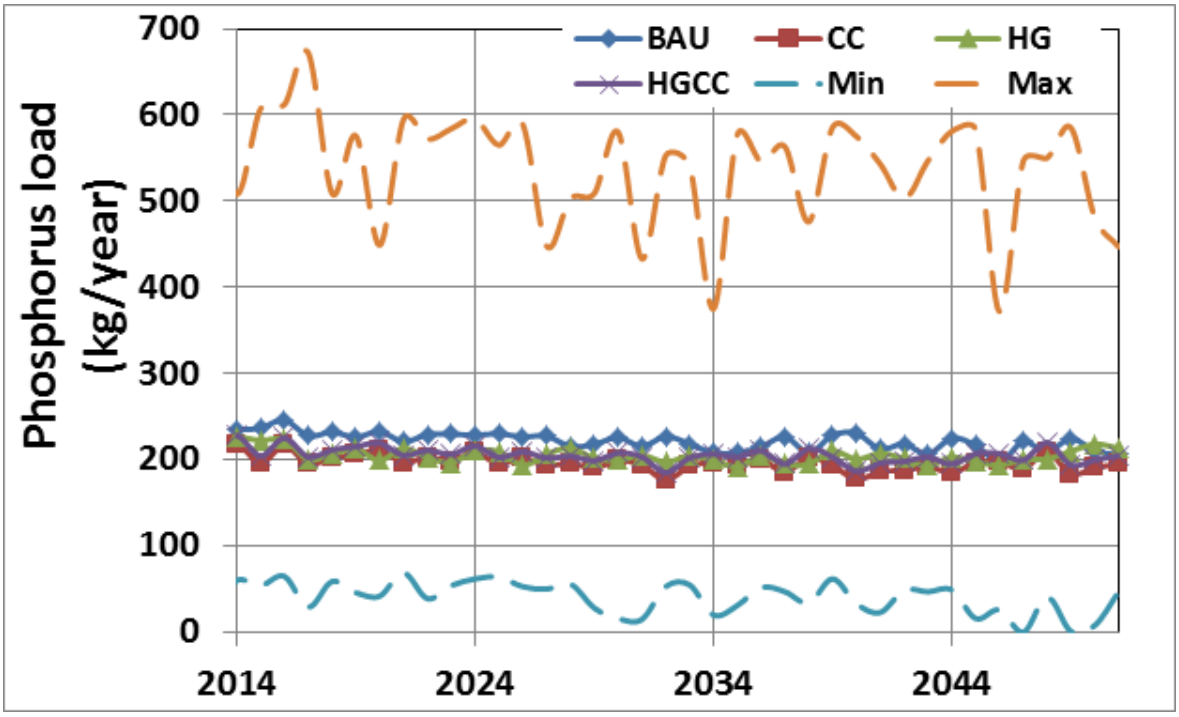

Figure 6.19: Annual phosphorus loads generated by stormwater runoff in the Burrumbeet Creek below City of Ballarat

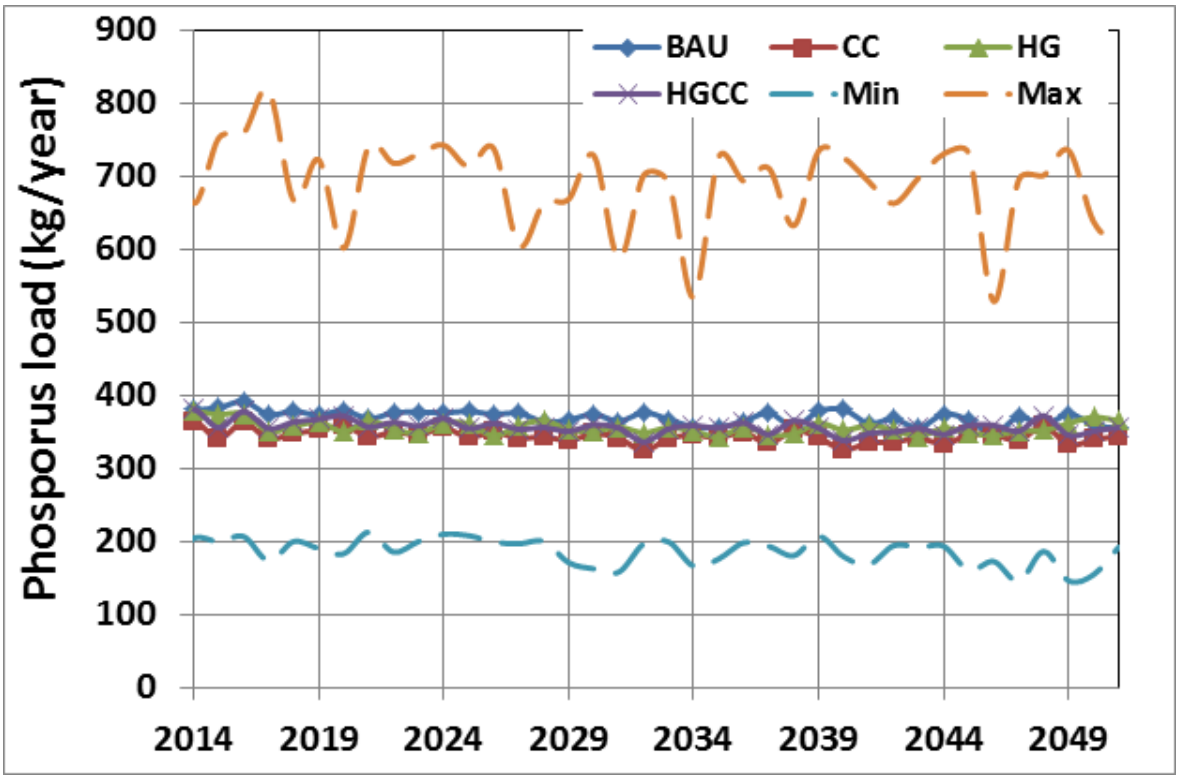

Figure 6.21: Total annual loads of phosphorus in Burrumbeet Creek upstream of Sunraysia Highway

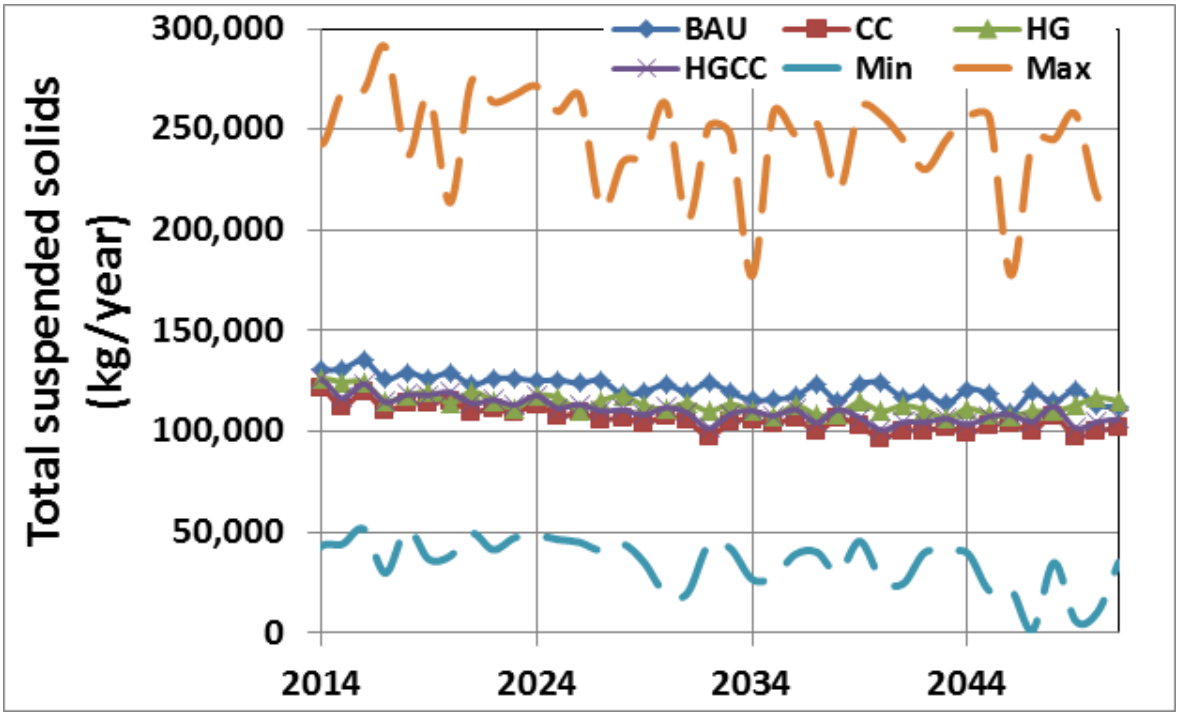

Figure 6.22: Annual loads of total suspended solids generated by stormwater runoff in the Burrumbeet Creek below City of Ballarat

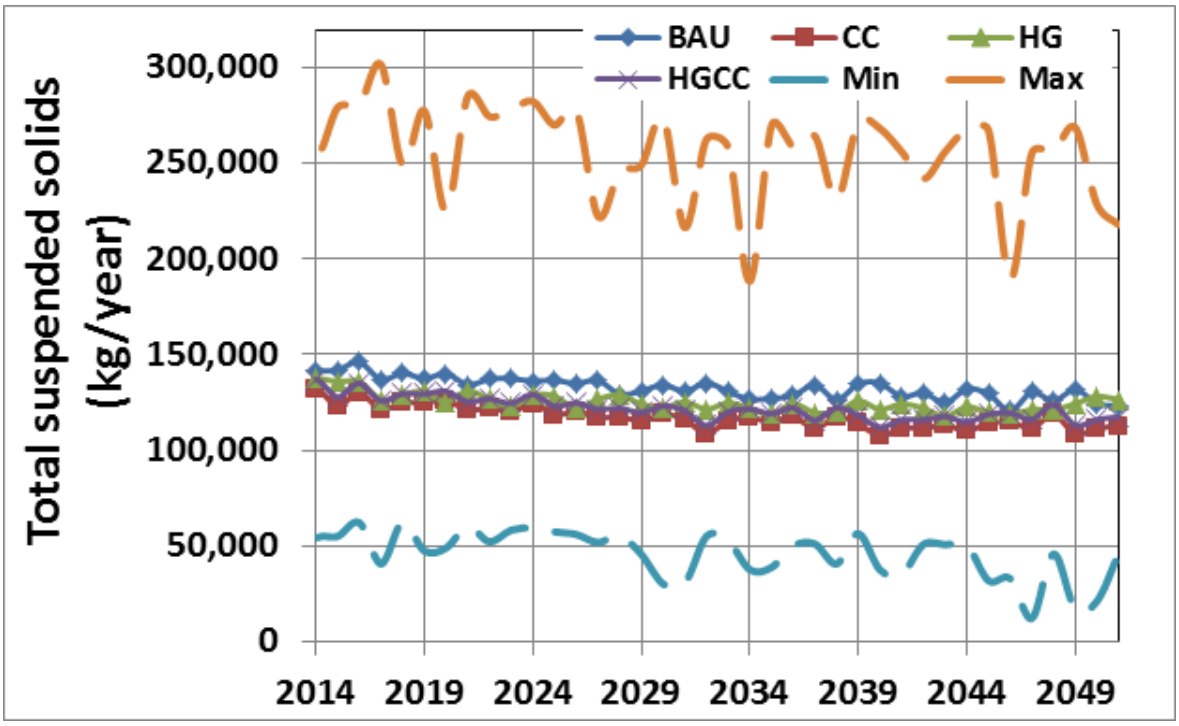

Figure 6.23: Total annual loads of total suspended solids in Burrumbeet Creek upstream of Sunraysia Highway

Figures 6.20 to 6.23 show that diminishing loads of phosphorus and total suspended solids are expected in Burrumbeet Creek due to urban development replace a proportion of agricultural activity. However, discharge of effluent from the Ballarat North wastewater treatment plant

increases these impacts and reuse of wastewater has limited the impacts of discharging effluent into the waterway.

The catchments supplying the Moorabool River are subject a range of rural land uses including grazing, cropping and water storages. The river is highly degraded upstream of Lal Lal reservoir as a consequence of rural land uses and extractions of water to meet urban demands.[27] The West Moorabool River is considered to be one of Victoria's most flow-stressed rivers. In addition to changes brought about by river regulation and increasing water consumption between 1997 and 2009, south-eastern Australia has experienced the worst drought of the instrumental record. The prolonged drought conditions resulted in a qualification of rights for critical human supply in November 2006. The resultant changes to passing flow requirements led to a series of prolonged cease to flow events. The river was reduced to a series of isolated pools.[28] The performance of West Moorabool River downstream of Lal Lal Reservoir is provided in Figure 6.24.

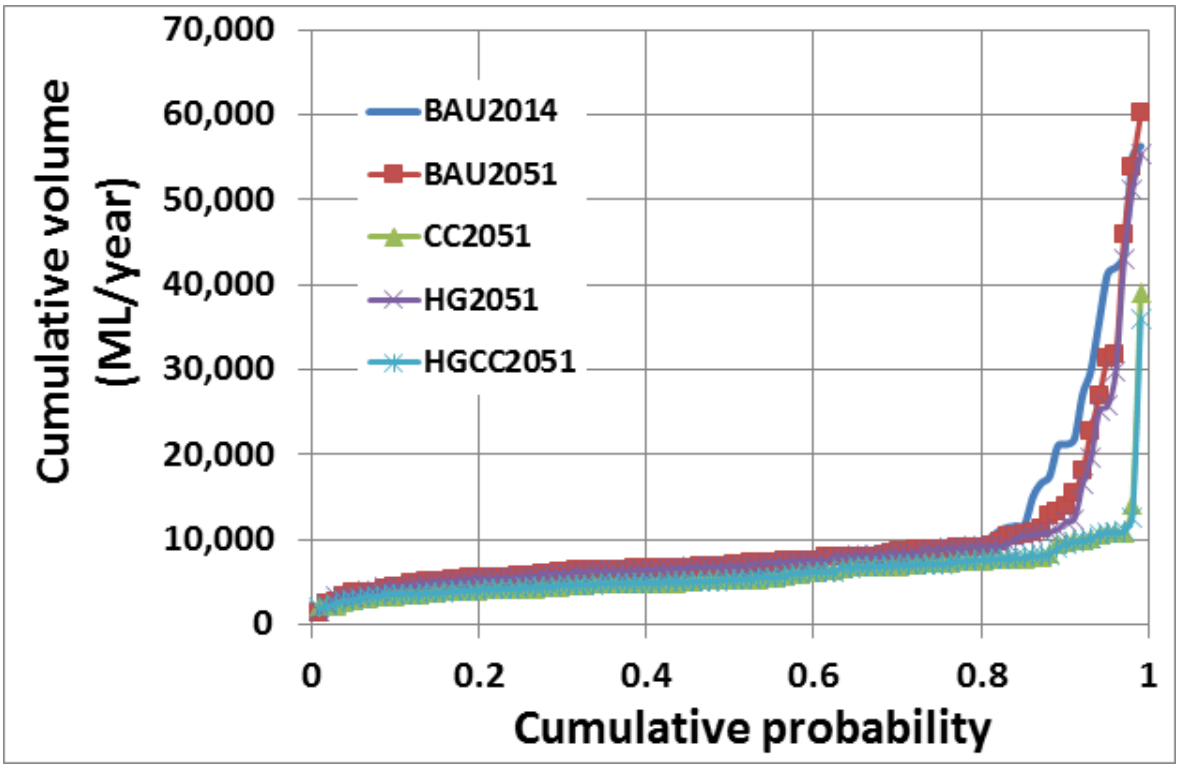

Figure 6.24: Stream flow volumes in the West Moorabool River downstream from Lal Lal Reservoir

Figure 6.24 shows that the annual volumes of stream flow in Moorabool River below Lal Lal Reservoir have lower flows in 2051 as compared to 2014 for the BAU and HG scenarios. The climate change scenarios (CC and HGCC) generate lower flows by 2051.

The impacts of the scenarios on average daily flows in the West Moorabool River are presented in Table 6.9

[27] Fletcher Tim (1998). The cumulative effects of recent land and water use on the West Moorabool River, Victoria, Australia. PhD Thesis. University of Melbourne.
[28] http://www.ccma.vic.gov.au/What-we-do/Water/Environmental-Water/Moorabool-River-Environmental-Entitlement.aspx

Table 6.9: Average daily stream flow in the West Moorabool River below Lal Lal Reservoir

Scenario	Average daily flow (ML)	Change from 2014 (%)	Change from 2051 (%)
BAU 2014	26	-	-
BAU 2051	25.7	- 1.1	-
CC	17.8	- 31.5	- 30.7
HG	24.6	- 5.4	- 4.3
HGCC	16.7	- 35.8	- 35

Table 6.9 shows that the West Moorabool River will experience substantial decreases in flows by 2051 for all scenarios due to increased urban water demands and climate change.

The results for Burrumbeet Creek and Moorabool Rivers indicate that lower flows are expected by 2051. The climate change scenarios are expected to substantially reduce flows in the waterways. In contrast, the Yarrowee River is likely to be subject to substantial increases in flows that are generated by effluent discharges from wastewater treatment.

However, the flows in Moorabool River are dependent on the operating rules applied to the water supply system whereas the flows in the Yarrowee River are also dependent on options chosen for urban development and for water supply within the catchment. Decisions about water supply and urban development in each river catchment impact on downstream ecosystems and communities.

The future quality of the Yarrowee River and Burrumbeet Creek are also dependent on management of wastewater treatment plants in the associated catchments. In addition, the health of the waterways is dependent on frequency and quantum of freshwater flows. The Yarrowee River may be subject flow regimes that are too high and the West Moorabool River is likely to be subject to flows that are too low for preserve the resilience of the streams.

The Systems Framework has provided an opportunity to examine and optimise the trade-offs between centralised and local water supply, river health and flooding issues throughout the Ballarat water district.

Maryborough

The Maryborough water district includes the town of Maryborough and surrounding localities including Talbot, Carisbrook, Bet Bet and Daisy Hill.

Water Demand

Simulated water demands from this district are presented in Figure 6.25.

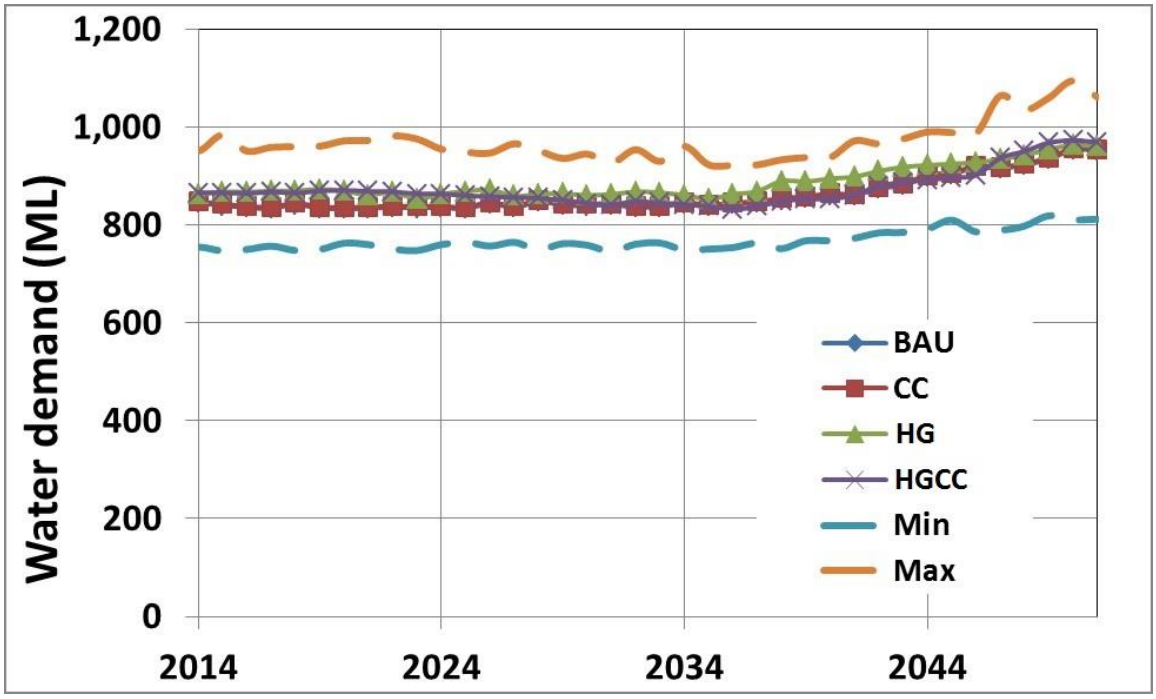

Figure 6.25: Water demand for Maryborough

Figure 6.25 shows that the Maryborough water district is expected will be subject to moderate increases in annual water demands to 2051 that range from an increase of 135 ML for BAU (17%) to 153 ML for HGCC (19%). The future annual water demands for the district are also subject to significant variation with annual water demands ranging from a minimum of 812 ML to a maximum of 1,061 ML in 2051. The scenarios with high population growth (HG) climate change (CC) produce higher water demands.

The results presented in Figure 6.16 represent the summation of water demands from end users of water. The simulations include an additional 24% allowance for losses and unaccounted for water consumption and produce water demands that are consistent with the Water Supply Demand Strategy for Maryborough.

Water Security

The results for the security of water supplies as defined by the annual probability of water restrictions or water shortages are provided in Table 6.10.

Table 6.10: Summary of the timing of water supply augmentation

Scenario	Timing
Base case (BAU)	>2051
Climate change (CC)	2037
High growth (HG)	>2051
HG + CC	2027

Table 6.10 reveals that the different scenarios impact on the timing of the increasing annual probability of water restrictions or shortages. The annual probability of water restrictions does not exceed the 5% trigger for unacceptable water security for the BAU and High Growth scenarios.

Inclusion of the Stoney Creek and Moolort bore fields in the simulations has produced a low probability of water restrictions whilst the climate change scenarios have diminished availability of water from waterways. This result is consistent with the published Water Supply Demand Strategy for Maryborough.[29]

The uncertainty about water supply yields versus water demands for the Maryborough water district are presented in Figure 6.25a. Note that the maximum water supply yield for Maryborough includes the full time use of the Moolort borefield.

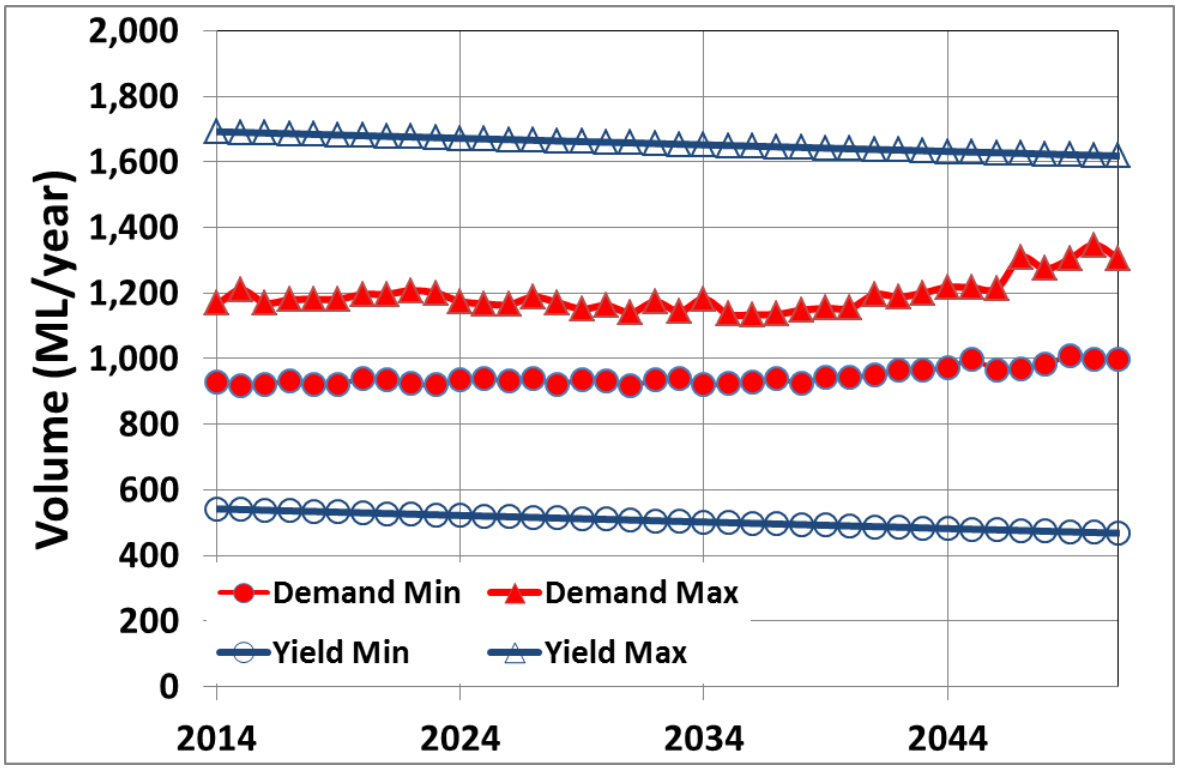

Figure 6.25a: Variation in water demands versus water supply yields for the Ballarat water district

Figure 6.25a reveals that the expected variability of water demands and water sources generates considerable uncertainty about the future security of water supplies to the Maryborough water district. The timing of need to augment that water supply system ranges from 2014 to beyond the planning horizon. This insight highlights a requirement for a diverse portfolio of water supply strategies, the importance of ground water resources and for careful monitoring of the behaviour of regional systems.

Bulk Water Sources

The simulated bulk water extractions from Tullaroop Reservoir to supply water to the Maryborough district are presented in Figure 6.26.

[29] Central Highlands Water (2012). Maryborough and District Water Supply Demand Strategy 2011 – 2060.

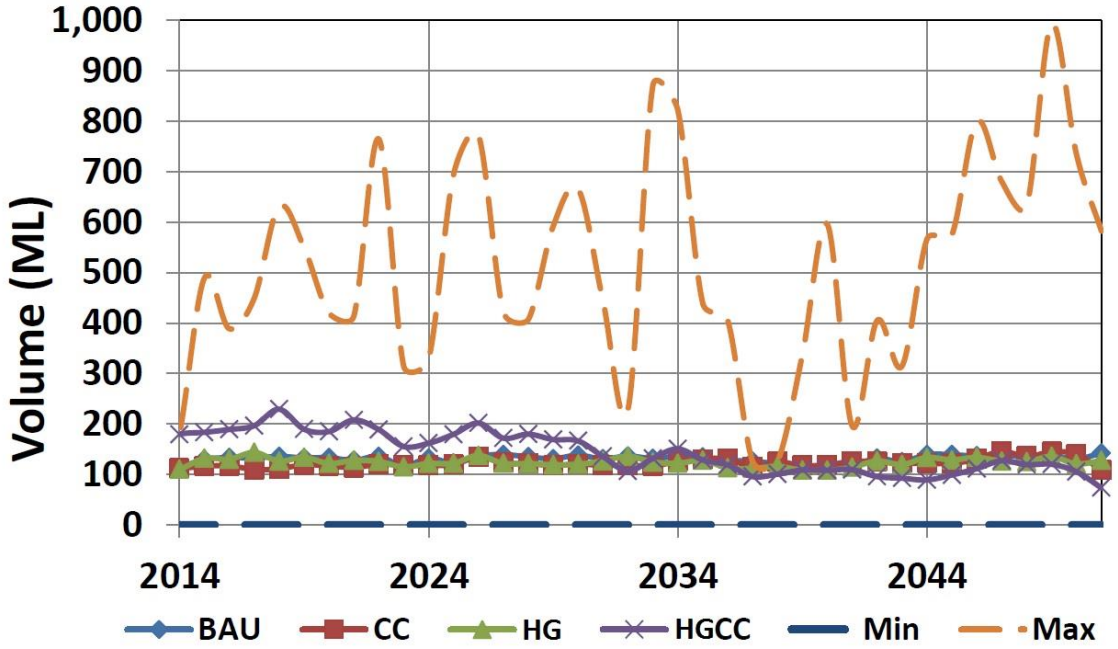

Figure 6.26: Bulk water extractions from Tullaroop Reservoir

Figure 6.26 reveals that the average annual water supply from Tullaroop Reservoir is less than the annual allocation of 600 to 1,200 ML throughout the period from 2014 to 2051. However there is a 10% probability that the lower annual allocation of 600 ML will be exceeded, in some years, after 2016.

Water Balance

The components for fulfilling water demands for the Maryborough water district in 2051 are presented as a combination of the four scenarios in Figure 6.27.

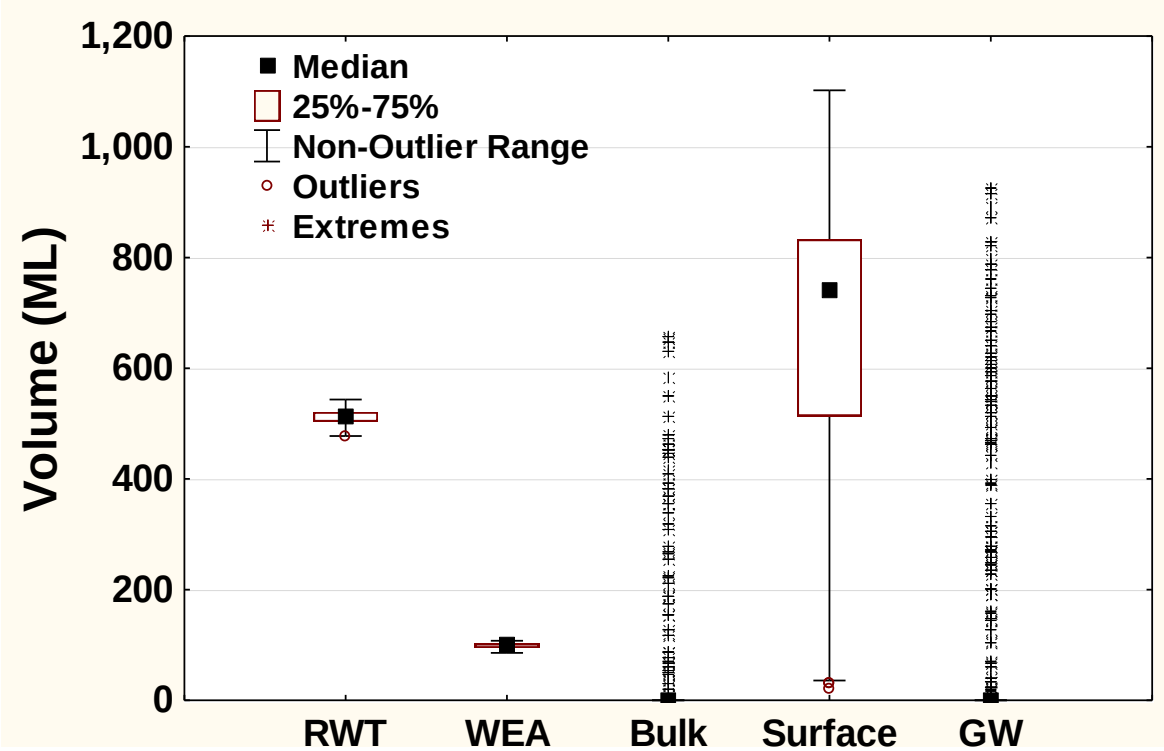

Figure 6.27: The components of fulfilling water demands of the Maryborough water district in 2051

Figure 6.27 shows that water demands in 2051 for the Maryborough district were fulfilled using water supplies from bulk water (Bulk), local surface water (Surface), rain water (RWT) and ground water (GW) sources. Note that the water balance also includes water savings (WEA) from water efficient appliances and practices. Water supply or reductions in water use provided by water efficiency (WEA) and rainwater harvesting (RWT) represent the embedded reductions in local water use that have reduced the overall demands on the water supply system since 2002.

This Figure also highlights the relative magnitude and variability of the components of meeting water demands for the BAU scenarios. The Maryborough district is highly dependent on surface water supplies from McCallums (Evansford reservoir) and Stoney (Talbot Reservoir) Creeks and the supply this water form these sources is highly variable. The magnitude of water supply from bulk surface water sources (Tullaroop reservoir) and from ground water is significantly less than supplies from surface water sources. Nevertheless, the variability of water supply from Tullaroop Reservoir and ground water (Stoney Creek and Moolort bore fields) is significant as a consequence of the variability of local surface water supplies.

A majority of centralised water supplies to the Maryborough district is represented by surface water supplies with relatively small contributions of bulk water from Tullaroop Reservoir and ground water from the Stoney Creek and Moolort bore fields. Over 80% of centralised water supplies and over 50% of the overall water balance for the Maryborough district in 2051 are provided by surface water sources from the upper reaches of waterways. This is a substantial dependence on water resources that are shared with other urban communities, the rural sector and ecosystems. There is a need to examine the availability of local water sources that will reduce dependency on external water sources.

The availability of stormwater runoff generated by urban areas and wastewater discharges to the Maryborough wastewater treatment plant in 2051 is presented in Figure 6.28.

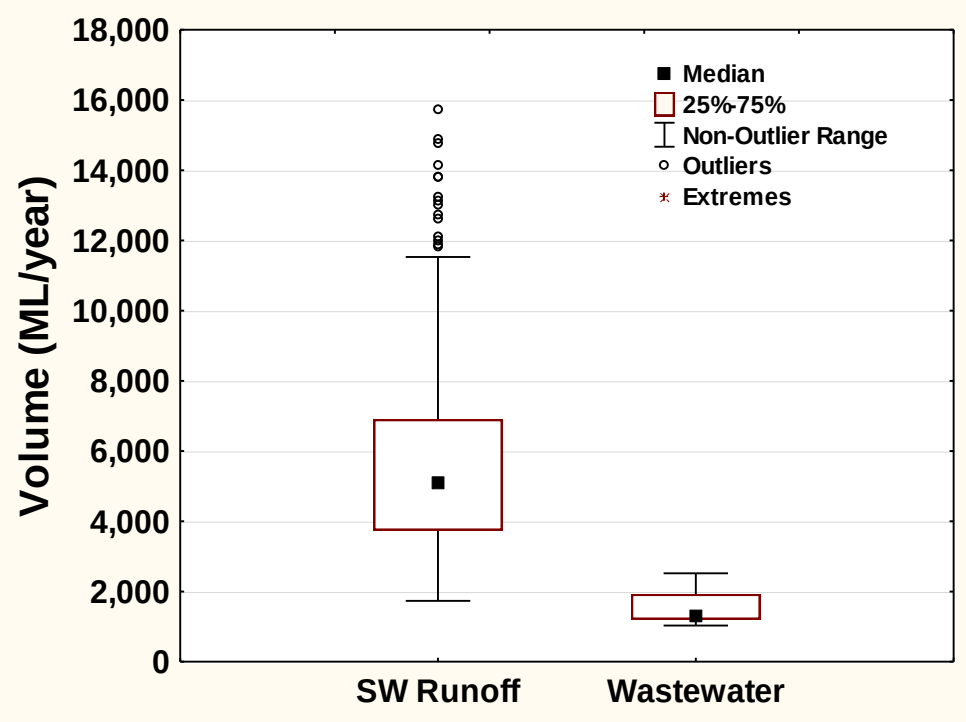

Figure 6.28: Urban stormwater runoff and wastewater discharges to treatment plants in the Maryborough district for 2051

Figure 6.28 shows that the stormwater runoff generated by urban areas within the Maryborough district is highly variable but substantially greater than water demands. Wastewater discharges from the urban areas that include infiltrated stormwater are a similar magnitude to water demands with a similar variance. The Maryborough water district generates volumes of local water resources that are up to six times the magnitude of water demands.

Locally available water resources including urban stormwater runoff, wastewater, rainwater and groundwater provide significant opportunities for the Maryborough district to reduce dependency on water resources from waterways and external sources. The addition of local water sources to the portfolio of water supply options will also improve the security of water supplies.

Waterways

The linked behaviour of the major waterways throughout the Maryborough district was also generated by the Systems Framework. The major waterways of Bet Bet Creek and Tullaroop Creek surrounding Maryborough are subject to variable water quality impacts. A declining trend in water quality as indicated by increased algal blooms and the Stream Invertebrate Grade Number – Average Level (SIGNAL level) were all recognised as key threats in several sub-catchments of Bet Bet Creek and Tullaroop Creek.[30]

[30] NCCMA, 2005. North Central River Health Strategy 2005

Goulburn Murray Water has also issued Blue Green Algae warnings for the Tullaroop Creek downstream of the reservoir during summer periods, particularly in the summer of 2006 and 2008. With regards to water quality and algal blooms many of the sub-catchments of Bet Bet Creek and Tullaroop Creek were considered to be in a "critical priority" category for the threat they pose to significant fauna values, the rarity of wetlands, native fish migration, recreational fishing (in some areas), and to water supply for irrigation and human consumption.

The Loddon River catchment which includes Bet Bet and Tullaroop Creeks generates 115 tonnes/year of Phosphorus and 517 tonnes/year of Nitrogen and has a history of exceeding the SEPP guidelines for salinity in many locations. Priority actions for water quality improvement relevant to Bet Bet and Tullaroop Creeks focus largely on riparian management and farm nutrient awareness, targeted actions for management of urban stormwater runoff and outfalls from waste water treatment plants.

More recent information will become available in the 2013 River Health Strategy due for release March 2014. Although the Loddon Nutrient Management Strategy (2005) was also not available at the time of writing, the NCCMA have since reported on progress toward actions and targets. Goulburn Murray Water have also completed modelling of the Tullaroop Reservoir catchment in partnership with the Cooperative Research Centre for Catchment Hydrology in regards to several water quality concerns and this report is also being sought.

The impact of the scenarios on stream flows in the Bet Bet Creek below the Maryborough district is presented in Figure 6.29.

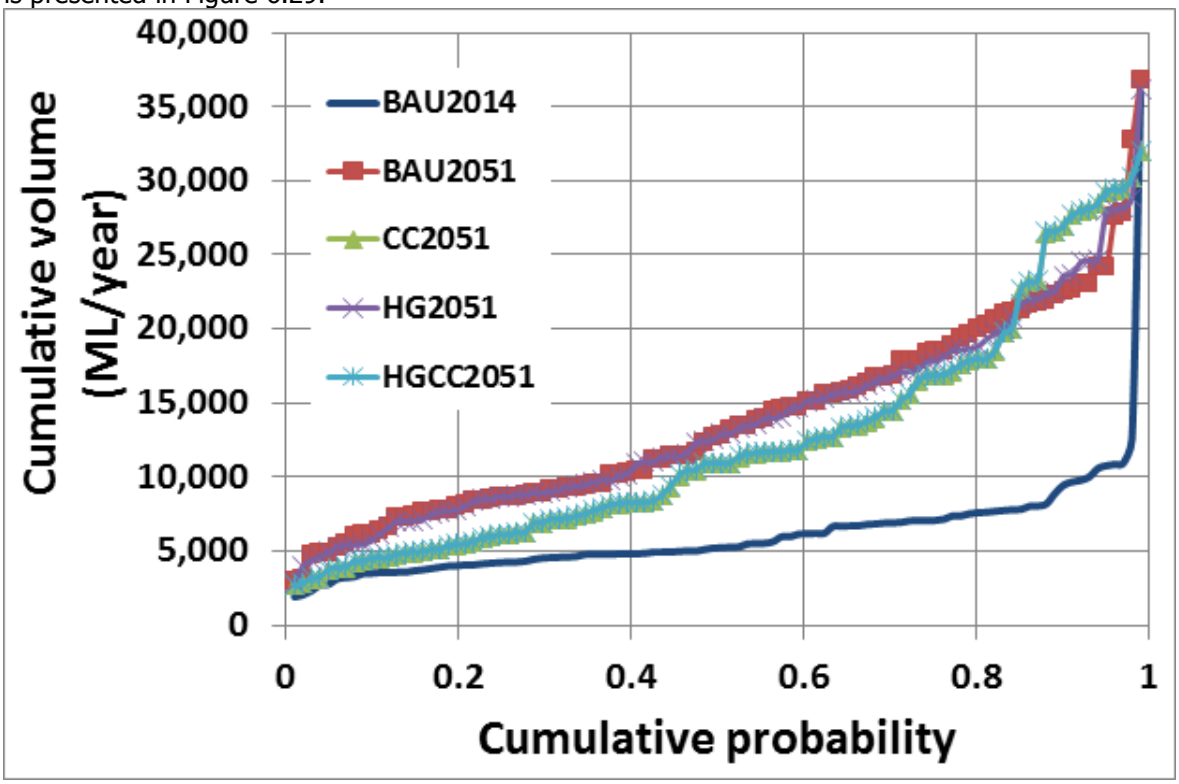

Figure 6.29: Stream flow in Bet Bet Creek downstream from Maryborough

Figure 6.29 shows that the Bet Bet Creek in 2051 is subject to substantial increases in annual flows as compared to flows in 2014 for all scenarios due to increased urban development. The climate

change scenario creates lower frequent flows and higher infrequent flows in the creek as compared to the BAU scenario in 2051. High population growth scenarios generate greater frequent flows that are a product of increased urbanisation of the upstream environment. These results indicate that the Maryborough district may be subject to increases of frequent (every day) flows in waterways and higher flood risks in 2051.

The impacts of the scenarios on average daily flows in Bet Bet Creek are presented in Table 6.11.

Table 6.11: Average daily stream flow in Bet Bet Creek below Maryborough

Scenario	Average daily flow (ML)	Change from 2014 (%)	Change from 2051 (%)
BAU 2014	35	-	-
BAU 2051	37.7	+ 7.7	-
CC	34	- 2.9	- 9.8
HG	37.6	+ 7.4	0
HGCC	34	- 2.9	- 9.8

Table 6.11 shows that Bet Bet Creek will experience significant increases in flows by 2051 for the BAU and HG scenarios due to increased urban development. The climate change scenarios generated reductions in stream flows by 2051. The impact of the scenarios on peak daily stream flows in Bet Bet Creek is presented in Figure 6.30.

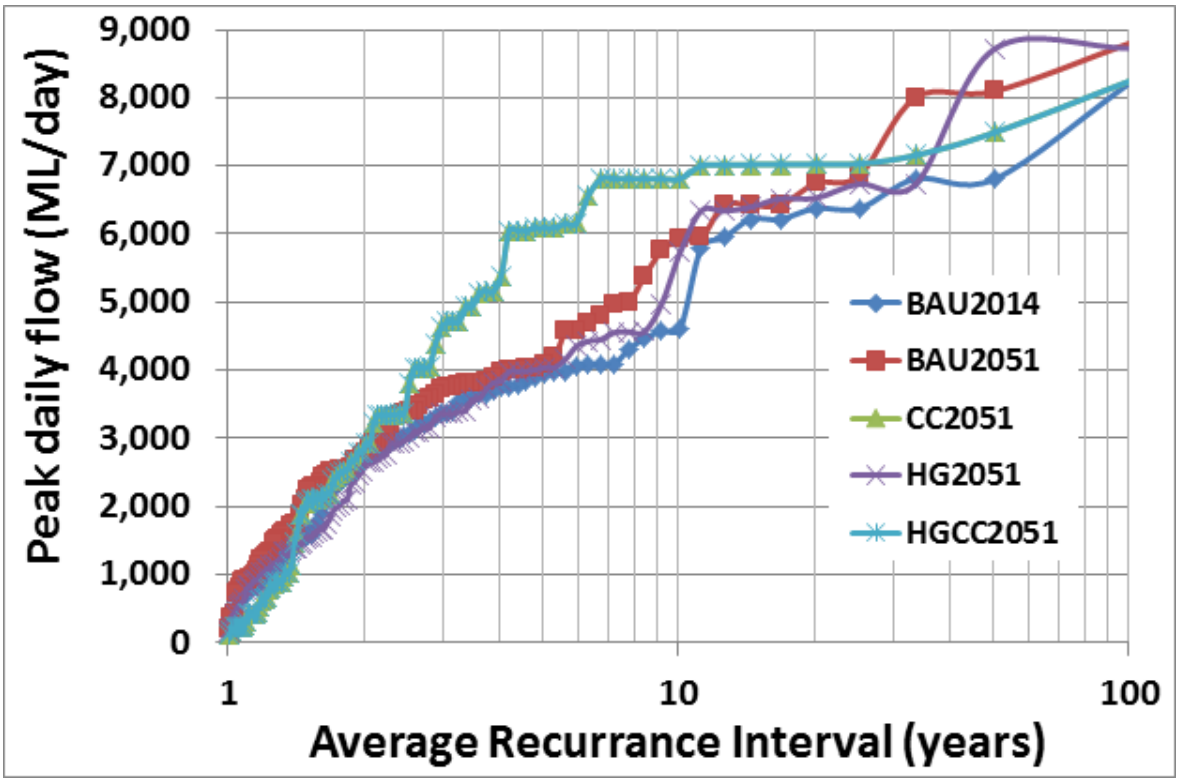

Figure 6.30: Peak daily flows in Bet Bet Creek downstream of Maryborough

Figure 6.3 shows that the climate change scenarios may create greater peak daily flows for the 2 to 30 year ARI rain events and all 2051 scenarios are expected to increase peak daily flows for 100 year ARI events.

The Systems Framework has provided an opportunity to examine and optimise the trade-offs between centralised and local water supply, river health and flooding issues throughout the Maryborough water district. The impacts of the scenarios on the likelihood of flooding in the Bet Bet Creek Catchment within the Maryborough district are presented as a proportion of current flood risks in Table 6.12.

Table 6.12: Estimated impacts on likelihood of flooding in Bet Bet Creek Catchment from 100 year ARI events

Scenario	Impacted properties (%)	Impacted buildings (%)	Change in impacted properties (%)	Change in impacted buildings (%)
BAU2014	4.1	3.6	-	-
BAU2051	4.4	3.9	+ 7	+ 7
CC2051	4.1	4.1	0	0
HG2051	4.3	3.8	+ 6	+ 6
HGCC2051	4.1	4.1	0	0

Table 6.12 shows that the risk of flooding of properties and buildings in the Bet Bet Creek Catchment is expected to increase by 2051 in response to increased urban development. The impact of stormwater runoff from all land uses on water quality in Bet Bet Creek just below the Maryborough district as indicated by annual loads of nitrogen, phosphorus and total suspended solids are presented in Figures 6.31, 6.32 and 6.33.

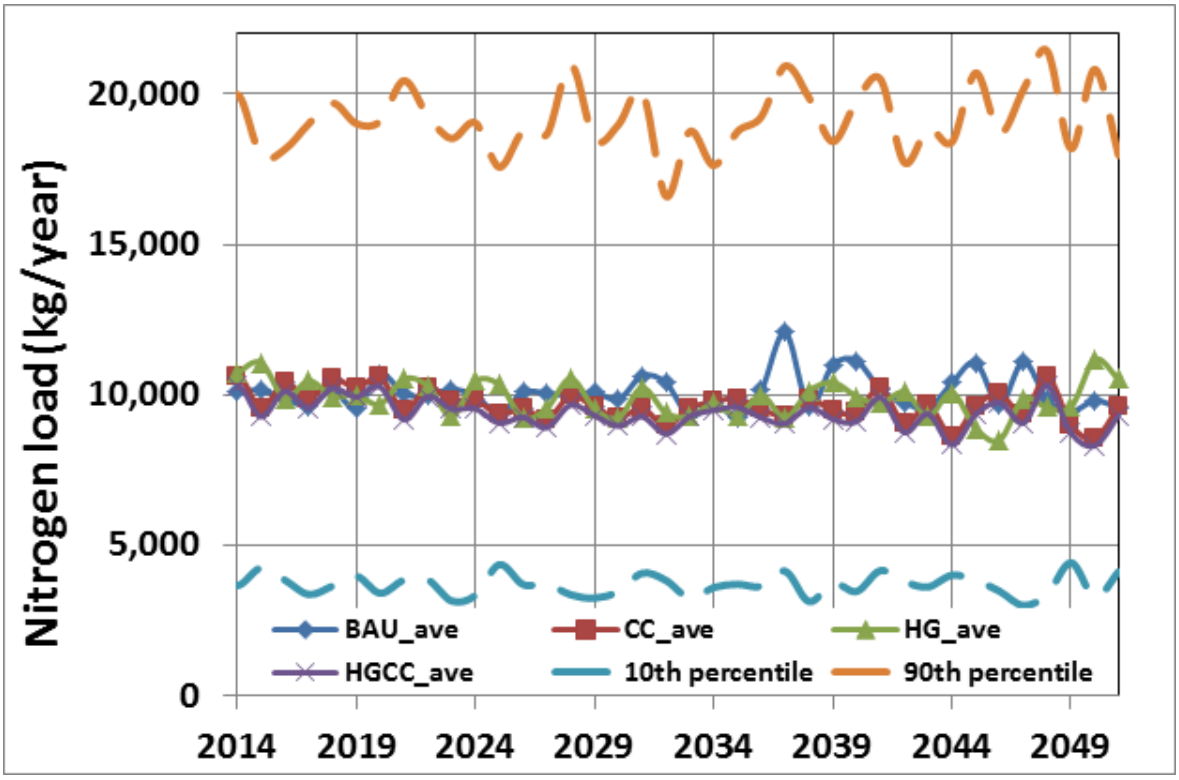

Figure 6.31: Total annual loads of nitrogen in Bet Bet Creek below Maryborough district

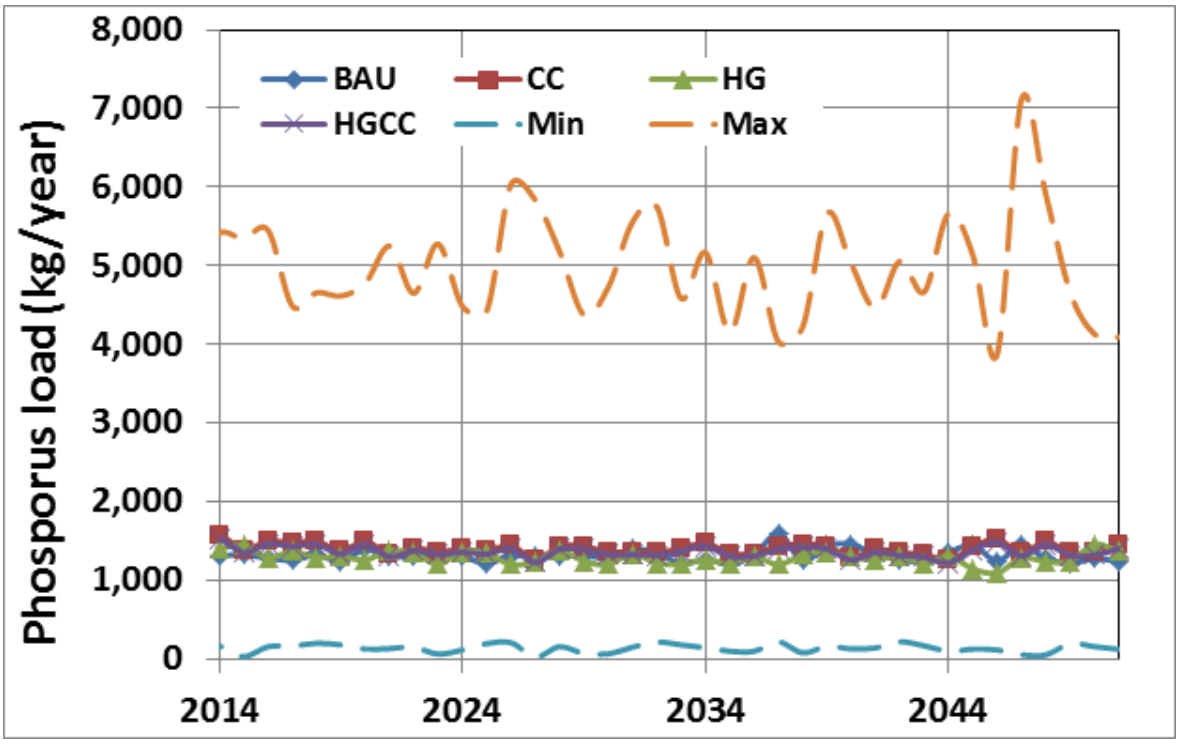

Figure 6.32: Total annual loads of phosphorus in Bet Bet Creek below Maryborough district

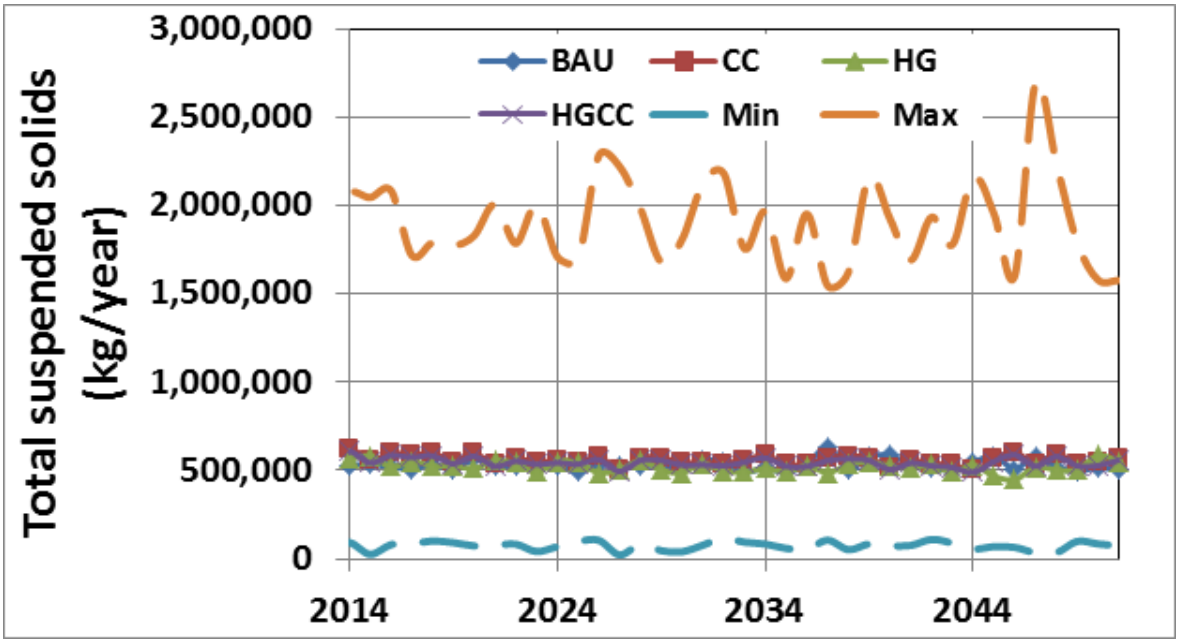

Figure 6.33: Total annual loads of total suspended solids in Bet Bet Creek below Maryborough district

Figures 6.31, 6.32 and 6.33 reveals that replacing agricultural land uses with urban land uses reduced average annual loads of nitrogen, phosphorus and total suspended solids generated by stormwater runoff to the waterway. The lower volumes of stream flows and higher rates of urban development in the climate change and high growth scenarios has generated further reductions in average annual loads of nitrogen. However, these results are highly variable.

7 Key Insights

This report is focused on the base case behaviour of the Ballarat and Maryborough water districts from the context of the performance of the entire region. A Systems Framework of the Ballarat region was developed as part of the Living Ballarat Project to assist in understanding the whole of water cycle challenges and opportunities across the region.

Development and enhancement the Systems Framework for the Ballarat region included ongoing interactions with stakeholders via the Strategy Development Team (SDT) that included representation from Central Highlands Water, City of Ballarat and the Office of Living Victoria. This process also included liaison with a broader group of collaborators including Catchment Management Authorities, land developers and environmental groups via formal workshops and various discussions.

The Systems Framework of the base case for the Living Ballarat project is complete. This framework includes high population growth and climate change scenarios. The Systems Framework was built up from 25 local scale land uses within 144 State Suburbs across the region and includes whole of water cycle processes at local, suburb, town and regional scales. This structure captures timelines of spatial, temporal and behavioural variations of the water cycle across the region.

The framework has been developed to a state where it can be reliably and robustly applied to detailed and targeted 'what if' analyses, including assessments of future water security under a range of climatic and population growth scenarios, and future alternative strategies. The spatial and temporal detail within the Systems Framework allowed understanding, reproduction and testing of the complex interactions between waterways, reservoirs, operations, water demands and water restrictions.

The Systems Framework has demonstrated capability to understand local versus regional trade-offs for water sources and operating decisions. This process has the necessary capability to support development of policies for water operations and allocations for the Ballarat region.

The detail of operating rules can be included in the Systems Framework which captures the variable response times of the components (such as local land uses, waterways, infrastructure and town planning strategies) of the system. The water supply system is highly sensitive to assumptions and operating decisions. This sensitivity has been revealed by the detail in the Systems Framework. This process has allowed important opportunities to optimise operating rules, allocations and water restrictions. We are currently working on refining the operating rules within the Framework to achieve optimum system performance for water cycle management.

The framework can be utilised to optimise planned system behaviours including water restrictions, operating rules, allocations and reservoirs. This includes prioritising and optimising of operating rules and allocations throughout the system. The Systems Framework can be used to develop strategies and policies for management of waterways from the perspective of the entire water cycle – including a necessary governance structure for managing regimes for stormwater harvesting and use of aquifers.

The short duration of the input data for hydrology may have created an optimistic view of water security in our analysis. We have extended the daily hydrology for the region using a calibrated

hydrological model to confirm the future security of the region. We have also finalised analysis of the regional water quality and waterway health outcomes. These results are included in this report.

The Ballarat region has a significant interaction with surrounding regions that includes sharing of water resources and impacts on waterways. These interactions are subject to high spatial and temporal variation in climate, water demands and demographic processes. Surrounding regions experience lower rainfall frequencies and depths – especially during droughts. Moreover, the region is subject to cyclic patterns of wet and dry conditions which drive strong variations in spatial weather conditions. As a consequence, there are stark differences in the resilience of river basin and water catchments across the region. These strong spatial and temporal variations indicate that the use of averages and analysis that utilises monthly or annual periods will limit understanding of challenges and opportunities throughout the region. The detail within the Systems Framework has unlocked this understanding.

Water demands for within the Ballarat and Maryborough water districts have almost halved during the last decade. The characteristics of water use throughout the region have changed dramatically over the last decade. A majority of building stock now includes water efficiency measures and there may be diminishing returns for the impact of ongoing current approaches to water efficiency on balancing the impact of future population growth on increasing water demands. Nevertheless, it is vitally important to continue with strategies to encourage water efficiency and to establish additional methods of water efficient practices. This will assist to limit the expected growth in regional water demands into the future.

The Systems Framework has successfully replicated the observed changes in water use behaviour over the last decade as behaviour change, water efficient appliances and behaviours, and rainwater harvesting. Nevertheless, the mix of these actions is not well understood. For example, the changes in water use could be dominated by behaviour changes.

The Ballarat West bore field, local water efficiency and water restrictions had a significant impact during the last decade on the security of water supplies for Ballarat. The introduction of the Goldfields pipe and flooding rains finally ended critical water shortages in the Ballarat District.

A majority of water storages and harvesting for water supply within the Ballarat region are situated in the upper reaches of waterways or the head waters of catchments that exhibit ephemeral behaviours that generate highly variable flows. The health of waterways and downstream flood risks in urban areas are also influenced by actions within the headwaters of catchments. There are opportunities to better understand and respond to this situation from multiple perspectives.

The behaviour of the water systems and the required structure of operating rules have changed by inclusion of the Goldfields Pipe that conveys allocations to Ballarat from the Campaspe and Goulburn River basins. The spatial and temporal detail within the Systems Framework allows optimisation of this new system. Inclusion of the Ballarat West bore field in the water supply network also increases the need to optimise the system. Regional storages are subject to highly variable irrigation and evaporation demands. These complex processes have been replicated by Systems Framework for Lake Eppalock, Warranga Basin and Tullaroop Reservoir. These storages may not have water that is consistently available into the future for the Ballarat region. This can be further explored using the Framework.

The Ballarat district is expected to be subject to relatively high population growth to 2051 and the application of the scenarios for climate change and higher population growth indicate highly variable future water demands. The Systems framework has produced average water demand projections that are consistent with the published Water Supply Demand Strategy. However the additional detail in the framework has allowed understanding of the expected variability of those demands. This allows insight about an uncertain future of water security and can inform policy processes.

The analysis indicates that the Ballarat district may not be subject to unacceptable levels of water restrictions or shortages within the planning horizon. Understanding of the future water security is highly sensitive to assumptions and operating rules. Inclusion of the Ballarat West bore field and the connection to the Campaspe and Goulburn river systems has increased the security of the Ballarat water district. The published Water Supply Demand Strategy indicates that augmentation of the Ballarat district water supply will be required by 2050 for the base case and by 2040 for a return to dry situation.

The detail in the Systems Framework required additional optimisation that has revealed greater water security. However, additional focus is required on the magnitude of allocations from groundwater and from the West Moorabool River system. In particular, the West Moorabool River is currently high flow-stressed and it is expected that flows in the river will further diminish in the future.

The differences in the understanding of water security in the Ballarat district are attributed to the greater temporal and spatial detail included in the Systems Framework. Importantly, the Systems Framework also employs a time based analysis of changes in the entire system (such as population growth, inflows to reservoirs, generation of wastewater and impacts on waterways) whereas traditional analysis employs static (independent of time) methods of analysis that are based on average inputs.

In addition, local processes in the Framework are based on simulations of the climate and socioeconomic driven behaviour of all land uses and do not assume the average behaviour of an input from an average household or land use. This process replicates the high level of natural spatial and temporal variation that is common to urban areas and biophysical environments.

The use of a daily time step allowed simulation of the biophysical limitations of water sources within the system that may occur that could exclude access to water allocations or other supply sources. The current process of deriving "yields" from water sources as a process remote from the entire water cycle using static analysis methods may not allow understanding of risks and opportunities. Clearly these "yields" are dependent on time and space. It is unlikely that "yields" and allocations can be added with any confidence to understand regional water security. A linked analysis of the entire water cycle is better equipped for this task.

Waterways throughout the region are impacted by extractions for water supply, population growth, urban stormwater runoff, rainwater and stormwater harvesting, wastewater discharges and climate change. Lower frequent flows and higher infrequent flows are expected for waterways by 2051. This implies increased impacts on waterway health and increased risk of flooding.

The waterways throughout the region have been subject to water quality and flooding challenges. For example, in the Ballarat district, the Yarrowee River and Burrumbeet Creek have reported high

loads of phosphorus and nitrogen which has impacts on the health of the waterways. Upgrades to the Ballarat North and South wastewater treatment plants during the last decade have improved these water quality impacts. There are a considerable number of properties that are subject to flood risks and there may be opportunities to manage water supply storages in the upper catchment to also mitigate some of the flood risks.

By 2051, the Yarrowee River will experience substantial increases in stream flows due to effluent discharges from wastewater treatment and the proportion of wastewater effluent from the Ballarat South wastewater treatment plant to fresh water will increase substantially. It is likely that wastewater discharges will dominate summer flows in the river by 2051. The impact of the climate change scenarios will further reduce fresh water flows in the river by 2051.

The Yarrowee River will be subject to large increases in nutrient loads and the potential for diminished waterway health by 2051. These impacts can be mitigated by rearranging the water supply priorities within the Yarrowee Catchment to reduce extractions of fresh water, decrease wastewater discharges and managing urban stormwater runoff. It is possible that risk of flooding from minor events (ARI less than 10 years) will increase and flood risks from major events may diminish in the Yarrowee catchment by 2051.

This analysis has revealed some interesting paradoxes including understanding that replacement of agricultural land uses with urban development results in the decreased loads of nutrients in waterways. However this waterway health impact is countered by increased nutrient loads from wastewater discharges and increased frequent flows in waterways.

In contrast, Burrumbeet Creek is not subject to extractions for water supply and experiences diminished wastewater discharges (from Ballarat North wastewater treatment plant) due to wastewater reuse strategies. This catchment may experience increased flood risks and moderate increases in nutrient loads. These impacts are reduced by the climate change scenarios. However, it is likely that flows in Burrumbeet Creek will be dominated by effluent from the Ballarat North wastewater treatment plant during dry periods.

Bet Bet Creek in the Maryborough district may experience increased risk of flooding by 2051. These impacts may be diminished by climate change scenarios.

It is an important insight that the waterways throughout the region are subject to cumulative impacts including loads of contaminants, flood risks from high flows and diminishing fresh water flows. Whilst indicators for water quality (as indicated by concentrations of contaminants), peak flows (flooding) and average flows or flow regimes (waterway health) may be acceptable at a location in a catchment (especially in the headwaters), the resultant downstream cumulative impacts may not be.

The Systems Framework can be used to develop strategies and policies for management of waterways from the perspective of the entire water cycle – including a necessary policy of managing regimes for stormwater harvesting and use of aquifers.

Urban areas in the Ballarat and Maryborough water districts generated greater stormwater runoff from urban areas than water demands throughout the last decade. The combination of urban stormwater runoff and wastewater discharges to existing treatment plants equated to a minimum of twice the water demands at each location.

Ballarat is highly dependent on bulk water supplies from external sources – there is a need to reduce impacts on downstream environments and communities. By 2051, the volume of urban stormwater runoff and wastewater discharges to existing treatment plants will be three times the volume of water demands. Water supply to Maryborough in 2051 is dominated by surface water extracted from McCallum and Stoney Creeks with back up from bulk water allocations and ground water. Urban stormwater runoff and wastewater discharged to existing treatment plants is expected to be six times the volume of water demands in 2051.

There is an outstanding opportunity to include local water resources of urban stormwater runoff, wastewater discharges to treatment plants, groundwater and rainwater harvesting in future water strategies. Utilisation of local water resources will decrease dependence and impacts on surrounding communities and ecosystems. The Systems Framework can be used to develop strategies and policies for management of waterways from the perspective of the entire water cycle.

Analysis of finance and economic outputs from the Systems Framework are included in a companion report. A range of Options and Scenatios to "test the system" have been simulated and the results are discussed in the Systems Economics report.